Smith Mountain Lake
Water Quality Monitoring Program

2001 Report

SMLA

Ferrum College

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Sponsored by
The Smith Mountain Lake Association

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1. INTRODUCTION

The Smith Mountain Lake Water Quality Monitoring Program (SMLWQMP), now in its fifteenth year, is a water quality program designed to monitor the water quality and the trophic status of Smith Mountain Lake, a large (25,000 acre) pump-storage reservoir located in South Western Virginia. Scientists from Ferrum College and designated members of the Smith Mountain Lake Association (SMLA) jointly manage the project. This report describes the 2001 monitoring season, the fifteenth year of the program. Secchi depths were recorded and water samples collected every other week from the first week of June to the third week of August.

The sampling season for the monitoring program runs roughly from Memorial Day to Labor Day. The samples are picked up at the homes of the monitors by Ferrum College interns and analyzed for total phosphorus, chlorophyll-*a* and nitrate concentrations. The monitoring network includes "trend stations" on the main channels and "watchdog stations" in coves off the main channels. One of two types of monitoring is carried out at each site; at "basic stations" water clarity is measured with a Secchi disk while, at "advanced stations", water clarity is measured and samples are collected for further analysis in the Water Quality Laboratory at Ferrum College. In 2001 there were 85 stations in the lake monitoring network (56 advanced stations and an additional 29 basic stations, all but one located in coves).

Beginning in 1995, Ferrum College personnel began collecting 20 tributary samples each sampling period in order to begin assessing tributary inputs of nutrients to the lake. In 1996 a volunteer monitoring team began collecting samples in the upper Roanoke channel just below the confluence of Back Creek, 34 miles from the dam. This sample site has been designated T21 and is considered the headwater station for the Roanoke channel. Sample site T3 is the headwater station designated for the Blackwater channel and it is located at the Route 834 bridge near Riverside Exxon. Both headwater stations are considered to be tributary stations, although there is minimal velocity at either site during base flow conditions. All other tributary stations are on flowing tributaries near their confluence with the lake except for the upper Gills Creek site. This site, T0, is several miles from the lake and a volunteer monitor collects samples there.

Collection of lake samples for fecal coliform enumeration also began in 1995 with samples collected at 8 sites on three occasions. In 1996 and 1997, the number of sampling sites was increased to 12 and, during 1998 - 2001 fecal coliform samples were collected at 14 sites on six occasions. Personnel from the SMLA and Ferrum College collected bacterial samples every other week, alternating with the weeks during which trophic samples were to be picked up from the volunteer monitors.

The 2001 training session was carried out in May by the Ferrum College scientists, Carolyn Thomas and David Johnson, and the SMLA Volunteer Monitoring Coordinators, John Singer and Stan Smith, with assistance from the student technicians, Patricia Moyer, Kristen Cardinale, Greta Roberts, Jack Wallace, and Philip Davis. The training session was held at the Bethlehem United Methodist Church in Moneta. The program included a review of the previous year's findings and planning for the upcoming season. Experienced monitors reviewed their sample site locations and sample site identification numbers, received new supplies (sample bottles and filters), and had their monitoring equipment checked. The program co-directors worked with the new volunteer monitors to assign sample site locations and sample site identification numbers, practiced the sampling procedures and issued sampling equipment and supplies. Sample collection began the week of May 27 through June 2, and the first sample bottles and sample filters were picked up Tuesday, June 5. Newsletters were written and published by the program co-directors and student technicians during the summer, reporting on activities of the program. Announcements were included in the newsletters in addition to advice and tips on sample collection. Two newsletters were written in 2001. In October, the annual end-of-the-season meeting and social event at Smith Mountain Lake State Park was attempted, however because of a thunderstorm the activity was canceled. Instead a “Town Meeting” was held, and reports were made on the monitoring results on February 26th.

The Virginia Environmental Endowment (VEE) provided primary funding for the project during the first three years and the final report to the VEE describes the development of the project during the period from 1987-1990 (Johnson and Thomas, 1990). Beginning in 1990, support for the project has come from the Commonwealth of Virginia (through the Smith Mountain Lake Policy Advisory Board, now known as TLAC), the SMLA and Ferrum College. Monitoring results from 1990 to 2000 can be found in the project annual reports.

This year's monitoring results, data analyses and conclusions, and comparisons with the fourteenth years' data will be discussed in the following sections.

2. METHODS

Detailed descriptions of the methods of sample collection, preservation and analyses, and quality control/quality assurance procedures can be found in the VEE Report (Johnson and Thomas, 1990).

The water quality parameters measured include water clarity (turbidity), measured as Secchi disc depth; total phosphorus, measured spectrophotometrically (λ = 700 nm) after persulfate digestion; nitrate, also measured spectrophotometrically (λ = 540 nm) after cadmium reduction; and chlorophyll-*a*, determined using the acetone extraction method and measured fluorimetrically.

The quality control and quality assurance procedures evaluate sample collection and storage by the volunteers as well as laboratory procedures.

Sampling station codes contain information on the location of the site. The sample site codes are based on:

(1) The section of the lake in which the site is located ("C" for Craddock Creek, "B" for Blackwater, “M” for main basin, “R” for Roanoke, “G” for Gills Creek).

(2) The approximate number of miles to the Smith Mountain Lake Dam (i.e. 23 miles from the dam would have a "23" in the site code).

(3) Designation of the sampling station as a cove, main channel or a tributary (cove site codes start with "C", tributary sampling site codes begin with “T”, channel sampling site codes have no letter designation and begin with the letter of the channel as given in (1) above).

(4) Basic monitoring site codes begin with an "S" (for Secchi depth).

An example of a sampling site code would be "CB14" which would indicate a cove sample off of the Blackwater channel 14 miles from Smith Mountain Lake Dam.

Sampling sites are located about every two miles on the Roanoke and Blackwater channels to monitor the movement of the silt and nutrient laden waters moving toward the main basin of the lake. These sites begin at the dam and extend 2 miles beyond the Hardy Ford Bridge on the Roanoke channel and to the 834 Bridge in Franklin County on the Blackwater channel. The cove sampling sites are also important for trend analysis and help us fulfill the role of "watchdogs". In the "watchdog" mode, we monitor as much of the lake as possible for signs of localized deterioration of water quality, which may be due to site-specific problems such as malfunctioning septic systems. To evaluate tributary loading of nutrients, interns collect grab samples (to fill a bottle with water) every other week at 19 tributary sites on their rounds to pick up lake water samples. Volunteer monitors collect two additional tributary samples, one in upper Gills Creek and another in the upper Roanoke Channel just downstream from the confluence of Back Creek.

3. RESULTS FROM TROPHIC STATUS MONITORING

In this section the parameters used to monitor trophic status are displayed. These parameters include total phosphorus, nitrate, chlorophyll-*a*, and Secchi depth. Total phosphorus and nitrate are plant nutrients that stimulate the growth of algae. Phosphate, the form of phosphorus most immediately available to algae, is the limiting nutrient in Smith Mountain Lake. Chlorophyll-*a* is extracted from algae and is a measure of the algal population. Secchi depth is a measure of water clarity that decreases as algal populations and siltation increase. The seasonal average for the lake stations for each parameter over the past five years is shown in Table 1. The average concentration of chlorophyll-*a* was double again in 2001 as it also doubled from 1999 to 2000. This increase in the algal population in the lake is of great concern. This increase may be due to the lack of rainfall in 2001 resulting in greater water clarity as indicated by the slightly greater Secchi disk depth in 2001. Greater water clarity allows more light to reach to greater depth, therefore stimulating greater algal growth. It is reassuring to observe in reference to evaluation of quality control the high degree of internal consistency among the data in Table 1. A more complete discussion of water quality trends is presented in Section 5 of this report.

Table 1. Summary of trophic state data from 1997 to 2001.

	Nitrate (ppb)	*Total Phosphorus (ppb)*	*Chlorophyll-a (ppb)*	*Secchi Depth (m)*
2001	217	33.3	27.9 (correct value = 4.1)	2.3
2000	129	35.9	14.6	2.2
1999	296	28.9	3.9	2.2
1998	257	24.4	3.8	2.3
1997	180	27.6	4.1	2.1

3.1 Lake Stations

3.1.1 Variation of trophic parameters over time

The values for each parameter were averaged for each sampling week to indicate the variation of the parameters during the sampling season. The results are displayed in Figures 1-4.

(a) Total Phosphorus: The Smith Mountain Lake stations (56 sites) exhibited the lowest average concentration of total phosphorus (TP = 24.5 ppb) during the fifth week (June 24-June 30) and the highest mean concentration (TP = 40.99 ppb) during the ninth week (July 22-28).

(b) Nitrate: The lowest average concentration (56 sites) of nitrate (NO3 = 76.1 ppb) occurred during the twelfth week. (August 12-18) and the highest average nitrate concentration (NO3 = 341.3 ppb) occurred during the fifth week (June 24-30).

(c) Chlorophyll-*a*: The sample set (56 sites) with the lowest average chlorophyll-*a* concentration (CHA = 17.9 ppb), was collected during the third week (June 10-16) and the set with the highest average chlorophyll-*a* concentration (CHA = 33.2 ppb) was collected during the ninth week (July 22-28). (Values for chlorophyll-*a* were calculated incorrectly. See Appendix Table A7a for corrected values. Corrected average value; CHA = 4.1 ppb.)

(d) Secchi Depth: The lake (85 sites) exhibited the highest average Secchi depth (SD = 2.81 m)(highest water clarity) during the fifth week (June 24-30). The lowest average Secchi depth (SD = 1.97 m) occurred during the first week (May 27-June 2).

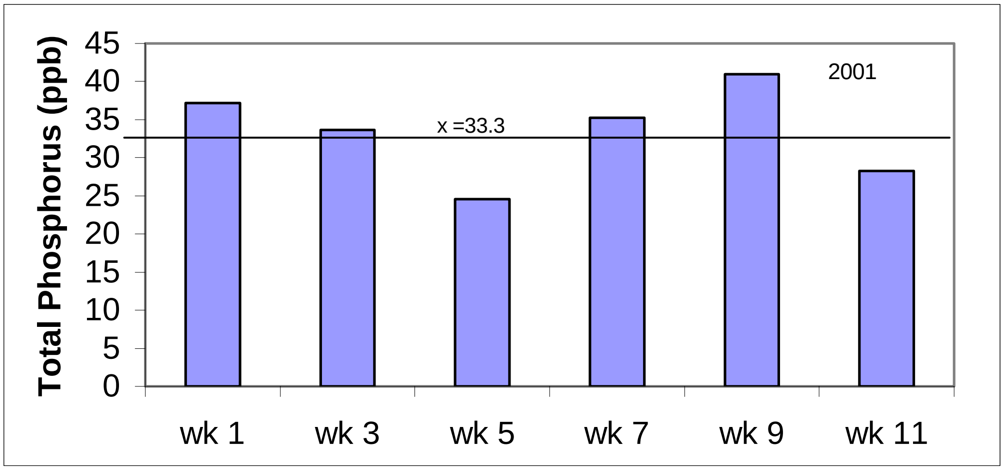


Figure 1. **Average total phosphorus concentration for each sampling week in 2001.**

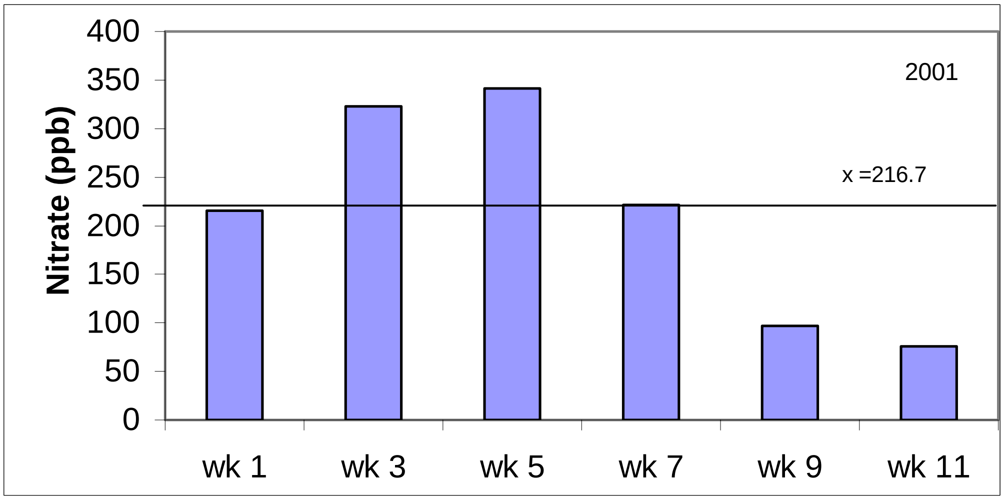


Figure 2. **Average nitrate concentration for each sampling week in 2001.**

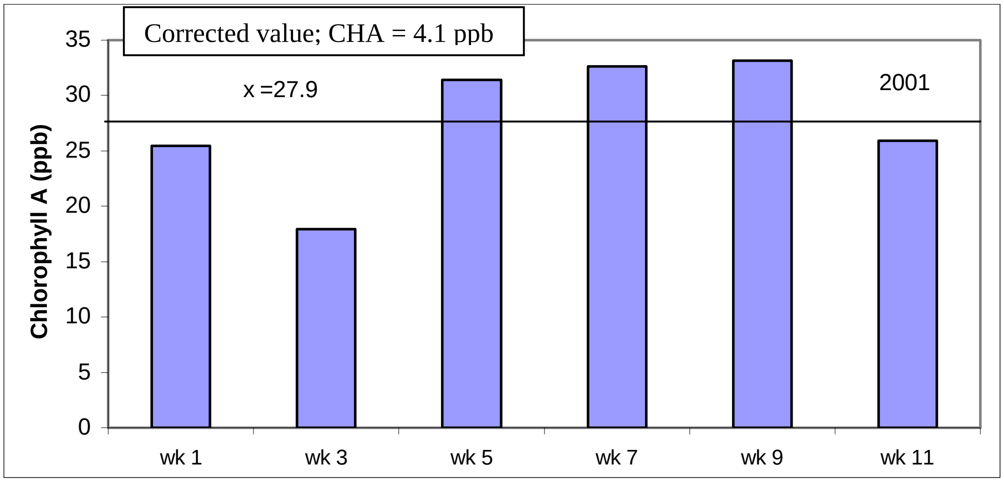


Figure 3. **Average chlorophyll-*a* concentration for each sampling week in 2001.**

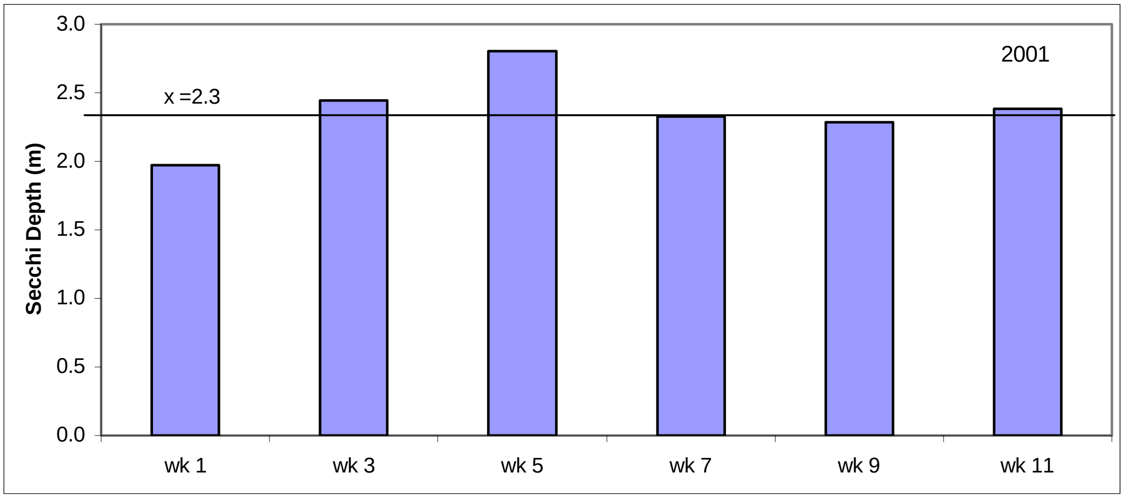


Figure 4. Average Secchi depth for each sampling week in 2001.

3.1.2 Variation of trophic parameters with distance from the dam:

The parameters were averaged by station over the six sampling weeks and the average values were graphed as a function of distance from the dam. The results are displayed in Figures 5-8.

(a) Total Phosphorus: Total phosphorus levels in the lake increase as distance from the dam increases, but not as regularly as in the past. The correlation coefficient (R^2) is lower than usual and the cause is a group of stations in coves off the Roanoke Channel between 20 and 25 miles from the dam (Figure 5). The sampling site with the highest average total phosphorus concentration (TP = 78.5 ppb) was in a cove of the Roanoke channel (CR 21.1). The lowest average total phosphorus concentration (TP = 11.6ppb) was at a site fourteen miles from the dam (R14). The trend line in Figure 5 is significant (α =0.01) with a sample size of 336.

(b) Nitrate: Unlike the phosphorus measurements, nitrate concentrations do not increase linearly as distance to the dam increases. Instead we may be seeing a bimodal distribution because of the pump back characteristic. The sampling site with the highest average nitrate concentration (NO3 = 1217.8ppb) was in the Roanoke Channel (R31). The lowest average nitrate concentration (NO3 = 29.96 ppb) was also in the Gills Creek section (G18). Figure 6 shows the annual average nitrate concentration by station as a function of distance from the dam. It is interesting that the nitrate levels increase again closer than 10 miles from the dam. This observation, as was the case last year, suggests that there is an upwelling of nitrate rich waters near the dam, perhaps as a result of the mixing that occurs at the confluence of the two main channels or of the water pumped back from Leesville Lake. The nitrate concentration right at the dam, (M0 =202.9) and the nitrate concentration at sites below the dam have been greater than 300ppb over the last four years which could be the source of the observed higher nitrate concentration.

(c) Chlorophyll-*a*: Chlorophyll-*a* levels (CHA) decreased as samples were taken closer to the dam but, as with total phosphorus, the trend was less regular this year (Figure 7). Rather than the normal pattern of regularly increasing concentration with increasing distance the stations show a bimodal distribution. The chlorophyll-*a* levels are rather uniform until about 17 miles from the dam and then rise rapidly to a higher level, then decrease to a low level at 21 miles, and rise again at 22 miles from the dam and stay high. The highest average total chlorophyll-*a* concentration (CHA = 94.7 ppb), was on the main channel of the Roanoke River (R31). The lowest average chlorophyll-*a* concentrations (CHA = 3.7 ppb) was found in a cove of the Roanoke River (CR9.2). The trend line in Figure 7 is significant (α =0.01) with a sample size of 336. (Values for chlorophyll-*a* were calculated incorrectly. See Appendix Table A2a for corrected values. Corrected average value; CHA = 3.0 ppb.)

(d) Secchi Depth: Secchi depth increased as miles to the dam decreased, indicating greater water clarity toward the main basin (Figure 8). The highest average Secchi depth (SD = 3.75 m) in the lake was measured at a station in the Craddock Creek section of the lake (C4) as was true last year. The lowest average Secchi depth (SD = 1.10 m) was at station R31.

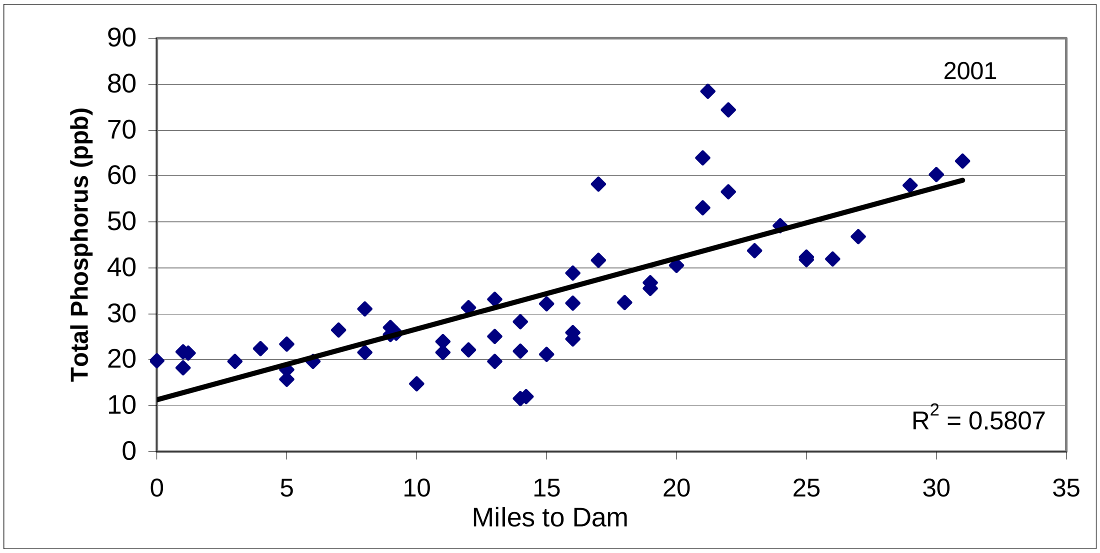


Figure 5. **Variation of total phosphorus concentration with distance from the dam.**

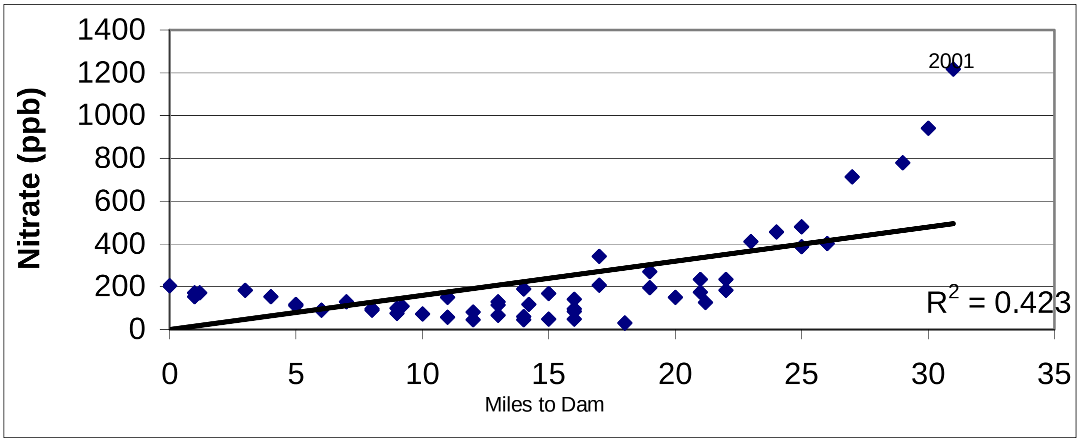


Figure 6. **Variation of nitrate concentration with distance from dam.**

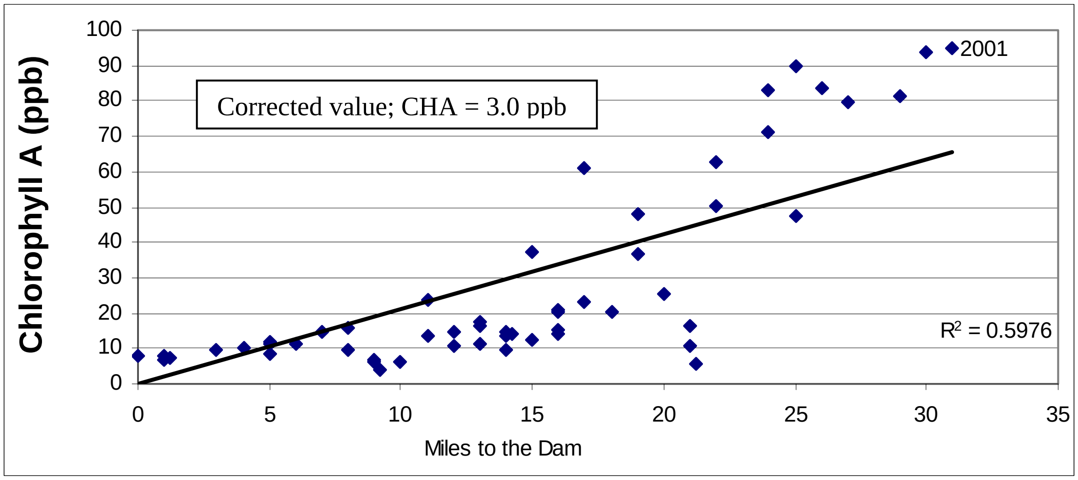


Figure 7. **Variation of chlorophyll-*a* concentration with distance from the dam.**

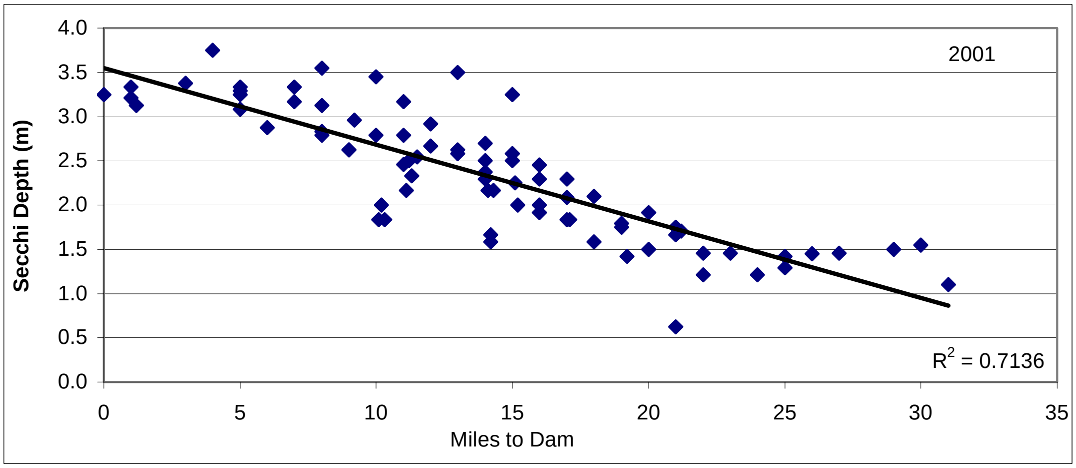


Figure 8. **Variation of Secchi depth with distance from the dam.**

3.2 Tributary Stations

3.2.1 Variation of total phosphorus and nitrate during the sampling season

The values for each parameter were averaged for each sampling week to indicate their variation during the sampling season. The results are displayed in Figures 9 and 10.

(a) Total Phosphorus: The tributaries (22 sites) exhibited the lowest average concentration of total phosphorus (TP = 61.4 ppb) in the third week (June 10-16) and the highest mean concentration (TP = 83.4 ppb) in the ninth week (July 22-28).

(b) Nitrate: The lowest average concentration (22 sites) of nitrate (NO3 = 413.3 ppb) occurred during the ninth week (July 22-28), and the highest average nitrate concentration (NO3 = 878.1 ppb) occurred during the third (June 10-16) week. These were the same weeks the low and high were exhibited by total phosphorus.

For nitrate, both the highest and lowest average concentrations are higher than in 2000; however, for phosphorus, only the lowest average concentration was higher this year than last year.

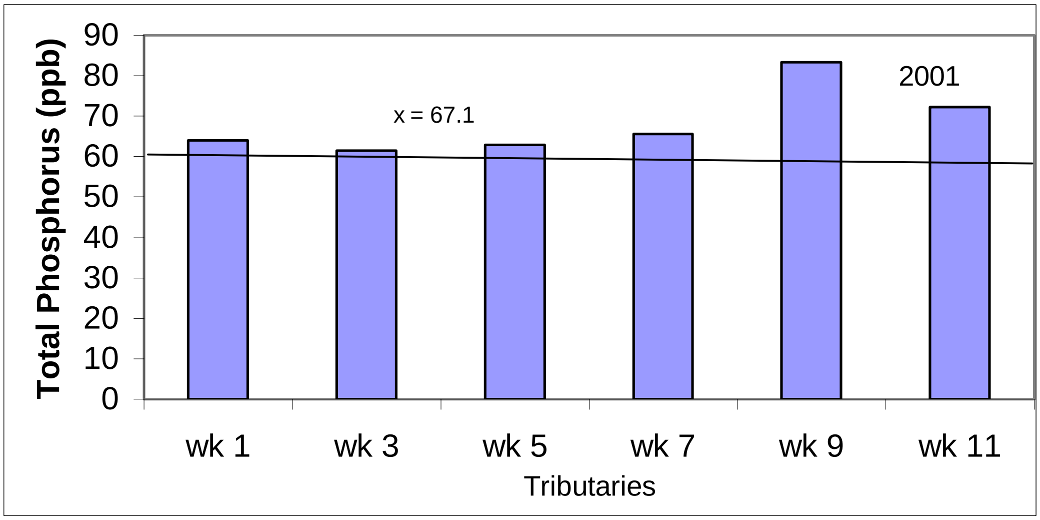


Figure 9. Average total phosphorus concentration at tributary stations for each sampling period.

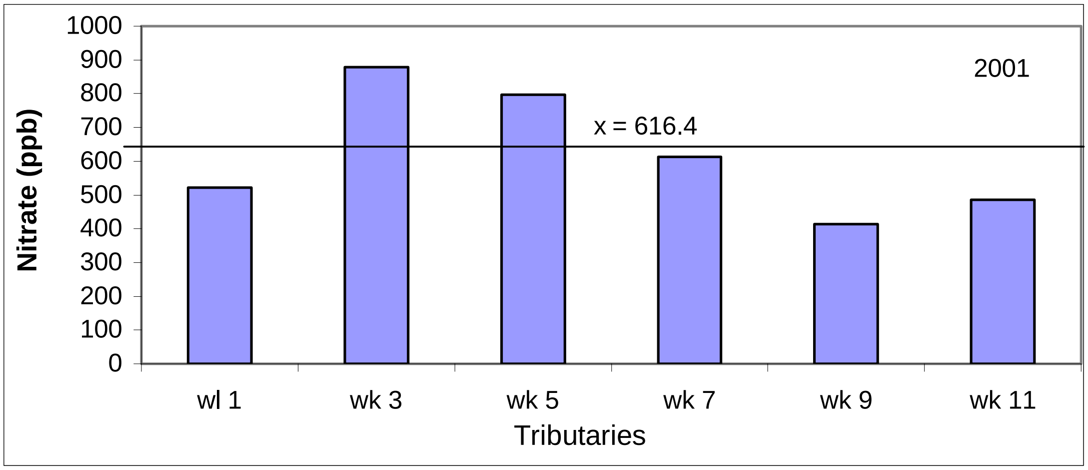


Figure 10. Average nitrate concentration at tributary stations for each sampling period.

3.2.2 Average tributary concentration of total phosphorus and nitrate by year

Table 2 indicates that tributary phosphorus levels, after a substantial increase in 2000, decreased again in 2001. Nitrate monitoring in tributaries was begun in 1998 and the average concentration was higher in 2001 than the 2000 mean.

Table 2. Average tributary concentrations of total phosphorus from 1995-2001. TP is the phosphorus concentration.

Year	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Average Tributary TP (ppb)	91.5	63.5	67.4	50.9	61.8	80.9	67.1
Average Tributary Nitrate (ppb)				568	621	570	617

3.2.3 Seasonal average nutrient concentrations for each tributary

In order to obtain information on relative impact on Smith Mountain Lake by each tributary, the average for each tributary has been calculated over the six sampling periods. The results are shown in Figures 11 and 12, which also include the average tributary and lake concentrations of total phosphate and nitrate. To compare actual nutrient loading by tributary, the flow rate of each tributary must also be measured in the future. The tributary stations are identified below:

Trib. Station	**Stream Name**	**Trib. Station**	**Stream Name**
T0	Upper Gills Creek	T11	Leesville Lake-Former Station 103
T1	Maggodee Creek	T12	Creek at Summit Drive
T2	Lower Gills Creek	T13	Creek at Snug Harbor
T3	Blackwater River	T14	Stoney Creek
T4	Poplar Camp Creek	T15	Jumping Run
T5	Standiford Creek	T16	Beaverdam Creek
T6	Bull Run	T17	Roanoke Channel at Bay Roc
T7	Cool Branch	T18	Lynville Creek
T8	Branch at Lumpkin's Marina	T19	Grimes Creek
T9	Below Dam - Former Station 105	T20	Indian Creek
T10	Pigg River - Former Station 104	T21	Roanoke Channel near Back Creek

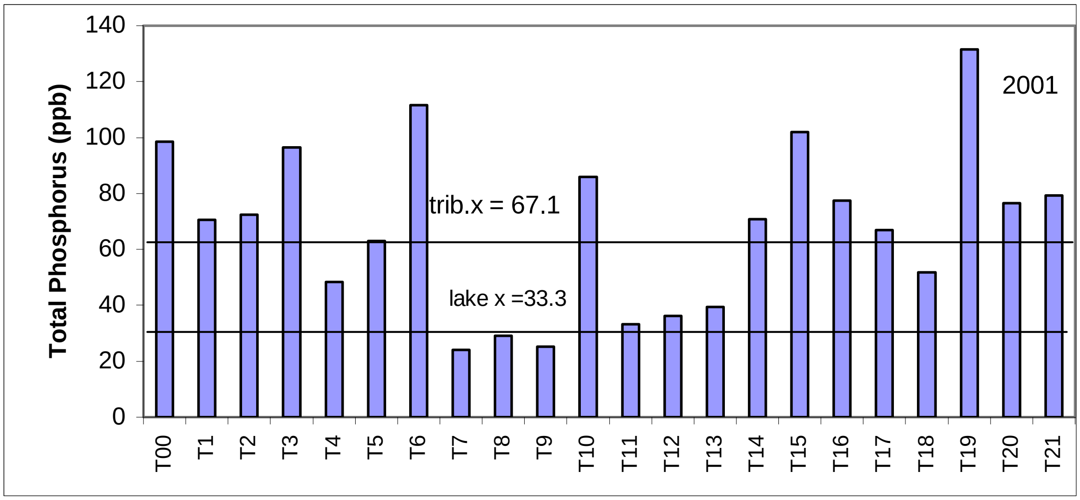


Figure 11. Seasonal average total phosphorus concentration for each tributary.

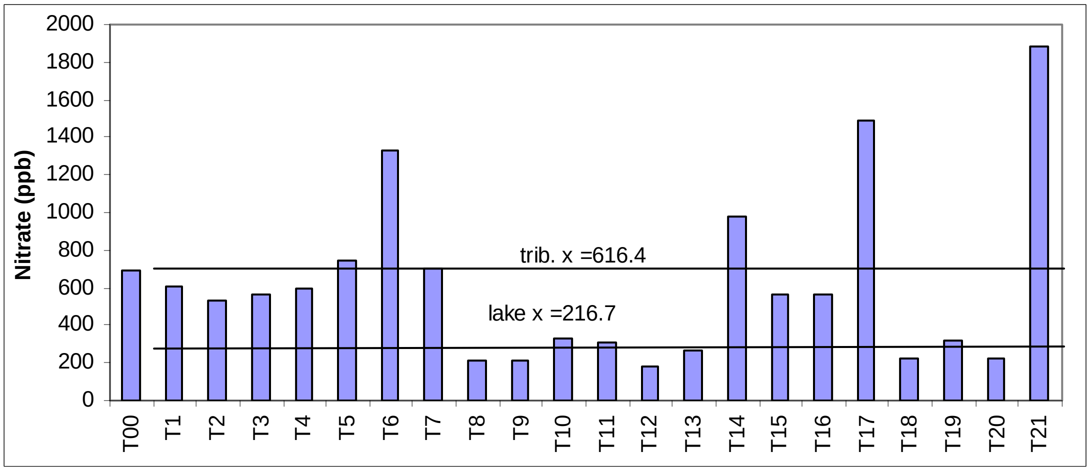


Figure 12. Seasonal average nitrate concentration for each tributary.

3.3 Results for Sample Sites Below the Dam

The students collect grab samples from a bridge in the same manner as the tributary samples. The difference is that these samples are collected below the dam and are not tributaries flowing directly into the lake. Because of the pump back system, water from these sites may end up in the lake. T9 is in the Roanoke River just below the dam at the AEP Visitor Center, T10 is in the Pigg River near its confluence with the Roanoke River, and T11 is in the Roanoke River after the confluence with the Pigg River and near where Leesville Lake begins. The results for 1994 through 2001 are summarized in Table 3. The values given for each year are the annual averages. The average total phosphorus concentration in the Roanoke River below the dam generally decreased until 2000, which may be a one year phenomenon and not a sign of decreasing water quality in the lake since the total phosphorus was less in 2001 at this site. The higher phosphorus concentration in the Pigg River (site T10) compared to the lake continues to elevate the phosphorus levels in the main basin of Smith Mountain Lake because of the pump back system. There was a significant increase in phosphorus concentrations in the Pigg River in 2001 again. The mean total phosphorus concentrations in the sites below the dam went from 15.3ppb in 1999 to 44.5 ppb in 2000 and to 48.1 ppb in 2001.

Table 3. Summary of results for total phosphorus at sites below the dam (1994 to 2001).

	Total Phosphorus (ppb)								
Site/Location	1994	1995	1996	1997	1998	1999	2000	2001	avg.
T9/ Roanoke R. below dam	25.6	40.5	38.3	19.7	11.4	11.5	28.8	25.1	25.1
T10/Pigg R. at Rt. 605	64.5	83.4	48.3	38.9	43.4	22.2	48.7	86.0	54.4
T11/Roanoke R. at Rt. 608	38.7	62.1	48.1	33.9	33.1	12.3	56.0	33.2	39.7
Average by year	42.9	62.0	44.9	30.8	29.3	15.3	44.50	48.1	39.7

Table 4 gives similar results for four years of nitrate monitoring at sites below the dam. The nitrate levels below the dam, and in the Pigg River, were lower in 2001 than in 2000, but slightly higher at the Route 608 Bridge over the Roanoke River, again an indication of increasing nutrient loads in the lake for this year but also lack of rainfall in 2001.

Table 4. Summary of results for nitrate at sites below the dam (1998 to 2001).

	Nitrate (ppb)				
	1998	1999	2000	2001	avg.
T9/ Roanoke R. below dam	516	225	246	209	299
T10/Pigg R. at Rt. 605	447	200	454	331	358
T11/Roanoke R. at Rt. 608	427	182	302	309	305
average by year	463	202	334	283	321

3.4 Summary of Section

Overall, it would appear that water quality in Smith Mountain Lake declined significantly from 2000 to 2001. It is more accurate to say that the trophic level (nutrient status) increased due to chlorophyll-*a*. The changes are small for nitrate but significantly higher for chlorophyll-*a* (91%) again in 2001 following the 274% increase from 1999-2000. Average total phosphorus levels decreased slightly in both lake and tributary samples, average nitrate levels increased in both lake and tributary samples however, water clarity actually improved. The water clarity was better due to the lack of rainfall and therefore lack of sediment-laden runoff. The increase in chlorophyll-*a* levels in 2001 is of great concern following the great increase in the previous year. The relative change in each parameter from 1998 to 2001 is shown in Table 5.

Table 5. Relative change (%) in water quality parameters from 1998-2001.

	TP-Lake	TP-Tribs	NO3-Lake	NO3-Tribs	Chlorophyll-*a*	Secchi Depth
98-99	+18%	+21%	+15%	+9%	+3%	-4%
99-00	+24%	+31%	-56%	-8%	+274%	0%
00-01	-7%	-17%	+59%	+8%	+91%	+5%

Water circulation, nutrient interchange and biotic relationships connect the channels and the coves of Smith Mountain Lake. Tributaries provide nutrients to coves, especially phosphorus as demonstrated with the data in this section. The average concentration of total phosphorus from the sampled tributaries was 67.1 ppb, substantially higher than the average concentration of 33.3 ppb for the lake. The situation with nitrate is not as clear. Because nitrate is not the limiting nutrient in Smith Mountain Lake, it is not easy to assess the impact that high nitrate levels have on water quality. The 59 % increase in nitrate levels may have been due to the lack of rainfall and the increased concentration potential, because of lack of flushing. It is highly unlikely that the nitrate concentration limits the growth of algae in a sediment-rich habitat like Smith Mountain Lake.

As has been observed since the second year of the monitoring project, water quality improves significantly as it moves from the upper channels toward the dam. Eroded soil is carried to the lake by silt-laden streams but sedimentation begins in the quiescent lake water. Phosphorus, in the form of phosphate ions, strongly associates with soil particles and settles out during the sedimentation process. Total phosphorus, chlorophyll-*a* and Secchi depth all correlate significantly with distance from the dam. This is not the case for nitrate, which is a labile ion; that is, it does not adsorb to silt particles. As a result nitrate ions do not settle out of the water column and there is not a correlation between nitrate concentration and distance from the dam. It is also apparent from the lower correlation coefficients in Figures 5-8 that this relationship was less well defined again in 2001 as in 2000 than most other years. This may be due to the aging of the lake and the suspected movement downstream of a sediment plume.

4. FECAL COLIFORMS IN SMITH MOUNTAIN LAKE

4.1 Fecal Coliform Monitoring

Water samples were collected from fourteen sites on Smith Mountain Lake on May 29, June 12, June 26, July 5, July 24, and August 7, 2001. These samples were collected and stored according to standard methods (APHA). Two sites were sampled at each station and three replicates at each site were filtered. A standard 100mL aliquot of sample was filtered immediately upon return to the laboratory. The membrane filtration method for bacterial analyses was used with DIFCO m-Fecal Coliform media prepared with rosolic acid, as prescribed in standard methods (APHA). Characteristic blue fecal coliform colonies were counted and recorded after 22-24 hours of incubation at 45.5° C in an incubator.

The sites on Smith Mountain Lake that were sampled included the following:

Non-marina sites

1. Main basin at the confluence of the Blackwater and Roanoke Channels.
2. Forest Cove on the Bedford County side of the lake.
3. Fairway Bay on the Franklin County side of the lake.
4. Palmer’s Trailer Park Cove on the Franklin County side of the lake.
5. Smith Mountain Lake State Park Cove on the Bedford County side of the lake.

Marina sites

6. Shoreline Marina on the Franklin County side of the lake.
7. Pelican Point Marina on the Franklin County side of the lake.
8. Smith Mountain Lake Dock on the Pittsylvania County side of the lake.
9. Smith Mountain Lake Yacht Club on the Bedford County side of the lake.
10. Foxport Marina on the Franklin County side of the lake.
11. Indian Point Marina on the Franklin County side of the lake.
12. Bay Roc Marina at Hardy Ford Bridge on the Franklin County side of the lake.

Headwaters Sites

13. Ponderosa Campground on the Franklin County side of the lake.
14. Beaverdam Creek on the Bedford County side of the lake.

These sites were selected as representative coves around Smith Mountain Lake, to allow comparison between non-marina coves and marina coves and to allow evaluation of two headwaters coves. (1) The main basin site at the confluence of the Blackwater and Roanoke Channels was selected to provide samples not influenced by runoff from nearby shoreline. (2) Forest Cove (Bedford County) is surrounded by a residential area of low density, includes a pasture and is located after the confluence of the two main channels and in close proximity to Smith Mountain Lake Dam. (3) Fairway Bay (Franklin County) is surrounded by homes and multi-family residences and is on the Roanoke Channel. (4) Palmer’s Trailer Park Cove is surrounded by trailers that have been there for a long time, each with a septic tank and drain field, and is located off Little Bull Run, a tributary of the Blackwater Channel. (5) Smith Mountain Lake State Park Cove was sampled where it intersects the main channel.

The marina sites include: (6) Shoreline Marina which is up Becky’s Creek, a tributary of the Roanoke Channel in Franklin County and is a storage place for many houseboats and may have some people living aboard their boats. (7) Pelican Point Marina is on the Blackwater Channel in Franklin County and is a storage place for many large sailboats and a few houseboats. (8) Smith Mountain Lake Dock Cove is a cove off the main basin in Pittsylvania County, in close proximity to Smith Mountain Lake Dam and is a storage place for many houseboats. (9) Smith Mountain Lake Yacht Club is in a cove off the Roanoke Channel in Bedford County and is a storage place for many houseboats. (10) Foxport Marina is on the channel of Gills Creek, a major tributary of the Blackwater River and has very few boats docked there. (11) Indian Point Marina is in a cove off the main channel of the Roanoke River, and is a recently developed marina with very few docked boats. (12) Bay Roc Marina at Hardy Ford Bridge is one of the oldest marinas and is on the Franklin County side of the lake located at the beginning of the lake.

There are two headwater sites which primarily indicate specific watershed influences and not within lake influences. Organic compounds and other nutrients in a body of water come from two possible sources, allochthonous inputs and autochthonous inputs. “Allochthonous” refers to input from outside the body of water (in other words, from the watershed) and “autochthonous” refers to input from within the body of water, for example the algal population photosynthesis. The two headwaters sites reflect two of the allochthonous inputs to Smith Mountain Lake. (13) Ponderosa Campground Cove is located on a curve far upstream on the Blackwater River not far from the non-navigable portion of the river, and (14) Beaverdam Creek is a tributary of the Roanoke River on the Bedford side of the lake.

Figure 13 indicates the mean fecal coliform colony forming units (cfus) commonly called colony counts, for the six sample dates. Figure 14 indicates the 2001 comparison of marinas, non-marinas and headwaters sites. Figure 15 indicates the average colony counts for each sample site. Figure 16 indicates the comparison of the sum of the ranks of each sample site. Figure 17 shows a comparison of mean fecal coliform counts for the six sample years 1996-2001 for each site and the means for both combined marina fecal coliform counts and non-marina fecal coliform counts.

Results:

1. All means of fecal coliform populations averaged over the whole summer were below the Virginia health standard for swimmable and fishable waters and the Virginia standard for potable waters.

2. There were no samples on any date nor at any site that violated the Virginia state standard for swimmable, fishable and potable waters (standard is 200cfus/100mL) (Figure 16).

3. The mean colony counts and variances for marinas in 2001 (15.75 ± 22.37cfus) were one of the lowest counts during all six years of the program, and the non-marinas counts in 2001 (14.31 ± 29.64 cfus) were the lowest counts measured during the six years samples have been taken. This may be because of the lack of rainfall and therefore lack of runoff and/or we may be having success in our Virginia Department of Health Boater and Marina Education Program, which has been in operation for four years.

4. As in 2000, sample date was an important influence on the fecal coliform population estimates, with the early summer sample date May 29, 2001 exhibiting the highest mean number of colonies (24 cfus). In 2001, as in 2000, a significant trend ($\alpha = 0.05$) toward

decreasing number of fecal coliforms was observed as the summer passed (See Figure 13). Other scientists have observed a relationship with rain events and increased number of coliforms in streams. Consistent with this observation, in the summer of 2001 there was no significant rainfall, probably causing lower fecal coliform populations observed.

5 The mean coliform population estimate for all marinas was not significantly higher (15.75 ± 22.37 cfus) than the mean coliform population counts for non-marina sites ± 29.64 cfus). The two headwaters sites' mean fecal coliform population was higher than the marinas and the non-marinas (19.47 ± 38.93 cfus) as seen in Figure 14.

6. All of the marina coves, other non-marina coves and the headwaters sample sites had lower fecal coliform mean counts for the summer than one of the non-marina coves (Palmer's Trailer Park). Each sample time during the summer had a different site with the highest count except the two weeks in July in which Palmer's Trailer Park was highest two dates in a row (Figure 15).

7. The confluence of the two main tributaries and the Smith Mountain Lake Park Cove had the lowest fecal coliform counts on all six sample dates, which was true in 1999 and 2000 also. This year the other two sites that were consistently low were Indian Point Marina and Foxport Marina (Figure 15)**.**

8. When all marina sites and non-marina sites are included, the mean fecal coliform population estimate for the marinas was higher than that for the non-marinas. Four of the seven marinas (Shoreline Marina, Smith Mountain Lake Dock, Bay Roc Marina, and the Smith Mountain Lake Yacht Club) had consistently higher fecal coliform counts than three of the non-marina sites in 1999, 2000 and 2001(Figure 15). In 2001, the Forest Cove site had an unusually large count especially in a year that had such low counts in general. The source of these fecal coliforms is not known and should be investigated more thoroughly (see Antibiotic Resistance Assay section). The high variability of fecal coliform counts is shown by the large standard deviations of each mean. In fact, the standard deviations are greater than the mean values and therefore it is not possible to show significant statistical differences among sites.

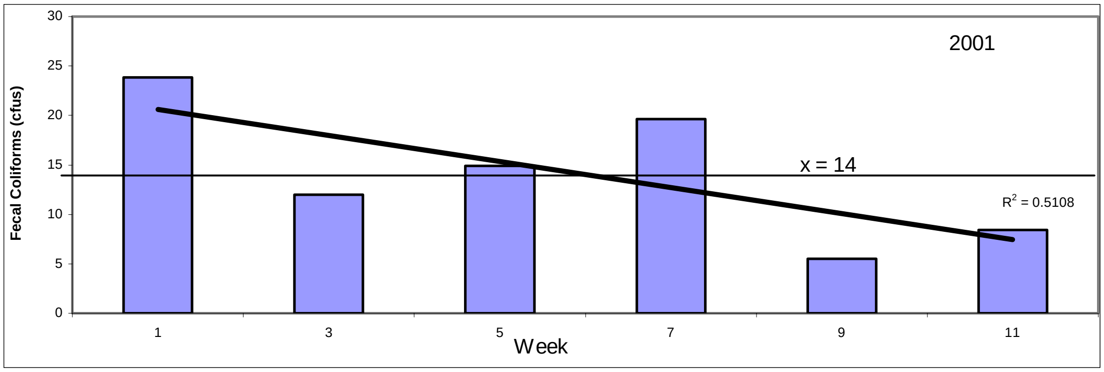


Figure 13. Fecal coliforms vs. week sampled on Smith Mountain Lake in 2001 (Each sample date included 14 sites with 2 samples per site and three replicate filters per sample, n =84).

9. In a comparison of the sums of fecal coliform populations for sample dates and sites (see Figure 16) in 2001, Palmer's Trailer Park (non-marina site), Smith Mountain Lake Dock, Bay Roc Marina, Shoreline Marina, and Beaverdam Creek (headwaters site) have the highest sum of fecal coliform populations, and the confluence of the Roanoke and Blackwater channels and the Smith Mountain Lake State Park Cove (non-marina sites) had the lowest sum of fecal coliform populations for the summer of 2001.

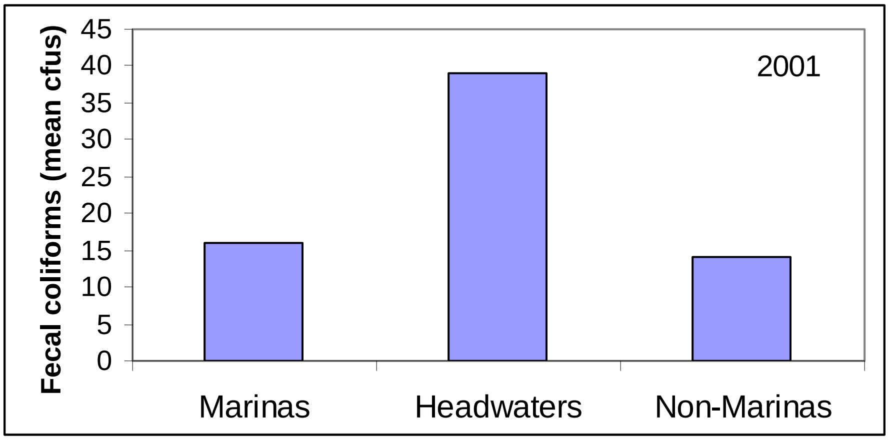


Figure 14. Mean Fecal Coliform Count vs. site type on Smith Mountain Lake 2001. (There were 7 marina sites, 5 non-marina sites, and 2 headwater sites)

10. The mean fecal coliform count for marina sites has been greater than the mean fecal coliform counts for the non-marina sites for five of the seven sample years (1996-2001). The two exceptions are 1999 and this year 2001, when the values were almost equal with the marinas' mean of 15 cfus vs. the non-marinas' mean of 14 cfus (See Figure 17).

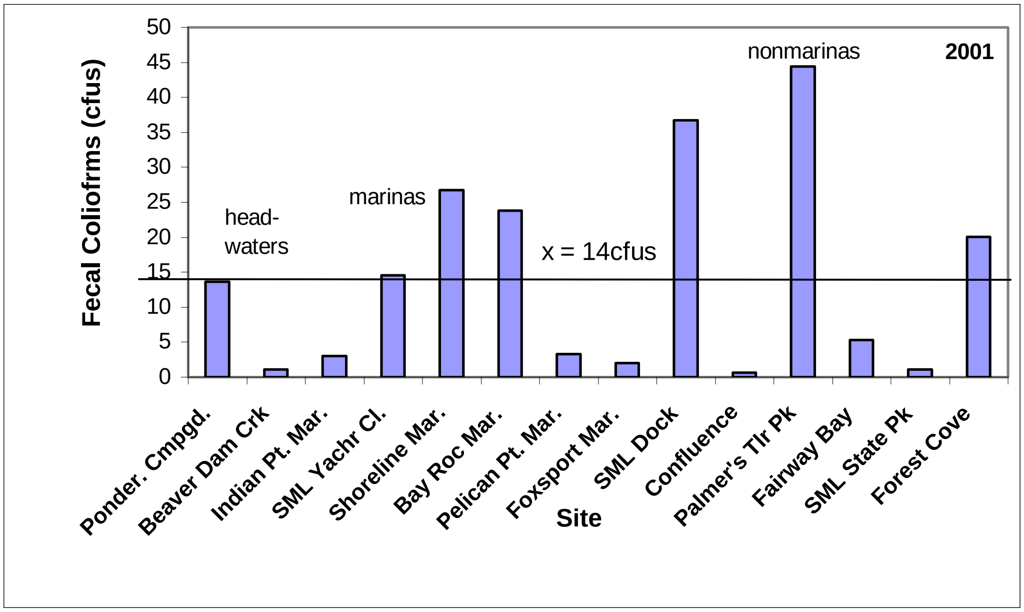


Figure 15. Mean fecal coliform count vs. sample site on Smith Mountain Lake 2001.
(Each site has two stations sampled 6 times during the summer.)

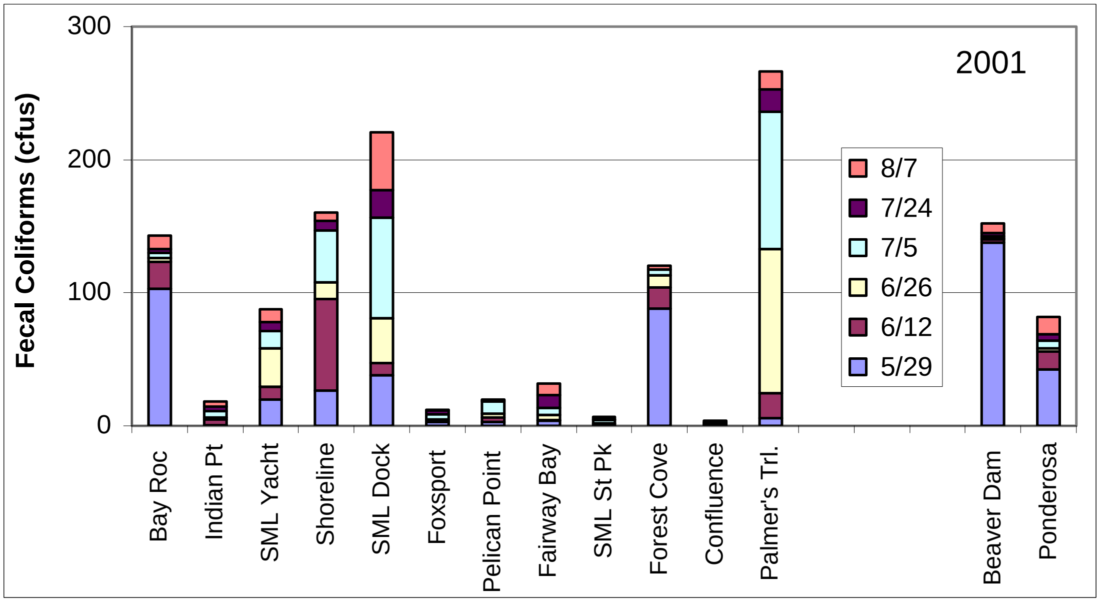


Figure 16. Sum of fecal coliform counts for Smith Mountain Lake in 2001 at each site for all sample dates.
(Each site and date has two stations per site.)

11. In the comparison of six years of sampling fecal coliform (1996-2001), the marinas have been consistently higher than the non-marinas. We also observed a very high fecal coliform

population at one of the headwaters sites in 1997. This high mean is a result of one sample date in which the fecal coliform count was unusually high at one of the two headwater sites which presents a possible false impression of extremely high fecal coliform counts in the headwaters of the lake (Figure 17).

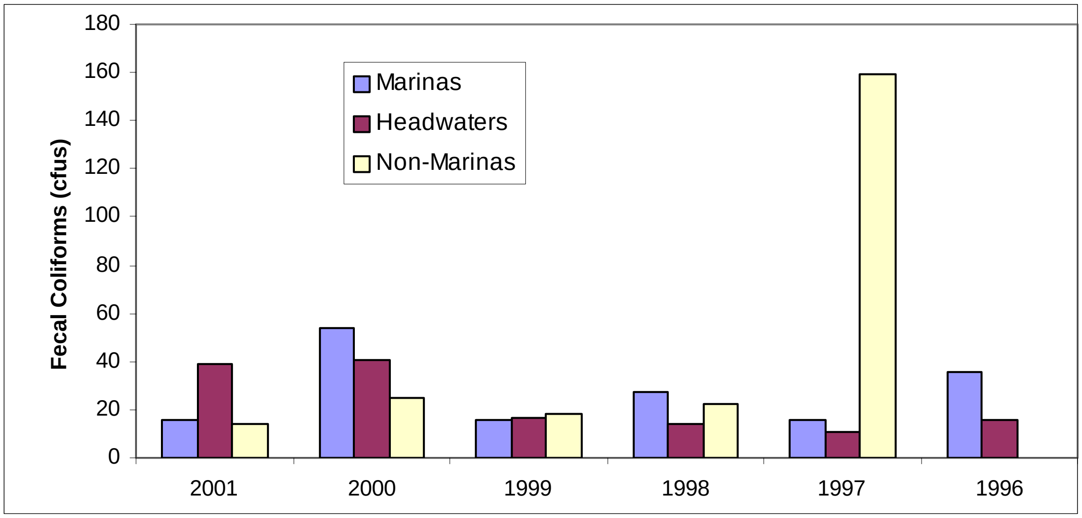


Figure 17. Mean fecal coliform counts per site type and year sampled for Smith Mountain Lake.

Note: In 1997 and 1998 there was considerable controversy about the fecal coliform populations in Smith Mountain Lake. The Virginia Department of Health, especially the Franklin and Bedford County offices, were sampling regularly around the shoreline of the lake in 1998 and found a few sites with unusually high fecal coliform counts. They continued to sample in 1999, 2000 and 2001 and identified no sites with high fecal coliform counts. The Virginia Department of Water Quality, especially the West Piedmont District, was also sampling occasionally at a number of open water sites around Smith Mountain Lake for fecal coliform population and identified no sites with high fecal coliform counts. The results of all three sampling groups were not always in agreement, but we feel that was to be expected with the knowledge that these sites were not the same nor were the sample times the same.

4.2 Fecal Coliform Rain Event Sample

There was no rain event sample in the summer of 2001 because of the lack of rainfall.

4.3 Antibiotic Resistance/Bacterial Source Tracking of Fecal Streptococci

4.3.1 Introduction

Ferrum College scientists Dr. Carolyn L. Thomas and Dr. David M. Johnson have been studying water quality at Smith Mountain Lake since 1985. For the last 7 years (1995-2001), the fecal coliform population has been assessed by comparing 14 marina and non-marina sites. For most of these samples the numbers have been below the Virginia standards for fecal coliform counts. Because this is a very important and controversial water quality parameter, it was decided that knowing the source of these fecal coliforms would be valuable in attempting to decrease the fecal coliform numbers in Smith Mountain Lake.

With this in mind, two years ago a preliminary study of bacterial sources was carried out using the DNA fingerprinting method developed by Dr. George Simmons at Virginia Tech. The work was done by Mr. Ron Stephens, an associate of Dr. Simmons and a professor at Ferrum College. Although interesting results were found (some fecal coliforms could be traced back to a specific farm) they were too time consuming and expensive for the information gained.

Antibiotic Resistance Analysis (ARA) became a more common research method and Dr. Charles Hagedorn from Virginia Tech and his associates shared the information with us about this method and its successes. The method is explained in Harwood et al. (2000). The ARA technique is based on fecal streptococci becoming resistant to antibiotics used in certain species of animals, for example cattle and humans. Therefore, when you find an antibiotic resistant colony you can identify the source (animal) based on the development of resistance in animals in which the particular antibiotic is used.

In July 2000, Dr. Hagedorn and his graduate student, Amy Bowman, showed faculty and students from Ferrum College's Water Quality Lab the method in their lab at Virginia Tech. Since that time, in discussions with Dr. Hagedorn, it was decided to try the methods at Ferrum College and collaborated with Dr. Hagedorn and other scientists in the fall and winter of 2000/2001. The results were described in the 2000 Smith Mountain Lake Report.

Ms. Carol Love (Ferrum College Life Sciences Division's Lab Coordinator) and Patricia Moyer (student lab assistant) have been responsible for almost all of the work on this project, including planning and ordering supplies, setting up the lab space, doing the antibiotic preparation, screening of colonies, and data analysis. The student sampling team took the samples at the fourteen fecal coliform lake sites, six Blackwater river sites, five Beaverdam Creek sites and twenty-two tributary sites. Amy Bowman Booth (Dr. Hagedorn's lab technician) instructed us in the use of the discriminate analysis program called "JMP" used to analyze data.

4.3.2 Sample Sites

4.3.2.1 First sample set

The isolates came from Beaverdam Creek in Bedford County, which empties into the Roanoke River channel of Smith Mountain Lake. These sites were used in a rain event sample in 2000 (see 2000 Smith Mountain Lake Report),

1. Site BD1 is way up the creek where it crosses Spradlin Road in Bedford County.
2. Site BD2 is where the creek crosses Fisherman's Cove Road (gravel). These two sites really are creek sites; the other three are lake sites.
3. Site BD3 is off Sweetwater Court.
4. Site BD 4 is off Bluewater Court.
5. Site BD5 is off Pleasure Point Drive at channel marker.

4.3.2.2 Second sample set

The six sites include watershed sites and lake sites on the Blackwater River, which were studied in 1999 in a rain event sample (see 1999 Smith Mountain Lake Report).

1. Maggodee Creek Site: a tributary of the Blackwater River, which primarily drains forested and agricultural land including dairy cattle pastures in Franklin County. The site was not far from the VA 122 bridge crossing of Maggodee Creek and less than 1/4 mile from the Blackwater River.

2. Blackwater River Crossing Site: a road crossing through the water of the Blackwater River less than a mile from the Maggodee Creek tributary. The Blackwater River primarily drains forested and agricultural land in Franklin County.

3. Blackwater River Bridge Site: at the SR 834 bridge over the Blackwater River near the Riverside Exxon station in Franklin County.

4. Ponderosa Campground Cove Site: at the campground cove, which is on a bend of the Blackwater River where debris collects when rain and overland flow push the debris into the river. This would be considered a lake site in Franklin County Blackwater Channel.

5. 4H Center Site 1: a lake site on the Blackwater Channel at the site of the dock and the gazebo on the 4H Center lakefront in Franklin County.

6. 4H Center Site 2: a lake site down the Blackwater Channel from the 4H Center Site 1 at the tip of the 4-H Center peninsula.

4.3.2.3 Third sample set

These sites are the fourteen lake sites we have been sampling for 7 years for fecal coliforms. These include 7 marina sites, 5 non-marina sites and 2 headwaters sites.

Non-marina sites

1. Main basin at the confluence of the Blackwater and Roanoke Channels.
2. Forest Cove on the Bedford County side of the lake.
3. Fairway Bay on the Franklin County side of the lake.
4. Palmer’s Trailer Park Cove on the Franklin County side of the lake.
5. Smith Mountain Lake State Park Cove on the Bedford County side of the lake

Marina sites

1. Shoreline Marina on the Franklin County side of the lake.
2. Pelican Point Marina on the Franklin County side of the lake.
3. Smith Mountain Lake Dock on the Pittsylvania County side of the lake.
4. Smith Mountain Lake Yacht Club on the Bedford County side of the lake.
5. Foxport Marina on the Franklin County side of the lake.
6. Indian Point Marina on the Franklin County side of the lake.

7. Bay Roc Marina at Hardy Ford Bridge on the Franklin County side of the lake.

Headwaters Sites

1. Ponderosa Campground on the Franklin County side of the lake.
2. Beaverdam Creek on the Bedford County side of the lake.

4.3.2.4 Fourth sample set

These sites are the twenty-two tributary sites we have been sampling for 7 years for fecal coliforms.

Trib. Station	Stream Name
T0	Upper Gills Creek
T1	Maggodee Creek
T2	Lower Gills Creek
T3	Blackwater River
T4	Poplar Camp Creek
T5	Standiford Creek
T6	Bull Run
T7	Cool Branch
T8	Branch at Lumpkin's Marina
T9	Below Dam
T10	Pigg River
T11	Leesville Lake
T12	Creek at Summit Drive
T13	Creek at Snug Harbor
T14	Stoney Creek
T15	Jumping Run
T16	Beaverdam Creek
T17	Roanoke Channel at Bay Roc
T18	Lynville Creek
T19	Grimes Creek
T20	Indian Creek

4.3.3 Results

The samples were compared with known sources of fecal streptococci as listed in Table 6 below. The larger the number of isolates, the more accurate the prediction of the bacterial source of the samples. Table 6 indicates how close the identification of source can be to known sources.

Table 6. Known bacterial sources and the percent agreement with the prediction of source.

Source Name	Domestic (%)	Human (%)	Livestock (%)	Wildlife (%)	Totals (%)	# of Isolates
Domestic	74.47	0.00	0.00	25.53	100.00	47
Human	0.47	84.24	11.29	4.00	100.00	425
Livestock	0.15	6.24	88.82	4.79	100.00	689
Wildlife	5.82	4.74	16.16	73.28	100.00	464

The first and second sample sets did not have enough fecal streptococci colonies for further analyses. The third and fourth sample sets did have enough fecal streptococci colonies for further analyses.

Figures 18, 19, and 20 show the predicted sources (based on comparison to known sources) of the bacterial isolates from the tributary samples (sample set 4). All tributaries except three had between 36 and 48 isolates in the water sample, which makes the predicted sources valid. Tributary 9 (Pittsylvania) and Tributaries 15 and 18 (Bedford) had smaller isolate numbers (8, 11 & 18 respectively) and therefore the predictions are suspect.

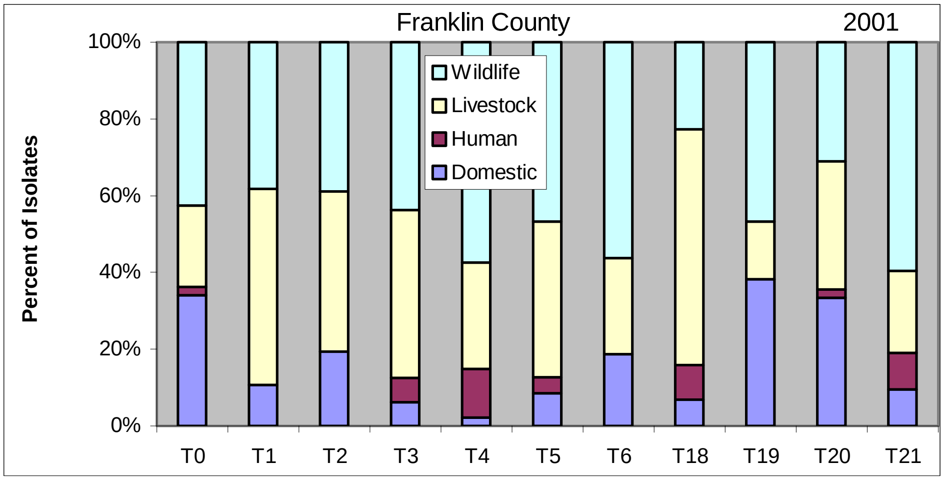


Figure 18. Percent of bacteria isolates from four potential sources in Franklin County tributaries.

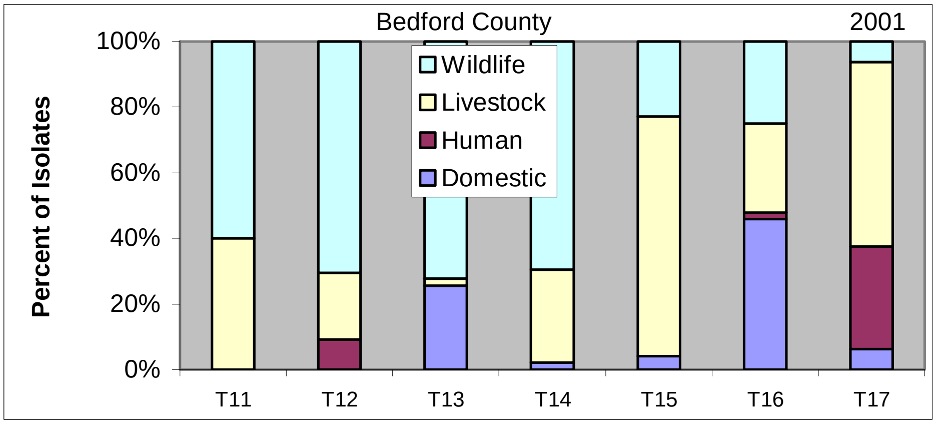


Figure 19. **Percent of bacteria isolates from four potential sources in Bedford County tributaries.**

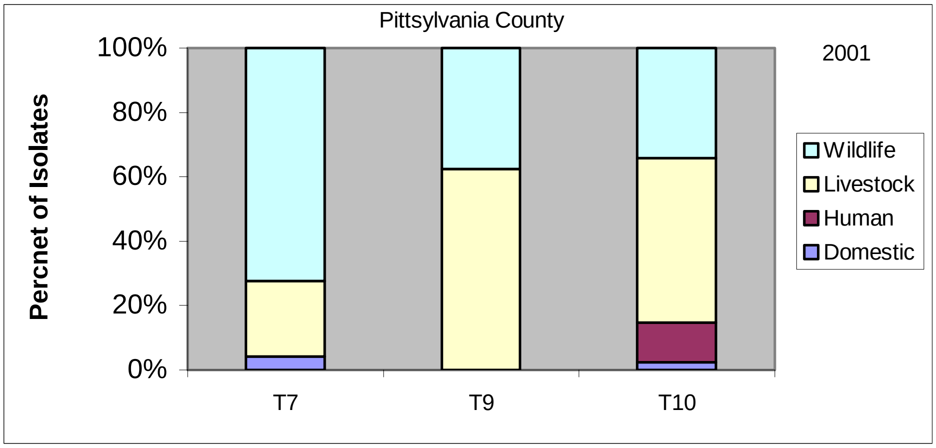


Figure 20. **Percent of bacteria isolates from four tributaries in Pittsylvania County.**

The predicted human source causes concern and should be investigated further as to the probable sources. Humans carry disease-causing organisms in their intestines and could lead to a health risk. The livestock source is probably cattle because of their prevalence in the Smith Mountain Lake tributaries' watersheds. Cattle are known to carry a toxic *Escherichia coli* species in their intestines, another health risk to humans drinking the water. The wildlife predictions are problematic since no solution is readily available, however wildlife are not known to carry human pathogenic organisms.

Table 7 shows the predicted bacterial sources for two of the fourteen samples taken in Smith Mountain Lake during one of our fecal coliform sampling dates. The other twelve sites had too few isolates for the predictions to be valid. Both of these samples show human bacteria sources present, which is a cause of concern.

Table 7. **Lake samples taken in Smith Mountain Lake with predictions of bacterial sources.**

Sample site	Domestic	Human	Livestock	Wildlife
SML 5-2	0.00	50.00	50.00	0.00
SML 11-2	0.00	42.59	9.26	48.15

5. WATER QUALITY TRENDS

5.1 Water Quality Trends by Zone.

In studying Smith Mountain Lake over the last fourteen years we have found that lake cannot be described as a single, homogeneous waterbody because of the broad differences between the upper reaches of the lake and the lower reaches nearer the dam. So, as a result, we have attempted to describe the lake in zones based on the distance to the dam and having similar physical characteristics. As you will see, the evaluation of water quality based on zones provides some interesting suggestions about multiple uses of the lake. For example, fishing would be best in those zones that have greater nutrient enrichment, and water used as potable water to produce drinking water would be better in those zones with lower nutrient enrichment.

The lake sample sites are divided into zones based on the site's distance from the dam:

Zone 1 = 0-5 miles
Zone 2 = 5-10 miles
Zone 3 = 10-15 miles
Zone 4 = 15-20 miles
Zone 5 = 20-25 miles
Zone 6 = 25 + miles

The data do not show much in the way of trends in a comparison of the fifteen years' worth of data that has been collected. It should be noted that Zone 5 and 6 have only five to nine years' worth of data.

In Figure 21, no significant trend in total phosphorus concentration over the fifteen-year period in any zone is noted. However, in 1992 in Zone 4 (15-20mi), a high concentration of total phosphorus was found, which appears to show up the next year (1993) in Zones 1, 2 and 3, perhaps indicating a movement of phosphorus downstream. All zones show a high total phosphorus concentration in 1995 but not the movement of phosphorus downstream. Zones 1, 2, 5, and 6 show a higher total phosphorus concentration in 2001 than in 2000, which was also true in 1998 and 1999. However the lake mean was slightly lower (-7%) in 2001 than in 2000, probably because of the lower than average runoff this summer because of the drought.

In Figure 22, chlorophyll-*a* shows a very significant increase in concentration in all zones, in 2001. For all zones the 2001 data point is the highest concentration over the fifteen years of data collection. (Values for chlorophyll-*a* were calculated incorrectly. See Appendix Table A7a for corrected values. Corrected average value; CHA = 4.1 ppb.) From 1998 to 2000 there was a 298% increase in chlorophyll-*a* over all zones and in 2001 there was a 91 % increase. The percent increase in each zone was as follows: zone 6 = 76%, zone 5 = 103%, zone 4 = 126%, zone 3 = 43%, zone 2 = 174%, and zone 1 = 97%. The highest percent increases were in zone 2 and zone 4. This increase causes concern and requires further investigation of potential causes especially because it is the second year in a row with a significant increase in chlorophyll (617 % over the two years).

The Secchi depth (Figure 23) means in all zones show no significant trend of increasing or decreasing over the fifteen years, except in zone 1 and zone 3 where the increasing trend is significant ($\alpha = 0.05$). An increasing trend indicates better water quality. In 2001, a zone 2, 3 4, 5 & 6 (5-25+ miles) show increases in water clarity. Many factors affect water clarity including algal populations and silt from soil erosion, subsequently, distinguishing causes of significant trends is difficult. Lack of rainfall and therefore little runoff occurred this summer, resulting in higher water clarity. The higher water clarity however allows greater penetration of light contributing to an increase in the algal population growth and water column distribution. The increase in the algal population will decrease the water clarity as a result of the greater light penetration.

It should be noted that the later years' (especially 1995-2001) data is based on more sample sites and broader coverage of the lake. Some of these trends may reflect the sample size difference (number of sites) and improved coverage of the lake.

When we compare all three parameters' trends (Figure 24) by year we see a significant increase in total phosphorus and chlorophyll-*a* concentrations, both indicating lower water quality as the years goes by. This finding has been reported in many previous reports as all three parameters were plotted versus time. This finding gives further credence to the division of the lake into zones for water quality evaluations and planning decisions around the lake.

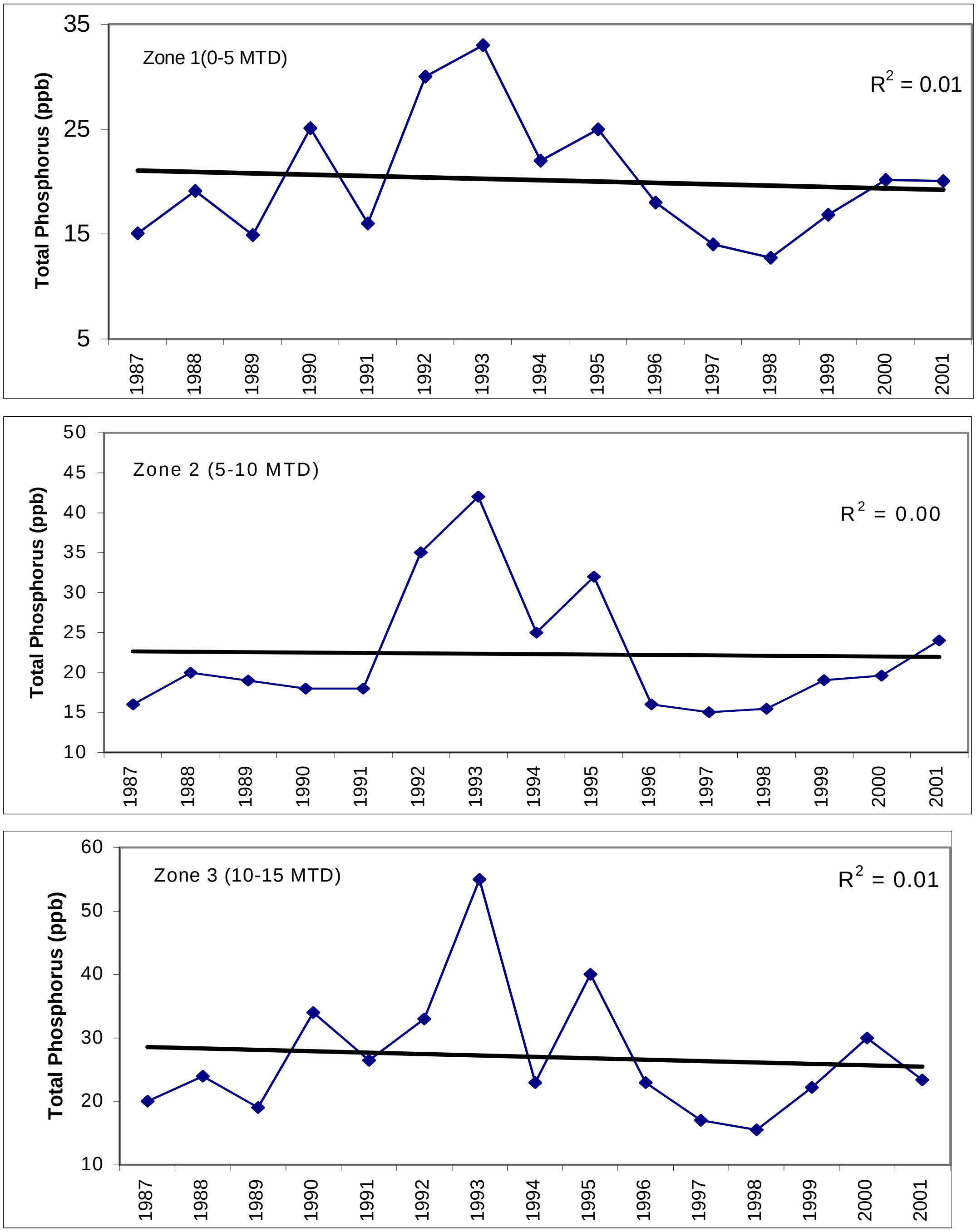


Figure 21. **Average annual total phosphorus concentration by zone in Smith Mountain Lake.**

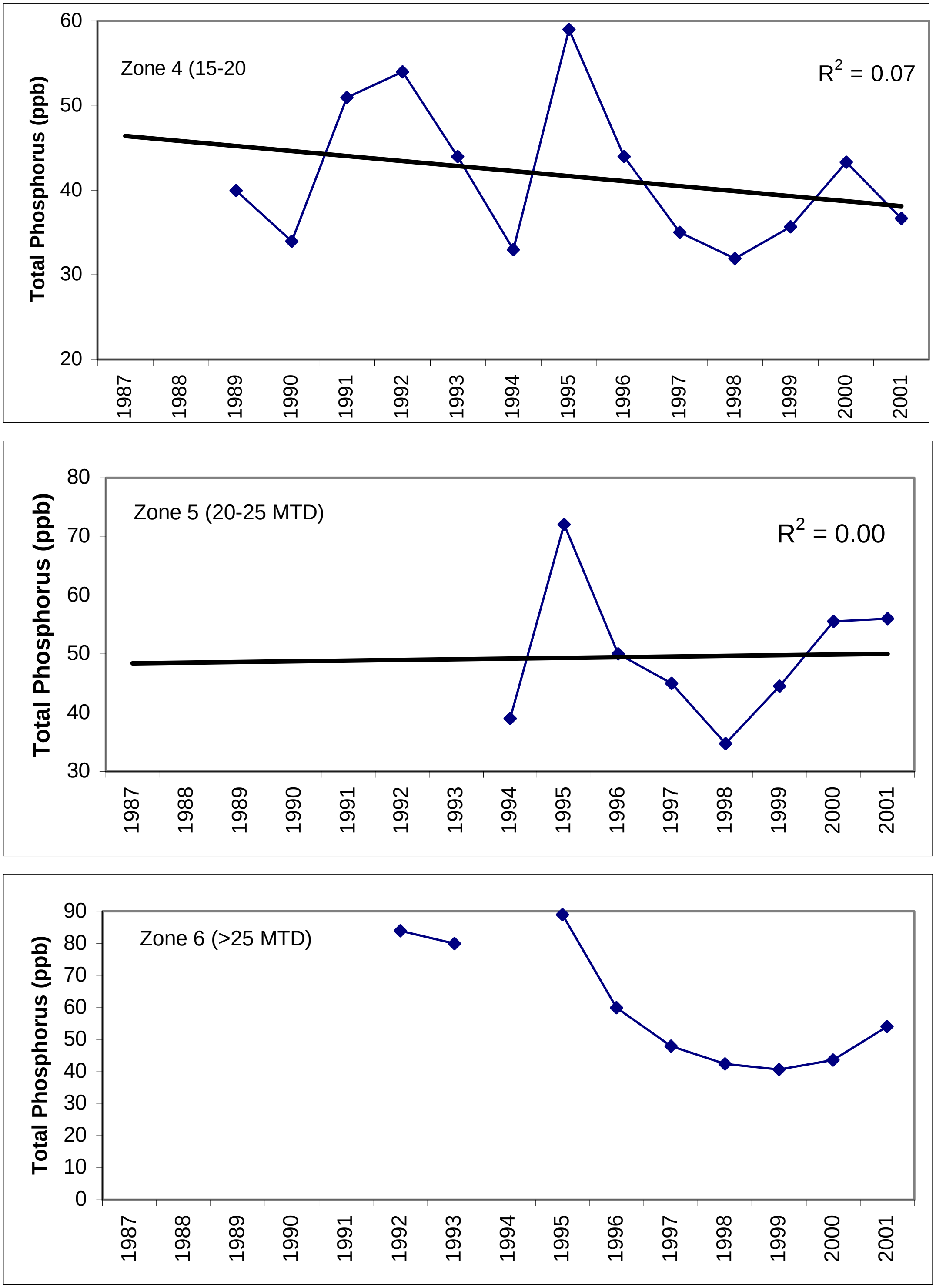
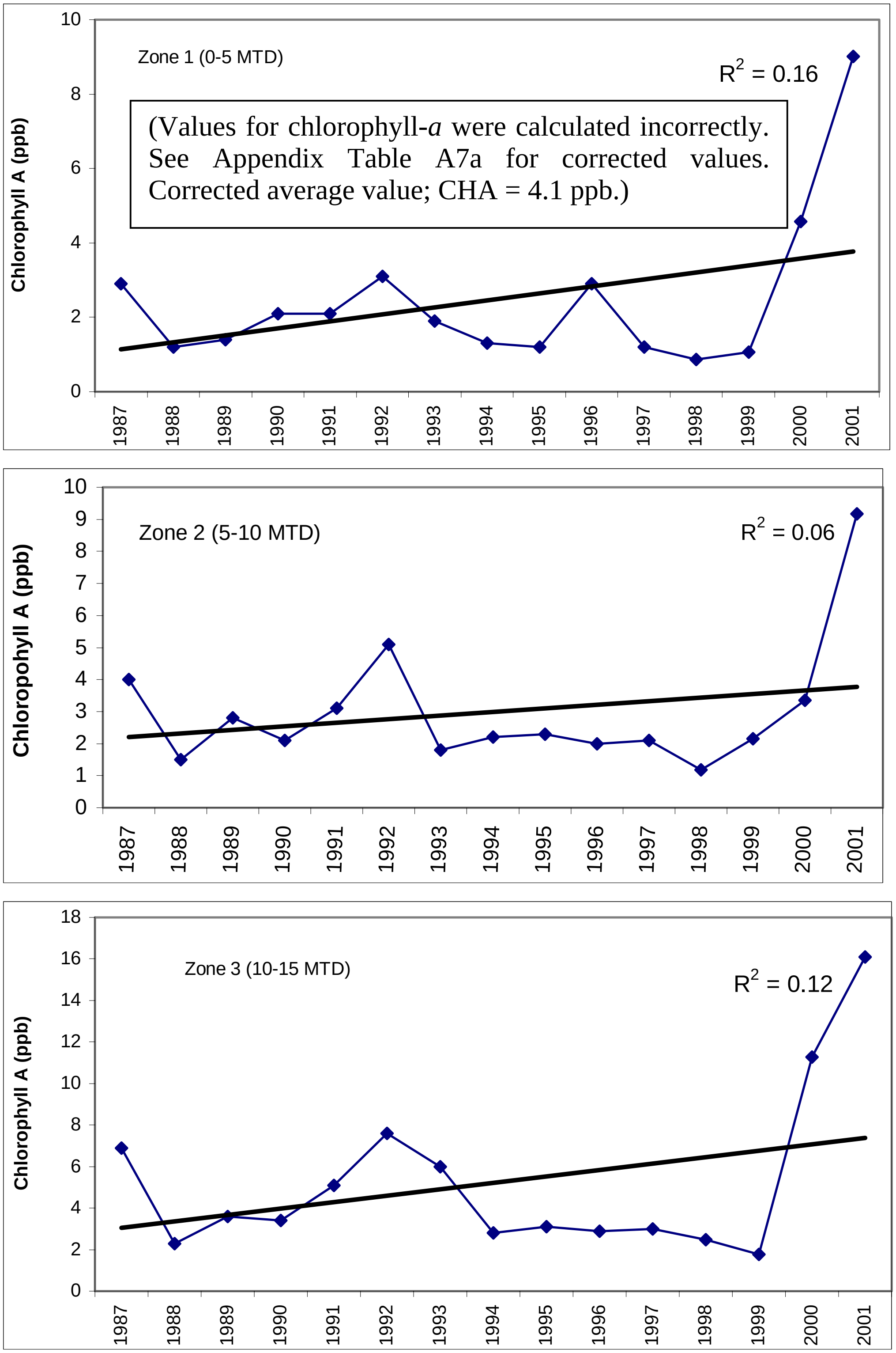


Figure 21. **Average annual total phosphorus concentration by zone in Smith Mountain Lake (cont.)**



(Values for chlorophyll-*a* were calculated incorrectly. See Appendix Table A7a for corrected values. Corrected average value; CHA = 4.1 ppb.)

Figure 22. Average annual chlorophyll-*a* concentration by zone in Smith Mountain Lake.

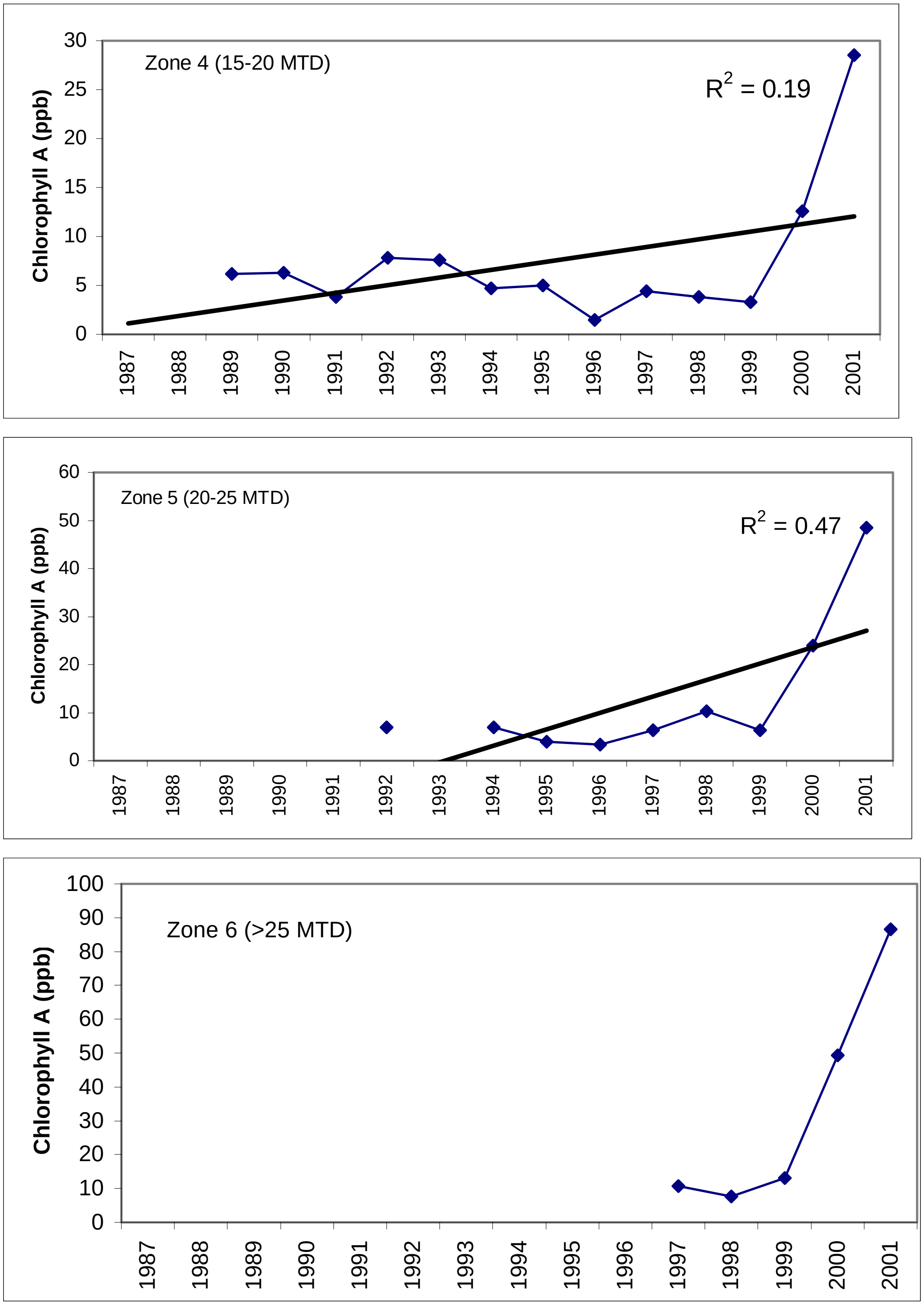


Figure 22. Average annual chlorophyll-*a* concentration by zone in Smith Mountain Lake (cont.)

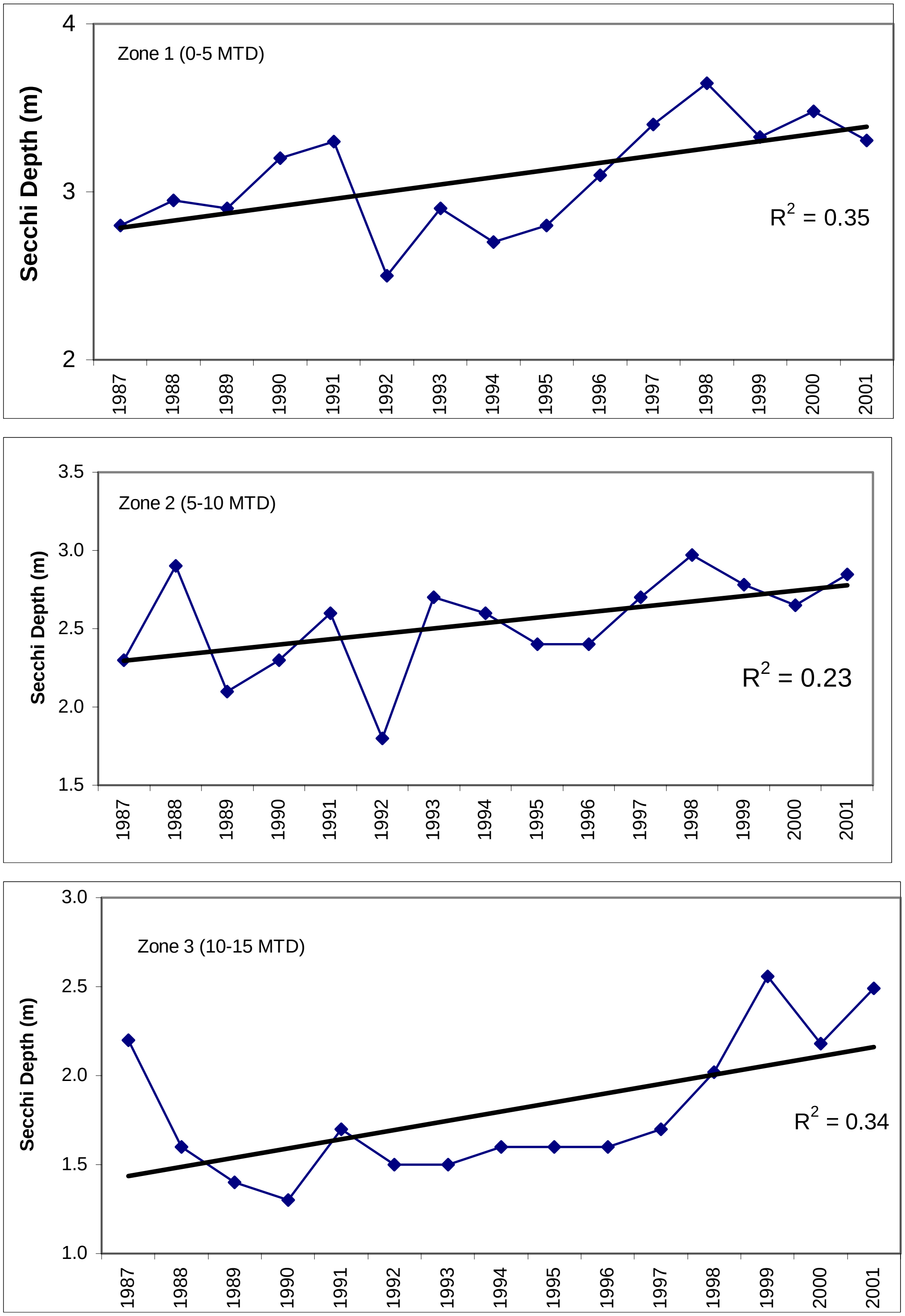


Figure 23. Average annual Secchi depth for zones in Smith Mountain Lake.

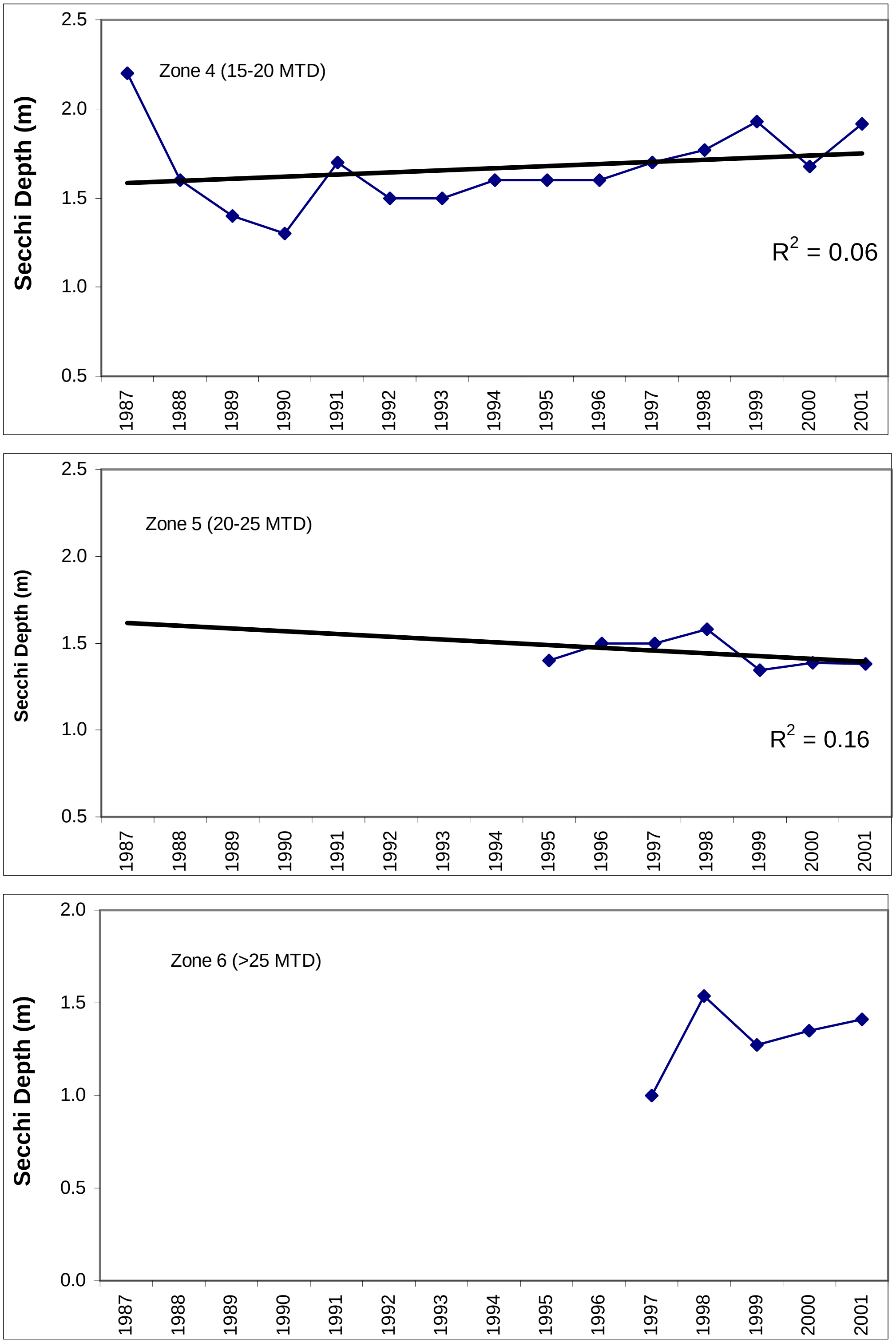
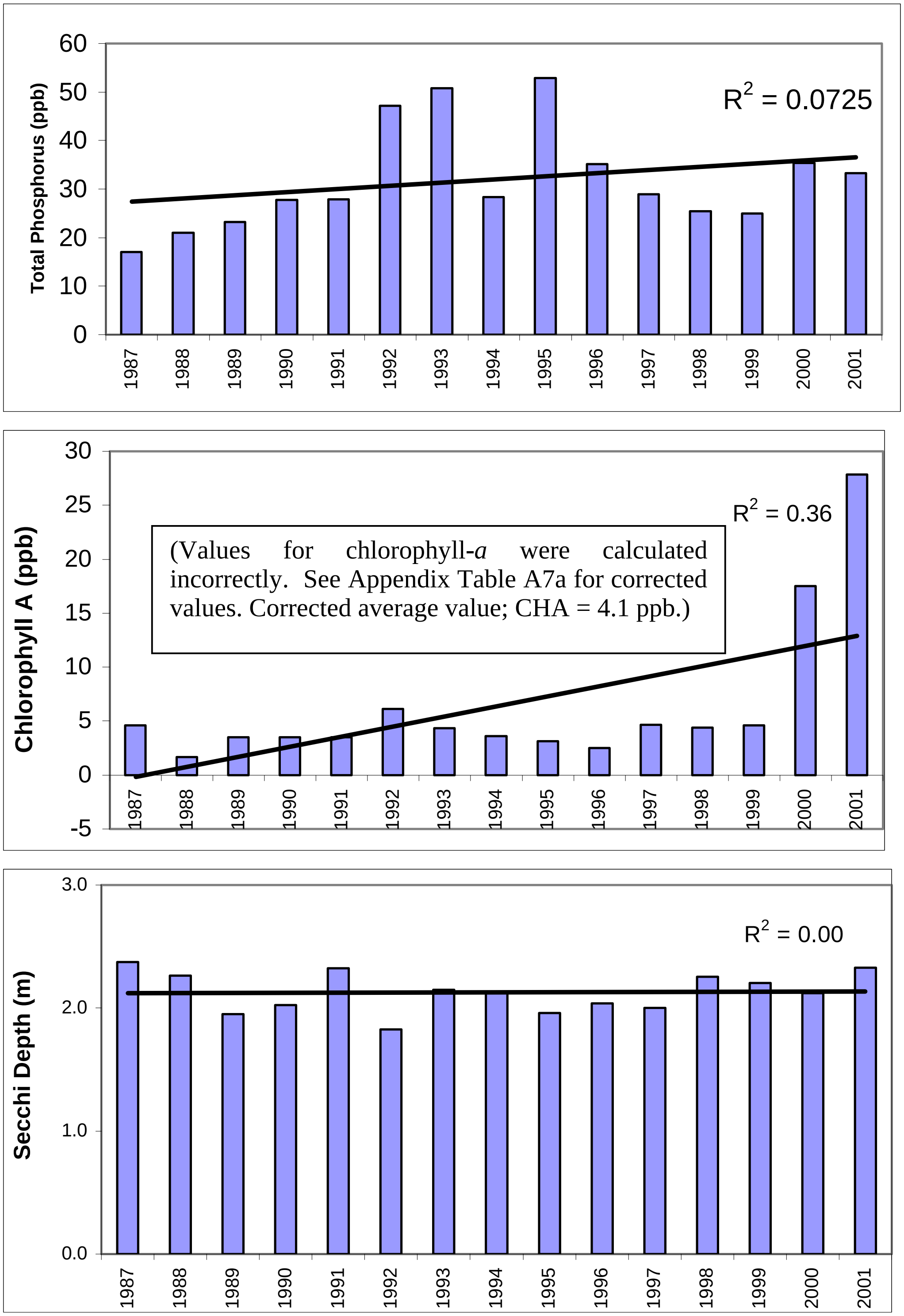


Figure 23. Average annual Secchi depth for zones in Smith Mountain Lake (cont.)



(Values for chlorophyll-*a* were calculated incorrectly. See Appendix Table A7a for corrected values. Corrected average value; CHA = 4.1 ppb.)

Figure 24. Average parameter value by year 1987-2001.

5.2 Carlson's Trophic State Index

The trophic status of a lake indicates the degree of nutrient enrichment and the resulting suitability of that lake for various uses. The process of eutrophication is described at the beginning of the Training Manual for the Volunteer Monitoring Program. Phosphorus is most often the nutrient that limits algal production and attempts have been made to relate the trophic status of a lake to concentration of phosphorus. Table 8 shows one such effort (note that the relationships are for northern temperate lakes and will not represent southeastern lakes as well).

Table 8. Proposed relationships among phosphorus concentration, trophic state, and lake use for northern temperate lakes.
(Reckhow and Chapra, 1983)

Phosphorus Concentration (ppb)	Trophic State	Lake Use
< 10	Oligotrophic	Suitable for water-based recreation and cold water fisheries. Very high water clarity and aesthetically pleasing.
10-20	Mesotrophic	Suitable for recreation, often not for cold water fisheries. Clarity less than in oligotrophic lakes.
20-50	Eutrophic	Reduction in aesthetic properties reduces enjoyment from body contact recreation. Generally productive for warm water fish.
> 50	Hypereutrophic	A typical "old-aged" lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth diminish open water surface area.

The algal growth resulting from inputs of phosphorus can also be used to evaluate the trophic status of a lake. This is done by extracting the green pigment, chlorophyll-a, from algae filtered from lake water samples and measuring its concentration. Table 9 shows the trophic status delineation based on the concentration of chlorophyll-*a*. It also shows that the evaluation of trophic status is a matter of professional judgment, not a parameter to be measured exactly.

Trophic status can also be evaluated from Secchi disk measurements since algal growth decreases water clarity. Researchers have also attempted to relate water quality parameters such as conductivity and total organic nitrogen to trophic status. Regardless of how trophic status is evaluated, a particular status is used to summarize the water quality in a lake with respect to certain uses. The particular summary term, such as mesotrophic, is assigned to a lake based on a summary statistic, such as the average total phosphorus concentration. Further, researchers have devised water quality indices based on one or more summary statistics to better communicate water quality information to the general public. Using an index, trophic status can be placed on a scale from 1 to 100, with 1 being the least eutrophic. An index can be derived from any summary statistic by means of a mathematical transformation and provides a way of directly comparing various parameters, which are measured in very different units. For example, without indexing, most people would have a hard time comparing the water quality significance of a 14 ppb total phosphorus concentration with a 3.5 meter Secchi depth.

Table 9. Trophic status related to chlorophyll-*a* concentration in different studies.
(Reckhow and Chapra, 1983)

	Chlorophyll-*a* Concentration (ppb)			
Trophic Status	**Sakamoto**	**NAS**	**Dobson**	**EPA-NES**
Oligotrophic	0.3-2.5	0-4	0-4.3	< 7
Mesotrophic	1-15	4-10	4.3-8.8	7-12
Eutrophic	5-140	> 10	> 8.8	> 12

One of the best-known trophic state indices is the Carlson Trophic State Index, TSI, named after the researcher who developed it. We will use this index to help interpret the water quality data collected on Smith Mountain Lake. The Carlson TSI may be calculated from total phosphorus concentration (TP), chlorophyll–*a* concentration (CHA), or Secchi disk depth (SEC). The index obtained from each of these parameters can be averaged to give a combined TSI. This is important because any of the individual parameters can be misleading in some situations. Secchi disk readings are a misleading indicator of trophic status in lakes with non-algal turbidity caused by soil erosion, such as in the upper river channels and near shore areas of Smith Mountain Lake. Phosphorus will not be a good indicator in lakes where algal growth is not limited by availability of phosphorus (algal growth in Smith Mountain Lake is phosphorus limited). Chlorophyll-*a* may be the best indicator during the growing season and the worst at other times.

The following equations are used for the calculation of TSIs. (TSI (C) is the combined trophic state index.)

$$\mathrm{TSI(TP)} = 14.42 \ln \mathrm{TP} + 4.15$$
$$\mathrm{TSI(CHA)} = 9.81 \ln \mathrm{CA} + 30.6$$
$$\mathrm{TSI(SEC)} = 60 - 14.41 \ln \mathrm{SD}$$
$$\mathrm{TSI(C)} = [\mathrm{TSI(TP)} + \mathrm{TSI(CHA)} + \mathrm{TSI(SEC)}]/3$$

Another useful aspect of the trophic state index is in comparing the stations being monitored. In Figure 25, the individual parameter trophic state index for each station has been plotted and in Figure 26 the combined trophic state index has been plotted as a function of its distance from the dam. The results demonstrate again the trend toward improved water quality near the dam, *i.e.*, lower TSI values.

In Smith Mountain Lake, the chlorophyll-*a* trophic state index is much higher than the total phosphorus or the Secchi depth trophic state index. The TSI for chlorophyll-*a* is in the eutrophic classification (> 50) throughout the entire lake. In the combined trophic state index, the eutrophic classification begins at about 10 miles from the dam. Closer to the dam, the classification is in the mesotrophic range.

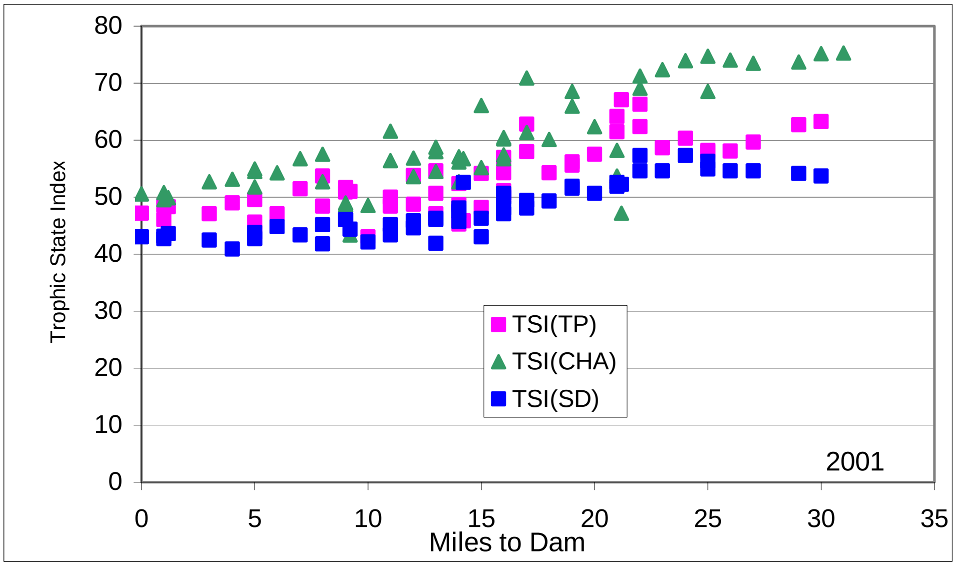


Figure 25. Trophic State Index as a function of distance from dam.

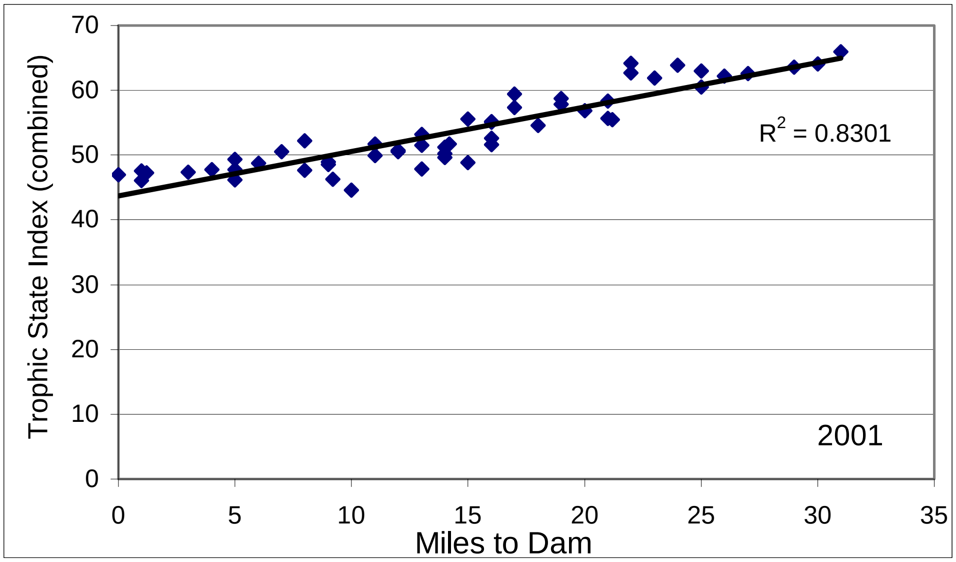


Figure 26. Combined Trophic State Index as a function of distance from dam.

Table 10 gives summary information from the TSI for 1997-1999 and 2001. In 1999, the average TSI, along with minimum and maximum values, increased very slightly while the correlation coefficient decreased slightly. In 2000, the TSI calculation was not done. It is interesting to note that, while the correlation coefficient decreased for each parameter plotted as average station value versus distance from the dam, the correlation coefficient for the combined TSI continued to give a highly significant correlation. In 2001, note that the average combined TSI was well over 50, which moves the lake into the eutrophic classification. Although for the TSI(C) the eutrophic classification is based primarily on chlorophyll-*a*, in other classification systems described above, the phosphorus concentration also puts the lake in the eutrophic classification.

Table 10. Combined Trophic State Index summary for 1997 – 1999 & 2001.

Year	Avg Combined TSI	TSI Range	R^2 (TSI vs MTD)
1997	47.0	36.7 - 56.3	0.867
1998	45.6	35.1 - 56.3	0.885
1999	46.7	35.3 - 59.5	0.833
2001	55.3	44.5 – 65.9	0.830

Table 11 gives the monitoring stations ordered according to the combined TSI. For each station, especially those with high TSI(C) values, it is useful to look at TSIs calculated on the basis of total phosphorus, chlorophyll-*a*, or Secchi depth to see which parameter(s) is most affecting the value of the combined trophic state index.

Table 11. Monitoring stations arranged in order of Combined Trophic State Index for 2001.

Miles to dam	2001 Station	TSI(TP)	TSI(CHA)	TSI(SEC)	TSI(C)
10	B10	43.0158	48.505156	42.155027	44.558661
1	M1	46.054687	49.500719	42.650752	46.068719
5	C5	43.900949	51.769437	42.832012	46.167466
9.2	CR9.2	50.989449	43.421479	44.370539	46.260489
0	M0	47.226808	50.571143	43.015582	46.937844
1.2	CM1.2	48.352039	49.846935	43.580752	47.259909
3	M3	47.095914	52.655871	42.471743	47.407843
1	CM1	48.586049	50.824046	43.20152	47.537205
8	B8	48.446311	52.751039	41.743285	47.646879
4	C4	49.040175	53.153965	40.953498	47.715879
5	M5	45.666113	54.989189	42.650752	47.768685
13	G13	47.114827	54.497812	41.947686	47.853442
9	CR9	50.884155	48.6246	46.093184	48.53398
6	C6	47.133599	54.265016	44.782281	48.726965
15	G15	48.182218	55.217574	43.015582	48.805124
9	R9	51.668887	48.967409	46.093184	48.909827
5	CM5	49.575383	54.515251	43.774178	49.28827
14	R14	45.313687	56.196366	47.535387	49.681813
11	CB11	49.956683	56.364572	43.389888	49.903714
14	G14	52.316409	52.652073	45.687242	50.218575
12	B12	48.801066	56.841288	45.86625	50.502868
7	R7	51.415623	56.785925	43.389888	50.530479
12	G12	53.854355	53.644543	44.574939	50.691279
14	B14	48.631927	57.05085	48.050084	51.244287
13	R13	50.623298	57.965267	46.093184	51.560583
16	G16	51.111931	56.755967	47.087372	51.651756
14.2	CR14.2	45.790054	56.717705	52.639003	51.715587
11	R11	48.420729	61.580605	45.206135	51.735823
8	CR8	53.719982	57.536044	45.206135	52.154054
16	CB16	50.28808	57.426268	50.011749	52.575366
13	CR13	54.632792	58.740589	46.323749	53.232377
18	G18	54.307164	60.140954	49.308683	54.5856
16	B16	54.301264	60.218877	50.625033	55.048391
16	CR16	56.933739	60.462093	48.050084	55.148639
21.2	CR21.2	67.058051	47.158701	52.283182	55.499978
15	R15	54.194593	66.043852	46.323749	55.520731
21	R21	61.417321	53.701189	51.935936	55.684815
20	CB20	57.560534	62.368229	50.625033	56.851265
17	CR17	62.75968	61.357065	48.050084	57.388943

Table 11. Monitoring stations arranged in order of Combined Trophic State Index for 2001 (cont.).

19	R19	55.642571	65.912899	51.935936	57.830469
21	CR21	64.119717	58.146442	52.639003	58.30172
19	CR19	56.135618	68.576482	51.596862	58.769654
17	R17	57.929768	70.902875	49.423504	59.418716
25	R25	58.180316	68.489579	54.980901	60.550265
23	R23	58.647433	72.412744	54.56319	61.874455
26	CR26	58.047948	74.003985	54.645769	62.232567
27	R27	59.619564	73.529261	54.56319	62.570672
22	CR22	62.347996	71.188978	54.56319	62.700055
25	CR25	57.996369	74.715298	56.312	63.007889
29	R29	62.697108	73.763494	54.157248	63.539283
24	CR24	60.306741	73.973026	57.273023	63.85093
30	R30	63.253256	75.146526	53.684746	64.028176
22	B22	66.282861	69.046675	57.273023	64.200853
31	R31		75.239189		65.93534

6. QUALITY CONTROL/QUALITY ASSURANCE

The full QA/QC program for the monitoring program is described in detail in the 1990 Final Report to the VEE. The results of this year's QA/QC program follow.

6.1 Calibration Data for Total Phosphorus and Nitrate

6.1.1 Total Phosphorus

Each week a set of standards is prepared so that a calibration curve can be constructed to determine the relationship between total phosphorus concentration in a sample and its absorption of light at 700nm. Table 12 summarizes the calibration data. The slope indicates the relationship between concentration and absorption and was very consistent from week to week. This gives us confidence that the spectrophotometer used to measure absorbance was stable and that the standards were prepared in a consistent manner. The intercept is the absorbance of the reagent blank and indicates the extent to which the standards are contaminated with phosphorus during the analytical process. This background is subtracted from each sample to compensate. The contamination is due almost entirely to sample digestion. During digestion four reagents are added which contain small amounts of phosphorus that, along with the extra handling and manipulation, lead to some inevitable contamination. The correlation coefficient (R^2) is a measure of how well the calibration line fits the data points with values ranging from 0 (no fit) to 1 (perfect fit). Averaging over 0.99, the correlation coefficient indicates excellent precision and shows both the care with which standards were prepared and the stability of the instrument.

Table 12. Summary of 2001 calibration data for total phosphorus.

Sampling Period	Slope	Intercept	R^2
1	0.0025	0.009	0.9996
2	0.0024	0.039	0.9936
3	0.0024	0.017	0.9974
4	0.0024	0.011	0.9880
5	0.0021	0.0265	0.9949
6	0.0024	0.0152	0.9991
avg	0.0024	0.0197	0.9954

6.1.2 Nitrate

This was the fourth season in which volunteer monitor samples and tributary samples were analyzed for nitrate. The calibration data for nitrate is displayed in Table 13. The correlation coefficient for nitrate is not as high as for total phosphorus and that is inherent to the method. The reduction of nitrate to nitrite is accomplished by shaking the samples with powdered cadmium and the conversion efficiency limits the precision of the method. The average correlation coefficient is still well above 0.98.

Table 13. Summary of 2001 calibration data for Nitrate.

Sampling Period	Slope	Intercept	R^2
1	0.0014	0.0665	0.9945
2	0.0008	0.0711	0.9894
3	0.0008	0.0504	0.9921
4	0.0008	0.0630	0.9903
5	0.0010	0.0312	0.9657
6	0.0010	0.0534	0.9894
avg	0.0009	0.0554	0.9869

6.2 Field Blanks and Surrogate Samples for Total Phosphorus and Nitrate

The QA/QC plan for the project is also to include field blanks and surrogate samples. The field blanks and surrogate samples are prepared in the same manner as blanks and standard solutions used in the laboratory for calibration. However, they are poured into sample bottles and given to volunteer monitors to carry out in the field and then stored in the same manner as the lake water samples. This is to examine the effect of sample collection, storage, and sample bottle on the results of phosphorus determinations. Insufficiently cleaned containers generally add phosphorus, but a very clean container may actually reduce the phosphorus concentration in a sample by adsorption of phosphate on container walls. To avoid container effects a sample must be stored in a container that has been previously equilibrated with a solution of similar phosphate concentration. In practice this is impossible since we don't know phosphorus concentrations before they have been analyzed. We minimize this source of contamination by designating a particular sample bottle for each site and reusing that bottle each week. At the beginning of this season a sheet was prepared giving the concentrations for surrogate samples in order to assure a full range of concentrations were included.

The field blanks and surrogates for total phosphorus analysis included the following concentrations: 0 ppm, 20 ppm, 40 ppm, and 80 ppm. The differences shown in Table 14 represent the analyses of 31 field surrogate samples and 12 field blanks that were given out to the volunteers to treat in an identical manner as their weekly samples. These samples were collected from the volunteers along with their regular samples, and analyzed identically to all other total phosphorus samples.

Table 14. Average percent differences between the actual concentrations of total phosphorus and the measured concentration for surrogate samples including spikes and blanks.

TP Surrogate sample date	**Average** %difference	Min. diff	Max. diff.
6/20	7.89	-22.9	54.1
7/18	19.12	-13.7	33.8
8/1	66.81	-102	348
8/16	-6.82	-37.2	10.5

The field blanks and surrogates for nitrate analysis included the following concentrations: 0 ppm, 200 ppm, 300 ppm, 400 ppm, 500 ppm and 800 ppm. The differences shown in Table 15 represent the analyses of 31 field surrogate samples and 12 field blanks that were given out to the volunteers to treat in an identical manner as their weekly samples. These samples were collected from the volunteers along with their regular samples and analyzed identically to all other nitrate samples.

Table 15. Average percent differences between the actual concentration of nitrate and the measured concentration for surrogate samples including spikes and blanks.

NO3 Surrogate	**Average**		
sample date	%Difference	Min. diff	Max. diff.
6/20	32.8	21.8	43.4
7/18	29.1	-2.9	73.8
8/1	-33.8	-78.8	8.4
8/16	25.4	-49.2	155.7

6.3 Laboratory Blanks and Standards for Total Phosphorus and Nitrate

Standards and laboratory blanks were analyzed spectrophotometrically along with the regular samples for quality assurance on three occasions (July 18, August 1, and August 18) at the midpoint and endpoint of the analysis to evaluate the loss of precision during the analytical period. The results for nitrate and phosphorus are presented below in Table 16.

Table 16. Average percent differences between the beginning absorbance readings of nitrate and total phosphorus and the middle and ending absorbance readings.

NO3 Standards	**Average Mid**			**Average End**		
sample date	%difference	Min. diff	Max. diff.	%difference	Min. diff	Max. diff.
7/18	N/A	N/A	N/A	10.5	0	21.04689
8/1	-23.4	-100.0	-1.6	-27.2	-100.0	-1.9
8/16	4.7	-37.3	105.7	-17.3	-60.7	-4.7
TP Standards	**Average Mid**			**Average End**		
sample date	%difference	Min. diff	Max. diff.	%difference	Min. diff	Max. diff.
7/18	N/A	N/A	N/A	6.5	5.9	7.1
8/15	-2.9	-23.1	260.0	25.7	-13.2	84.6

6.4 QA/QC for Chlorophyll-a

In 2001 a new fluorimeter was purchased and was calibrated according to installation and start up instructions. At the beginning of each sample analysis the fluorimeter was calibrated. In Table 17 two replicate analyses series are reported. Nine to ten aliquots of the same sample of lake water were filtered, extracted, and analyzed identically.

Table 17. Chlorophyll-*a* replicate analysis for two sample runs in 2001.

SML Dam Sample		**Bridgewater Sample**	
8/1/01	Conc. ppb	8/16/01	Conc. ppb
1	13.05	1	7.7
2	14.46	2	13.94
3	14.75	3	10.89
4	13.44	4	9.72
5	11.5	5	9.9
6	14.51	6	11.04
7	12.12	7	6.81
8	15.94	8	10.32
9	9.34	9	5.79
10	11.28		
10	5.53		
Max.	15.94		15.94
Min.	9.34		5.53
Range	6.6		10.41

6.5 QA/QC for Secchi Disk Depth

The training received by the volunteer monitors, the simplicity of the technique, and the fact that Secchi depth is recorded to the nearest quarter meter gives inherent reliability to this measurement.

6.6 QA/QC for Fecal Coliforms:

Three different quality control procedures were followed in 2001 to evaluate the quality of our fecal coliform analysis. The most basic was the inclusion of uninoculated plates (controls) with the same m-Fecal coliform media, filters, and absorbent pads in each sample processing. These plates were incubated with the Smith Mountain Lake water sample filters, media, and absorbent pads at 44.5 ^{o}C. All uninoculated controls for all sample dates counted 20-24 hours later were found to have zero colony forming units (0 cfus).

A second quality control procedure followed was the inoculation of a known bacterial culture of *Escherichia coli* received from Carolina Biological Supply in a sterile tap water solution and subsequent filtration of this *Escherichia coli* and water solution on the last sample date following the identical procedures used with the Smith Mountain Lake water samples. The results indicated convincingly that the blue colonies we were counting on our m-Fecal coliform media plates were fecal coliforms.

The third quality control method was to have three different lab technicians count the colonies on each plate. When the counts disagreed, a consensus was reached about the number of colonies. Differences in colony counts were rare.

7. SAMPLING EFFICIENCY

The monitoring program depends on volunteers for sample collection and one measure of success for the program is the consistency with which these volunteers attend to their stations. Table 18 indicates the sampling efficiency data for 2001 and Table 19 presents the collection efficiencies from 1993 through 2001. The figures show that the volunteer monitors are very conscientious about sample collection. Advanced monitors collected from 88-98% of the samples possible in 2001 and 89% of the samples possible for basic monitors. This sampling efficiency is remarkably high for any monitoring program, voluntary or otherwise. In 1995 a decrease in efficiencies was attributed to the implementation of Phase 2 of the Water Quality Monitoring Program and the change in sample sites to better cover the lake and to provide cove sites to match the tributary sites. In 1996 and in 1997 the sampling efficiencies were back up to the levels that they had been previously. In 2001 the advanced monitors' efficiency was back up to its high levels, however the basic monitors were the same efficiency as last year. The volunteers' sampling efficiency is as good as that of professionals in agencies responsible for environmental sampling. This degree of commitment no doubt carries over to the care with which samples are collected and is evidence of the volunteers' dedication to the program.

Table 18. Sampling efficiency data for 2001.

Sample Type	Monitoring Stations	Possible Samples	Samples Collected	% Efficiency
CHA/NO3/PO	56	336	314	93.5%
Secchi	85	510	453	88.8%

Table 19. Comparison of sampling efficiencies for 1993-2001.

	Sampling Efficiency (%)								
	1993	1994	1995	1996	1997	1998	1999	2000	2001
Secchi Depth	80	93	75	92	95	96	89	89	89%
Total Phosphorus	90	99	80	96	96	96	95	83	94%
Chlorophyll-*a*	90	98	80	96	97	96	95	81	98%
Nitrate	NA	NA	NA	NA	99	96	95	86	88%

8. CONCLUSIONS

The Smith Mountain Lake Water Quality Program accomplished a thorough study of the trophic status of Smith Mountain Lake in 2001 and began the involved task of tracking the sources of the fecal bacteria found in Smith Mountain Lake. In the summer of 2001 the Virginia Department of Environmental Quality visited (inspected) the Smith Mountain Lake Water Quality Lab. The purpose of the inspection was to check the quality control and quality assurance procedures in order to certify our results as being valid and usable by the Commonwealth of Virginia. We were evaluated very highly by the Department of Environmental Quality and were given a few suggestions that would make our lab procedures even better and these suggestions were adopted immediately in our lab.

Twelve students worked on water quality projects at Ferrum College over the summer. Two student technicians took primary responsibility for the monitoring program and a third acted as the liaison with the Claytor Lake Program. Six students worked on the Marina Education Program, sponsored by the Virginia Department of Health. Two students worked on the Ferrum College Watershed project. The last student worked primarily for the Life Sciences Division but worked in several capacities in the Water Quality Lab.

One of the water quality parameters measured in Smith Mountain Lake indicates a decrease in water quality and an increase in nutrient enrichment especially in the increase in the algal population. Chlorophyll-*a* exhibited an average concentration of 27.9 mg/L in the summer of 2001. This was a 91% increase in 2001 following a 274% increase in 2000. (Values for chlorophyll-*a* were calculated incorrectly. See Appendix Table A7a for corrected values. Corrected average value; CHA = 4.1 ppb.) An increase in the biota in a lake would be expected in the natural aging of lakes and not necessarily caused by anthropogenic activities, however the 615% increase in chlorophyll-*a* in two years is cause for concern (CHA = 27.9 ppb). This is too great an increase to be natural variation. No other obvious explanation is known except for the simple explanation of increased nutrient enrichment. The lack of rainfall in 2001 may have had a concentrating effect on the nutrients and the algal population but the result is still a very high algal population. Many lake residents commented last summer that they have never seen the lake so green, and these data confirm that observation.

The total phosphorus and Secchi disk depth did not change significantly in 2001, however the nitrate concentration increased by 59%. The increase in the algal population does influence the nutrient concentration by using the nutrients for growth and could be the reason for the lack of increase in phosphorus. Water clarity was probably not lower because of the lack of runoff sediment usually caused by rain events and the algal populations only affected the water clarity this year. The interactions between the nitrate concentration and the biota at Smith Mountain Lake are still not fully understood. The Roanoke Channel of Smith Mountain Lake continues to have significantly higher concentrations of nitrate.

The twenty-two tributaries studied around Smith Mountain Lake continue to indicate higher total phosphorus and nitrate concentrations (TP = 67.1 ppb and NO3 = 616.4 ppb) than found in Smith Mountain Lake (TP = 33.3 ppb and NO3 = 216.7 ppb). This indicates that a significant amount of the nutrients entering Smith Mountain Lake are coming from the watershed and a less significant amount from the shoreline of the lake. The total phosphorus went down by 17% in the tributaries in 2001 and the nitrate from the tributaries increased by only 8%. Neither parameter increased the nutrient load to the lake, however both nutrients are significantly higher in the tributaries than in the lake.

In the yearly trends in the six zones through Smith Mountain Lake, total phosphorus increased in only three of the zones and water clarity improved in five of the zones. However, chlorophyll-*a* increased significantly in all six zones. This indicates that the algal population increased in all areas of the lake, and this was not simply a point source phenomenon. The chlorophyll-*a* as a measure of the trophic state of the lake is a very important indicator because the biota (as represented by the algae) are the integrators of all physical and chemical characteristics of the lake ecosystems.

The analysis of the Trophic State Index (TSI) indicates that 2001 was the first year that the combined lake index was over 50 (a divining line between mesotrophic and eutrophic). This increase in the index is due to the increase in chlorophyll-*a* in 2001 as was mentioned previously.

The fecal coliform measurements made on Smith Mountain Lake in 2001 indicate a decrease in bacterial populations, which is good news. In 2001, the fecal coliform populations were the lowest they have been for the marinas and the non-marinas since the program began 6 years ago.

The headwaters in 2001 had a higher than usual population of fecal coliforms. Since we have learned from previous studies of the bacterial populations that most of the fecal coliforms enter the lake by non-point source runoff after a rain event, the decrease in bacterial populations may be due to the lack of rain events in 2001. Palmer's Trailer Park (a non marina) once again was the highest total fecal coliform population, and Smith Mountain Lake Dock was the highest total fecal coliform population for the marinas. It should be noted that none of the stations at any sample time exceeded the Virginia Department of Health standard for potable water.

In 2001 the antibiotic resistance assay (ARA) was done on 47 different sites in order to track the source of the fecal bacteria. The twenty-two tributaries exhibited the largest number of fecal streptococci bacteria and, therefore, the most usable results in the source tracking. The results are preliminary and will be repeated the summer of 2002, but do indicate some value in this method of attempting to identify the source so the source can be eliminated.

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Thanks go out to all of our volunteer monitors who once again made this program possible with their dedication and support. The Smith Mountain Lake Association again provided the much needed political and financial support. Patricia Moyer, Kristen Cardinale, and Greta Roberts were the student technicians this past summer and they did a fine job. Their conscientiousness and hard work kept the monitoring program running smoothly and everyone enjoyed their positive, friendly attitude. Assisting the student technicians when possible were Scott Queen, Lori Lowther, Sam Ragsdale, Eric Hoppis, Richard Middleton, Matthew Carter, Philip Davis, and Jack Wallace who had other duties assigned but assisted the Smith Mountain Lake Project when their other duties allowed. Matt Dittler assisted frequently in many capacities. We would also like to acknowledge the support and time of Stan Smith, the liaison with the SMLA. The enthusiasm and leadership that he brings to the program are wonderful. We would like to offer John Singer and John Short special thanks for their boats and time used for fecal coliform sampling. We would also like to thank Shoreline Marina for their assistance and allowing us to dock at their marina while taking samples. Finally we wish to thank the Tri County Lake Advisory Commission and Hilde Hussa (Executive Director) for providing political support, and Ferrum College for making space and equipment available at no cost to the project as a community service.

REFERENCES

American Public Health Association. 1995 *Standard Methods for Examination of Water and Wastewater*, 16th edition. Washington

Carlson, R.E. 1977. "A Trophic State Index for Lakes", *Limnol. Oceanog.* 22(2):361-369.

Downie, N.M. and R.W. Heath. 1974. *Basic Statistical Methods* p.314, Harper and Row, Publishers, New York, NY.

Harwood, Valerie J., John Whitlock, and Victoria Withington. 2000. " Classification of Antibiotic Resistance Patterns of Indicator Bacteria by Discriminate Analysis: Use in Predicting the Source of Fecal Contamination in Subtropical Waters. *Applied and Environmental Microbiology* vol.66: 3698-3704.

Johnson, David M. and Carolyn L. Thomas. 1993, 1995, 1997, and 1999 *Smith Mountain Lake Water Quality Volunteer Monitoring Program: 1993, 1995, 1997, & 1999 Annual Reports* published by Ferrum College.

Johnson, David M. and Carolyn L. Thomas. 1990. *Smith Mountain Lake Water Quality Monitoring and Public Education Program.* Final Report to Virginia Environmental Endowment, Grant # 86-27 and 88-20. 123pp.

Johnson, David M. and John W. Leffler. 1987. *An Assessment of the Effects of Shoreline Landuse on the Water Quality of Smith Mountain Lake, Virginia.* Final Report to Virginia Environmental Endowment, Grant 85-03. 39pp.

Ney, John. 1996. "Oligotrophication and Its Discontents: Effects of Reduced Nutrient Loading on Reservoir Fisheries", *American Fisheries Society Symposium* 16:285-295.

Reckhow, K.H. and, S.C. Chapra. 1983. *Engineering Approaches to Lake Management, Vol. 1: Data Analysis and Empirical Modeling*, pp 189-193, Ann Arbor Science Book Publishers, Ann Arbor, MI.

Thomas, Carolyn L. and David M. Johnson. 1992a,b, 1994, 1996, 1998 & 2000 *Smith Mountain Lake Water Quality Volunteer Monitoring Program: 1990-91, 1992, 1994, 1996, 1998 and 2000 Report.* Published by Ferrum College.

Thomas, Carolyn L. and David M. Johnson. 1988, 1992. *Training Manual for Smith Mountain Lake Lay Monitoring Program.* Published by Ferrum College, Ferrum, VA.

U.S. Environmental Protection Agency. 1974. "The Relationships of Phosphorous and Nitrogen to the Trophic State of Northeast and North-Central Lakes and Reservoirs", National Eutrophication Paper No. 23, U.S. EPA, Corvallis, Oregon.

APPENDIX

Table A1. 2001 Smith Mt. Lake monitoring stations with monitor names and station locations.

Station	Monitor	Longitude	Latitude	Site Number
B8	*no monitor 2001*			
B10	*no monitor 2001*			
B12	Chilton			
B14	Jamison	79.676	37.035	85
B16	Jamison	79.704	37.040	50
B18	*no monitor 2001*	79.720	37.035	52
B20	*no monitor 2001*	79.728	37.033	53
B22	Franz	79.743	37.063	55
C4	Hill	79.572	37.056	8
C5	Hill	79.565	37.066	7
C6	Hill	79.568	37.082	6
CB11	Chilton/Hatfield			
CB16	Jamison	79.703	37.045	49
CB20	Franz	79.737	37.036	54
CM1	Rice	79.539	37.055	2
CM1.2	Rice	79.535	37.063	1
CM5	E. Anderson	79.587	37.047	9
CR8	E. Anderson	79.593	37.065	33
CR9	Hunt	79.606	37.077	21
CR9.2	Hunt	79.617	37.070	20
CR13	Kastner	79.642	37.099	28
CR14.2	P. Dooley	79.682	37.119	97
CR16	Ollweiler	79.663	37.145	57
CR17	Ollweiler	79.667	37.150	58
CR19	Morris/Talbott	79.692	37.159	64
CR21	Bray	79.706	37.150	68
CR21.2	Bray	79.708	37.148	69
CR22	Bogsrud	79.712	37.167	71
CR24	Gascoyne/Mauney			
CR25	Gascoyne/Mauney			
CR26	B. Dooley/Holdgreve			
G12	Chilton/Hatfield			
G13		79.674	37.049	84
G 14	Dick	79.673	37.055	47
G15				
G16	Dick	79.688	37.062	48
G18	Dick	79.682	37.072	59
M0	Rice	79.538	37.043	3
M1	Overman	79.547	37.047	4
M3	Overman	79.564	37.041	5
M5	Overman	79.588	37.042	10
R7	E. Anderson	79.595	37.052	12
R9	Hunt	79.617	37.073	19
R11	E. Anderson	79.612	37.089	22
R13	Kastner	79.642	37.103	29
R14	P. Dooley	79.647	37.113	31
R15	Ollweiler	79.657	37.131	35
R17	Morris/Talbott	79.676	37.152	60
R19	Morris/Talbott	79.697	37.161	66
R21	Bray	79.707	37.155	70

Table A1. 2001 Smith Mt. Lake monitoring stations with monitor names and station locations (cont.)

R23	Bogsrud	79.717	37.180	74
R25	Gascoyne/Mauney			
R27	B. Dooley/Holdgreve			
R29	B. Dooley/Holdgreve	79.797	37.218	86
R30				
R31				
SCB8	Randa	79.599	37.026	38
SCB10	Randa	79.639	37.023	40
SCB11	Randa	79.632	37.017	24
SCB11.5	Randa	79.644	37.062	13
SB12	*no monitor 2001*	79.664	37.040	42
SCB14	*no monitor 2001*	79.683	37.031	51
SCB16	*no monitor 2001*	79.693	37.034	46
SCM5	Smith/Lorent	79.588	37.048	32
SCR7	Smith/Lorent	79.585	37.061	11
SCR8	Smith/Lorent	79.588	37.068	23
SCR10.1	Gore	79.629	37.073	18
SCR10.2	Gore	79.628	37.076	17
SCR10.3	Gore	79.635	37.080	16
SCR11.1	Collins	79.604	37.103	25
SCR11.2	Collins	79.616	37.105	26
SCR11.3	Collins	79.631	37.106	27
SCR14	Gerhart	79.642	37.112	30
SCR14.1	Hach	79.665	37.109	34
SCR14.2	Hach	79.679	37.105	91
SCR14.3	Hach	79.659	37.113	92
SCR15	Gerhart	79.646	37.120	93
SCR 15.1	Holasek			
SCR 15.2	Holasek			
SCR17	Gerhart	79.670	37.157	95
SCR17.1	Holasek	79.677	37.158	61
SCR18	A. Anderson			
SCR19.2	A. Anderson			
SCR20	A. Anderson			
SCR22.2		79.707	37.171	73
SCR 22.3	*No monitor in 2001*			
SCR 23	*No monitor in 2001*			
SCR 23.2	*No monitor in 2001*			
SCR23.3	*No monitor in 2001*	79.721	37.183	77
SCR24	*No monitor in 2001*	79.724	37.197	78
T0(Gills)	Snoddy			
T21(Roanoke)	Faber			

Table A2. **2001 Smith Mountain Lake tributary stations and other downstream stations.**

Tributary Station Number	Stream Name
T0	Upper Gills Creek
T1	Maggodee Creek
T2	Lower Gills Creek
T3	Blackwater River
T4	Poplar Camp Creek
T5	Standiford Creek
T6	Bull Run
T7	Cool Branch
T8	Branch at Lumpkin’s Marina
T9	Below Dam - Former Station 105
T10	Pigg River - Former Station 104
T11	Leesville Lake - Former Station 103
T12	Creek at Summit Drive
T13	Creek at Snug Harbor
T14	Stoney Creek
T15	Jumping Run
T16	Beaverdam Creek
T17	Roanoke Channel at Bay Roc Marina
T18	Lynville Creek
T19	Grimes Creek
T20	Indian Creek
T21	Roanoke Channel below Back Creek

Table A3. 2001 Total Phosphorus data from Smith Mountain Lake sample stations.

Date	37048	37062	37075	37090	37104	37118
Sample	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)
B8		19.166667	21.416667	25.208333	19.285714	22.833333
B10		17.5	9.0416667	17.708333	17.380952	12.416667
B12	22.48	27.5	18.208333	24.791667	26.904762	12.833333
B14	32.48	27.083333	24.458333	12.708333	21.190476	13.25
B16	30.48	35.416667	24.458333	63.541667	22.619048	17.833333
B22	76.88	63.333333	69.458333	74.791667	85.47619	76.166667
C4	22.08	26.25	13.625	25.208333	17.857143	29.916667
C5	17.28	32.5	14.875	5.625	12.619048	11.583333
C6	18.88	12.916667	12.375	22.708333	9.7619048	41.583333
CB11	25.28	30	17.791667	14.791667	43.095238	12.833333
CB16	26.48	22.916667	21.541667	28.541667	33.571429	14.083333
CB20	43.28	32.916667	49.875	25.208333	64.52381	27.833333
CM1	22.48	17.083333	15.708333	27.291667	34.52381	13.666667
CM1.2	27.28	27.916667	15.708333	14.791667	29.285714	13.666667
CM5	32.48	18.333333	24.875	14.375	35.47619	14.5
CR8	20.48	66.25	9.875	28.541667	47.857143	13.666667
CR9	18.88	23.333333	12.791667	42.291667	37.380952	18.666667
CR9.2	20.48	30.416667	12.791667	28.541667	43.571429	18.666667
CR13	44.583333	25	24.041667	40.208333	42.619048	22.416667
CR14.2	23.68	21.25	11.958333	0	0	14.916667
CR16	44.583333	30.833333	26.958333	38.541667	64.52381	27.833333
CR17	60.833333	60.416667	46.541667	69.791667	66.904762	44.916667
CR19	34.88	23.333333	25.708333	41.458333	65	30.333333
CR21	56.88	57.083333	45.291667	70.208333	108.33333	46.166667
CR21.2	71.28	66.25	77.791667	76.458333	117.38095	61.583333
CR22	50.88	65.416667	42.791667	66.458333	71.190476	42.833333
CR24	40.88	50	32.375	48.541667	75.952381	47
CR25	45.28	43.75	31.541667	26.041667	61.666667	42.833333
CR26	48.88		32.375	43.958333	47.380952	37.416667
G12	45.68	42.083333	19.875	33.125	23.571429	24.083333
G13		30.416667	9.4583333	21.875	18.809524	17.833333
G14		31.666667	21.125	38.958333	34.047619	15.333333
G15		31.25	9.875	30.208333	22.619048	12
G16		27.916667	20.708333	20.208333	40.238095	20.75
G18		27.5	22.791667	39.375	37.857143	34.5
M0	30.48	18.333333	10.291667	28.125	23.095238	8.6666667
M1	26.666667	20.416667	8.2083333	21.458333	19.285714	13.666667
M3	18.75	21.25	17.375	31.875	15	13.666667
M5	18.75	15.416667	12.791667	22.291667	22.619048	14.916667
R7	39.28	12.083333	8.625	32.708333	53.571429	12.833333
R9	34.48	25.833333	18.625	48.541667	21.190476	13.25
R11	29.68	31.666667	12.791667	35.208333	5	14.916667
R13	28.333333	32.5	14.458333	37.708333	23.095238	14.5
R14	29.68	12.916667	11.125	0	0	15.75
R15	35.833333	36.666667	18.208333	22.291667	58.333333	21.583333

Table A3. 2001 Total Phosphorus data from Smith Mountain Lake sample stations (cont.)

R17	44.48	37.083333	33.625	55.208333	48.809524	30.75
R19	40.08	23.75	26.125	50.208333	34.047619	39.083333
R21	61.68	44.166667	31.541667	67.291667	45	68.666667
R23	54.08	44.583333	30.291667	40.625	50.714286	42.416667
R25	46.48	38.333333	29.458333	46.875	61.190476	32
R27	50.08	39.166667	34.041667	36.041667	79.285714	42.416667
R29	56.88	62.916667	33.625	58.958333	79.761905	55.75
R30		65	36.958333	67.291667	68.809524	63.25
R31		34.166667	47.375	69.375	86.428571	78.666667

Table A4. 2001 Total Phosphorus data for Smith Mountain Lake tributaries.

Trib/date	37048	37062	37075	37090	37104	37118
T00	82.48	99.583333	98.625	126.04167	97.857143	86.583333
T1	84.48	-16.25	79.458333	78.958333	117.85714	78.25
T2	63.28	43.75	79.458333	41.458333	118.80952	87
T3	96.88	98.333333	75.708333	78.958333	139.28571	89.5
T4	50.88	40.416667	42.375	44.375	68.333333	43.666667
T5	44.08	55.416667	60.291667	83.125	70.238095	64.916667
T6	81.68	113.75	145.29167	105.625	93.095238	130.33333
T7	19.28	20	14.041667	26.041667	48.809524	16.583333
T8	44.48	71.666667				
T9	28.48	16.25	19.875	43.958333	35.952381	6.1666667
T10	48.88	68.333333	53.625	64.791667	75.952381	204.5
T11	30.48	35.833333	22.791667	43.541667	39.285714	27.416667
T12	32.88	27.916667	40.291667	26.875	61.190476	28.25
T13	35.28	32.083333	31.958333	45.625	62.142857	29.916667
T14	109.28	127.5				117
T15	106.08	122.08333	102.79167	87.708333	112.14286	81.166667
T16	67.28	72.916667	72.375	65.208333	104.04762	82.833333
T17	50.88	65.833333	71.958333	79.791667	78.333333	54.5
T18	42.08	55.833333	47.791667	42.708333	67.857143	54.916667
T19	170.08	80	73.625	186.45833	203.09524	75.75
T20	64.88	63.75	58.625	80.208333	133.57143	58.25
T21	54.48	56.666667	66.958333	90.208333	106.90476	99.916667

Table A5. 2001 Nitrate data for Smith Mountain Lake.

Date	37048	37062	37075	37090	37104	37118
Sample	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)
B8		67.375	135.75	95	89.8	98.6
B10		32.375	135.75	61.25	53.8	71.6
B12	80.333333	37.375	58.25	43.75	20.8	27.6
B14	106.16667	67.375	135.75	31.25	-3.2	23.6
B16	152.83333	146.125	167	73.75	16.8	13.6
B22	362.83333	304.875	303.25	65	29.8	25.6
C4	131.16667	188.625	222	142.5	83.8	155.6
C5	70.333333	156.125	198.25	155	47.8	58.6
C6	63.666667	86.125	148.25	115	45.8	86.6
CB11	44.5	36.125	105.75	56.25	42.8	48.6
CB16	101.16667	176.125	188.25	33.75	0.8	9.6
CB20	245.33333	246.125	325.75	58.75	15.8	5.6
CM1	129.5	227.375	234.5	187.5	158.8	90.6
CM1.2	161.16667	182.375	252	207.5	143.8	78.6
CM5	91.166667	142.375	178.25	135	59.8	51.6
CR8	92.833333	83.625	153.25	98.75	68.8	47.6
CR9	87.833333	74.875	139.5	110	39.8	0.6
CR9.2	83.666667	152.375	152	117.5	34.8	
CR13		83.625	245.75	148.75	77.8	18.6
CR14.2	87	169.875	203.25			1.6
CR16	-59.666667	333.625	304.5	205	37.8	18.6
CR17		411.125	343.25	176.25	54.8	48.6
CR19	252.83333	422.375	323.25	96.25	46.8	27.6
CR21	203.66667	297.375	234.5	93.75	39.8	
CR21.2	232	257.375	173.25	32.5	36.8	26.6
CR22	317	372.375	515.75	133.75	26.8	30.6
CR24	414.5	571.125	787	431.25	80.8	
CR25	333.66667	608.625	944.5	292.5	103.8	29.6
CR26	419.5		843.25	642.5	72.8	33.6
G12	136.16667	36.125	98.25	73.75	55.8	
G13		101.125	98.25	35	28.8	
G14		42.375	94.5	42.5	20.8	24.6
G15		77.375	94.5	16.25	6.8	44.6
G16		68.625	85.75	16.25	21.8	
G18		29.875	88.25	6.25	16.8	8.6
M0	163.66667	299.875	290.75	168.75	168.8	125.6
M1		194.875	224.5	117.5	109.8	118.6
M3		322.375	169.5	180	117.8	120.6
M5		121.125	214.5	126.25	47.8	70.6
R7	134.5	146.125	197	128.75	65.8	104.6
R9	124.5	154.875	168.25	86.25	24.8	43.6
R11	125.33333	213.625	238.25	122.5	50.8	
R13		214.875	244.5	106.25	41.8	33.6
R14	201.16667	329.875	202			18.6

Table A5. 2001 Nitrate data for Smith Mountain Lake (cont.)

R15		264.875	303.25	188.75	33.8	49.6
R17	277.83333	704.875	465.75	180	78.8	
R19	272	458.625	547	210	99.8	22.6
R21	339.5	318.625	535.75	181.25	-0.2	24.6
R23	427	424.875	697	481.25	16.8	
R25	517	784.875	697	676.25	203.8	3.6
R27	615.33333	1607.375	984.5	767.5	143.8	163.6
R29	648.66667	1506.125	1052	801.25	433.8	228.6
R30		1376.125	1230.75	1021.25	669.8	413.6
R31		1379.875	1254.5	1730	1049.8	674.6

Table A6. 2001 Nitrate samples for Smith Mountain Lake tributaries.

Tributary	May28-Jun3	Jun 11-17	Jun26-Jul 1	July 9-15	July 23-29	Aug 6-12	station avg	station stdev
T00	749.3	777.2	676.7	767.2	266.7	545.0	630.3	198.1
T1	1023.0	634.2	656.7	582.8	827.8	377.7	683.7	220.4
T2	898.0	660.2	743.3	602.8	716.7	177.7	633.1	244.3
T3	1048.0	589.2	756.7	385.0	1027.8	174.1	663.5	349.8
T4	589.3	396.2	482.2	689.4	702.2	377.7	539.5	142.4
T5	660.5	744.2	1282.2	871.7	678.9	682.3	820.0	239.3
T6	816.8	647.2	991.1	820.6	497.8	1076.8	808.4	213.6
T7	5.5	2.2	160.0	247.2	144.4	156.8	119.4	96.7
T8	311.8	164.2	505.6				327.2	171.2
T9	338.0	118.2	288.9	342.8	187.8	201.4	246.2	91.0
T10	798.0	449.2	458.9	357.2	437.8	225.0	454.3	190.0
T11	414.3	378.2	253.3	260.6	332.2	175.9	302.4	88.7
T12	166.8	140.2	161.1	232.8	126.7	104.1	155.3	44.4
T13	184.3	91.2	336.7	371.7	247.8	271.4	250.5	102.3
T14	603.0	499.2	1027.8	711.7	505.6	296.8	607.3	247.4
T15	703.0	844.2	900.0	619.4	514.4	326.8	651.3	213.0
T16	874.3	597.2	501.1	522.8	552.2	219.5	544.5	209.5
T17	1766.8	875.2	943.3	1939.4	1344.4	900.5	1294.9	468.2
T18	386.8	116.2	252.2	266.1	303.3	149.5	245.7	99.7
T19	408.0	208.2	243.3	330.6		265.9	291.2	79.1
T20	331.8	91.2	365.6	271.7	284.4	200.5	257.5	99.0
T21	1864.3	1732.2	1592.2	3085.0	1288.9	1499.5	1843.7	639.2
Week avg	679.1	488.9	617.2	679.9	549.4	400.2	GR mean	569.9
Week Stdev	465.1	391.9	382.3	667.2	355.0	358.6	GR stdev	452.7

Table A7. 2001 Chlorophyll-*a* data for Smith Mountain Lake.
(Corrected values in Table A7a)

Station	May28-Jun3	Jun 11-17	Jun26-Jul 1	July 9-15	July 23-29	Aug 6-12	station avg	station stdev
B12	2.55	4.95	4.8	15	6	18	8.550	6.331
B14	3.75	2.25	6.75	10.05	7.2		6.000	3.063
B16	2.1	2.85	11.25	10.8	10.8		7.560	4.653
B18			30	9.45		4.2	14.550	13.635
B20			9.9	19.5		21	16.800	6.022
B22	12.6	12.3	13.35	14.7	48	12.6	18.925	14.270
C4	1.2	0.9	4.95	6.6	9.75	6.75	5.025	3.448
C5	1.5	2.4	10.2	5.1	14.85	8.4	7.075	5.076
C6	1.8	1.2	14.55	3.45	10.35	10.35	6.950	5.527
CB11	1.95	3.15	13.65	10.95	4.95	21	9.275	7.339
CB16	4.8	1.65	19.5	7.8	21		10.950	8.780
CB20	6.3	5.1	4.05	11.55	10.05	9.6	7.775	3.032
CM1	0.9	0.45	1.05	4.05	2.7	3.9	2.175	1.590
CM1.2	1.05	1.5	6.9	2.85	3.3	2.7	3.050	2.071
CM5	1.65	2.4	0.9		3.45	9.6	3.600	3.484
CR5			13.5				13.500	
CR8	2.25	1.8			8.85	5.4	4.575	3.269
CR9	0.6	0.6	0.75	0.6	1.35	1.35	0.875	0.372
CR9.2	0.6	0.15	0.6	0.45	1.95	2.4	1.025	0.917
CR13			5.55		21	14.1	13.550	7.740
R14			2.1				2.100	
CR14.2	1.8	1.05	5.7	7.2	11.25	8.4	5.900	3.923
CR16	14.7	1.2	9.9	8.4	58.5	27	19.950	20.733
CR17	9.15	4.65	9.6	11.55	52.5	31.5	19.825	18.554
CR19	0.6	5.85	1.2	8.25	8.4	21	7.550	7.398
CR21	1.35	0.75	2.1	4.5	6.6	0.9	2.700	2.353
CR21.2	6.45	6.9	0.9	9.9	3.9	0.9	4.825	3.588
CR22	8.85	6.3	24		66	73.5	35.730	31.895
CR24	4.35	5.85	13.5	40.5	73.5	150	47.950	56.538
CR25	3.15	5.25	9.3	37.5	0	97.5	25.450	37.816
CR26			114	15	63	150	85.500	59.017
G12	1.8	1.8	7.05	7.95	81	7.65	17.875	31.054
G13								
G14	1.2	2.4	3.9	73.65	9.45		18.120	31.202
G15								
G16	1.05	3.3	3	14.4	8.25		6.000	5.395
G18	2.4	5.1	31.5	36	16.5		18.300	15.148
M0	1.05	0.9	2.25	5.25	3.6	2.85	2.650	1.642
M1			3.9	8.7	5.85	4.35	5.700	2.167
M3			4.5	7.2	7.5	4.65	5.963	1.608
M5			2.1	8.4	4.65	6.75	5.475	2.724
R7	2.25	1.8	4.95		9.3	10.35	5.730	3.945
R9	0.15	0.6	1.2	0	4.8	3.6	1.725	1.998
R11	1.95	1.95	7.95		18	9.15	7.800	6.602
R13			6.3	4.35	27	19.5	14.288	10.822
R14	1.35	1.05		12	30	19.5	12.780	12.354
R15	4.65	3.45	5.4	9	39	19.5	13.500	13.794
R17	0.45	3.15	1.05	7.95	40.5	45	16.350	20.668

Table A7. 2001 Chlorophyll-*a* data for Smith Mountain Lake (cont.)

R19	9.6	3.6	1.05	10.5	10.2	9.9	7.475	4.081
R21	1.05	1.05	12.15	13.5	0	25.5	8.875	10.097
R23	6	3.45	70.5		88.5	129	59.490	54.305
R25	2.4	5.7	15	51	67.5	73.5	35.850	31.973
R26	6						6.000	
R27	4.95	4.05	14.85	15	109.5	150	49.725	63.468
R29	9.9	5.25	16.5	49.5	79.5	30	31.775	28.321
mean/date	3.586	3.096	11.592	14.187	24.788	29.155	Grand avg	14.617
std/date	3.476	2.380	18.638	15.197	28.384	42.180	Grand stdev	23.706

Table A7a. 2001 Chlorophyll-*a* data for Smith Mountain Lake - CORRECTED

Date	6/6/2001	6/20/2001	7/3/2001	7/19/2001	8/8/2001	8/16/2001		
Site	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	**Sta Avg**	**Stdev**
B8		3.5	1.0	0.0	1.3	1.4	**1.4**	**1.1**
B10		1.3	0.7	0.0	1.4	1.2	**0.9**	**0.5**
B12	2.1	1.2	0.8	1.7	3.5	3.7	**2.2**	**1.1**
B14	3.5	2.4	1.9	2.8	1.6	1.1	**2.2**	**0.8**
B16	3.0	1.5	4.8	2.9	3.2	0.0	**2.6**	**1.5**
B22	2.0	5.3	6.3	8.3	13.6	9.8	**7.6**	**3.6**
C4	2.6	1.6	0.9	0.9	2.2	0.8	**1.5**	**0.7**
C5	1.1	1.0	0.6	2.0	1.8	1.3	**1.3**	**0.5**
C6	1.7	2.0	1.3	1.5	3.0	0.6	**1.7**	**0.7**
CB11	1.9	1.1	0.8	1.8	4.6	2.2	**2.1**	**1.2**
CB16	1.5	2.6	1.4	3.3	4.0	1.1	**2.3**	**1.1**
CB20	1.5	3.0	4.1	2.7	8.2	3.5	**3.8**	**2.1**
CM1	1.3	1.2	1.1	0.9	1.4	1.3	**1.2**	**0.2**
CM1.2	1.7	0.5	0.8	1.7	1.2	0.5	**1.1**	**0.5**
CM5	2.6	1.3	1.2	2.0	1.7	1.5	**1.7**	**0.5**
CR8	3.1	2.3	1.9	3.9	0.8	2.0	**2.3**	**1.0**
CR9	3.1	1.1	0.3	0.1	0.2	0.7	**0.9**	**1.0**
CR9.2	1.5	0.4	0.4	0.5	0.2	0.3	**0.6**	**0.4**
CR13	1.8	4.7	1.3	2.4	3.5	2.2	**2.6**	**1.1**
CR14.2	3.0	0.9	1.2	3.0	3.9	0.8	**2.1**	**1.2**
CR16	6.3	2.3	3.8	2.7	2.5	1.4	**3.1**	**1.6**
CR17	9.4	2.8	2.0	2.0	2.4	2.2	**3.4**	**2.7**
CR19	10.3	4.1	6.3	7.5	9.6	5.4	**7.2**	**2.2**
CR21	5.5	0.1	0.8	0.3	5.8	2.4	**2.5**	**2.4**
CR21.2	1.7	0.9	0.2	0.6	0.5	0.9	**0.8**	**0.5**
CR22	9.3	8.6	9.5	11.9	8.0	9.0	**9.4**	**1.2**
CR24	1.4	7.0	16.2	20.1	12.8	17.6	**12.5**	**6.5**
CR25	1.7	8.8	11.0	39.1	14.0	6.3	**13.5**	**12.1**
CR26	4.0		10.3	21.9	16.2	10.1	**12.5**	**6.1**
G12	1.4	0.9	1.5	1.8	2.2	0.0	**1.3**	**0.7**
G13		1.3	1.6	1.5	2.0	2.2	**1.7**	**0.3**
G14		1.2	1.4	1.3	1.8	1.5	**1.4**	**0.2**
G15		2.1	1.3	2.2	2.8	0.8	**1.8**	**0.7**
G16		1.3	1.6	3.2	3.5	1.2	**2.2**	**1.0**
G18		2.9	4.1	3.3	2.0	2.9	**3.0**	**0.7**
M0	1.3	1.2	1.1	1.3	0.7	1.2	**1.1**	**0.2**
M1	2.7	0.4	0.5	0.9	0.8	0.8	**1.0**	**0.8**
M3	3.4	0.7	1.0	1.0	1.3	1.1	**1.4**	**0.9**
M5	1.7	1.1	1.8	1.3	1.5	3.5	**1.8**	**0.8**
R7	2.8	1.4	1.6	3.6	1.8	1.8	**2.2**	**0.8**
R9	3.5	1.4	0.2	0.1	0.4	0.2	**1.0**	**1.2**
R11	7.5	1.7	4.8	1.8	1.9	3.4	**3.5**	**2.1**
R13	1.6	3.8	2.0	3.1	2.0	2.1	**2.4**	**0.8**
R14	2.1	1.1	1.6	1.4	3.3	2.7	**2.0**	**0.8**
R15	9.0	2.1	13.8	1.8	3.8	2.9	**5.6**	**4.4**
R17	3.1	2.3	26.6	5.5	8.1	0.0	**7.6**	**8.9**
R19	3.0	3.2	4.5	5.1	6.9	10.3	**5.5**	**2.5**
R21	0.5	0.5	0.8	0.4	4.1	3.2	**1.6**	**1.5**
R23	13.5	5.2	15.1	11.0	12.0	7.0	**10.6**	**3.5**
R25	1.4	6.9	7.9	9.9	12.2	4.7	**7.1**	**3.5**
R27	12.3	6.5	14.2	14.3	12.5	11.7	**11.9**	**2.6**
R29	12.4	5.5	11.8	11.1	16.5	15.9	**12.2**	**3.6**
R30		4.6	17.8	16.1	17.9	13.9	**14.1**	**4.9**
R31		9.5	23.0	12.8	13.7	12.1	**14.2**	**4.6**
mean	**3.8**	**2.7**	**4.7**	**4.9**	**5.0**	**3.7**	**Gr Avg**	**4.1**
StDev	**3.4**	**2.3**	**6.1**	**7.0**	**4.9**	**4.3**	**Gr Stdev**	**5.0**

Table A8. 2001 Secchi data for Smith Mountain Lake.

Station	May28-Jun3	Jun 11-17	Jun26-Jul 1	July 9-15	July 23-29	Aug 6-12	station avg	station stdev
B12	3.00	3.50		3.00	3.00		3.13	0.25
B12.2				3.50			3.50	
B14	2.50	3.00	3.00	2.00	2.50		2.60	0.42
B16	2.00	2.00	2.00	1.50	2.00		1.90	0.22
B18			2.00	2.00			2.00	0.00
B20			1.75	2.00			1.88	0.18
B22	0.75	1.00	0.75	1.00	1.00	1.00	0.92	0.13
C4	4.25	4.00	4.25	3.00	3.75	4.25	3.92	0.49
C5	3.50	4.00	4.25	3.00	3.00	3.50	3.54	0.51
C6	2.75	2.75	3.50	3.00	2.50	3.25	2.96	0.37
CB11	3.00	3.50		3.00	3.00		3.13	0.25
CB16	2.00	2.50	2.50	2.00	2.00		2.20	0.27
CB20	2.00	1.50	1.75	1.75	1.50	1.25	1.63	0.26
CM1	3.25	3.50	3.50	3.50	3.50	3.50	3.46	0.10
CM1.2	2.50	3.25	3.50	3.50	4.00	3.50	3.38	0.49
CM5	3.75	3.75	3.25	3.00	3.00	3.00	3.29	0.37
CR8	3.00	3.50	3.50	2.75	2.75	2.75	3.04	0.37
CR9	2.50	3.00	3.00	2.50	2.50	2.50	2.67	0.26
CR9.2		3.00	4.00		2.25	2.00	2.81	0.90
CR13		2.00	2.00	1.75	1.75	2.00	1.90	0.14
CR14.2	1.25	1.50	1.00	1.50	1.50	1.50	1.38	0.21
CR16	1.25	2.00	2.00	1.50	1.25	1.00	1.50	0.42
CR17	1.75	1.75	2.00	1.50	0.50	1.25	1.46	0.53
CR19	1.5	2.50	1.50	1.50	1.50	1.00	1.58	0.49
CR21	1.50	1.75	1.75	1.5	1.25	1.50	1.54	0.19
CR21.2	1.50	1.50	1.75	1.75	1.25	1.50	1.54	0.19
CR22	1.50	1.75	1.50	1.25	1.25	1.00	1.38	0.26
CR24	1.75	1.50	1.75		1.00	1.00	1.40	0.38
CR25	2.00	1.50	1.50		1.00	0.75	1.35	0.49
CR26	1.50	1.50	1.50	1.50	1.00	0.75	1.29	0.33
G12	2.50	3.00		3.00	3.50		3.00	0.41
G14	2.50	2.00	2.75	2.25	2.25		2.35	0.29
G16	2.00	2.25	2.50	2.00	2.00		2.15	0.22
G18	2.00	2.75	2.00	1.50	1.50		1.95	0.51
M0	2.25	4.00	4.00	3.75	3.25	4.00	3.54	0.70
M1			3.00	3.00	3.50	3.75	3.31	0.38
M3			3.50	3.00	3.25	4.00	3.44	0.43
M5			3.00	3.00	3.25	4.00	3.31	0.47
R7	2.75	3.75	3.75	3.75	2.50	3.00	3.25	0.57
R9	2.60	2.50	4.00	2.50	2.00	2.00	2.60	0.73
R 9.2	2.50			2.50			2.50	0.00
R11	2.00	2.50	2.75	2.50	1.75	1.75	2.21	0.43
R13		2.00	2.00	1.75	1.50	1.50	1.75	0.25
R14	1.25	1.75	1.75		1.50	1.75	1.60	0.22
R15	1.50	1.50	2.75	1.75	1.25	1.50	1.71	0.53
R17	2.00	3.00	1.50	1.75	1.00	1.50	1.79	0.68
R19	2.00	3.00	2.00	1.50	1.00	1.50	1.83	0.68

Table A8. 2001 Secchi data for Smith Mountain Lake (cont'd).

R23	1.50	1.75	1.50	1.25	1.25	1.00	1.38	0.26
R25	2.00	1.50	1.50		1.00	1.00	1.40	0.42
R27	2.00	1.25	1.50	1.50	1.50	0.75	1.42	0.41
R29	1.50	1.50	1.50	1.50	1.25	0.75	1.33	0.30
R34(T21)	1.50	1.25					1.38	0.18
SCB 8	3.00	3.00	3.50	2.75	3.00	3.50	3.13	0.31
SCB10	2.25	3.00	3.00	2.50	2.25	2.50	2.58	0.34
SCB11	2.25	2.50	3.25	2.75	2.00	2.75	2.58	0.44
SCB11.5	2.50	2.50	1.75	2.25	2.50	2.25	2.29	0.29
SCR10.1	2.25	2.25		2.25	2.00	1.50	2.05	0.33
SCR10.2	2.00	2.25		2.25	1.75	1.50	1.95	0.33
SCR10.3	2.00	1.75		2.25	1.50	1.75	1.85	0.29
SCR11.1	1.25	4.00	3.00	2.25	2.50	1.75	2.46	0.97
SCR11.2	1.75	3.50	3.50	2.75	2.50	1.50	2.58	0.85
SCR11.3	1.25	3.00	3.75	2.50	2.25	2.00	2.46	0.86
SCR14	1.75	2.50	3.25	2.25		1.50	2.25	0.68
SCR14.1	1.25	2.00	2.25	2.25	1.50	1.75	1.83	0.41
SCR14.2	1.00	1.50	1.50	1.75	1.25	1.50	1.42	0.26
SCR14.3	1.25	2.25	2.25	2.50	1.75	1.75	1.96	0.46
SCR15	1.75	2.50	3.00	2.00		1.50	2.15	0.60
SCR 15.1			2.75	1.75	1.75	1.75	2.00	0.50
SCR 15.2			2.25	1.50	1.75	1.50	1.75	0.35
SCR17	1.75	1.75	2.25	1.50		1.25	1.70	0.37
SCR17.1			2.00	1.50	1.50	1.25	1.56	0.31
SCR18	1.50	2.00	1.25	1.50	1.00	1.25	1.42	0.34
SCR19	1.25	1.50	1.00	1.50	1.00	1.25	1.25	0.22
SCR20	1.50	1.50	1.25	1.25	1.00	1.25	1.29	0.19
T 21					0.25		0.25	
Week avg	2.03	2.39	2.43	2.19	1.96	1.92	**Grand avg**	**2.16**
week stdev	0.69	0.82	0.91	0.69	0.84	0.96	**Grand Stdev**	**0.84**

Table A9. 2001 Fecal coliform data (cfu) from Smith Mountain Lake.

	Collected 5-29-01	Collected 6-12-01	Collected 6-26-01	Collected 7-5-01	Collected 7-24-01	Collected 8-7-01
	Read 5-30-01	Read 6-13-01	Read 6-27-01	Read 7-6-01	Read 7-25-01	Read 8-8-01
Site	At: 10:25 a.m.	At: 10:30 a.m.	At:12:50 p.m.	At:10:40 a.m.	At:10:30 a.m.	At: 10:15 a.m.
1-1-1	159	32	2	2	4	5
1-1-2	134	26	3	6	2	10
1-1-3	136	40	3	3	4	14
1-2-1	70	5	2	1	1	9
1-2-2	59	15	4	7	2	12
1-2-3	60	5	1	5	4	11
AVG	103	20.5	2.5	4	2.83	10.17
2-1-1	1	0	0	1	0	2
2-1-2	2	2	2	2	1	3
2-1-3	6	7	0	0	0	1
2-2-1	0	0	0	1	1	0
2-2-2	0	0	0	0	1	0
2-2-3	0	3	0	0	2	1
AVG	1.5	2	0.33	0. 7	0.83	
3-1-1	0	6	0	8	2	6
3-1-2	0	9	2	12	5	6
3-1-3	1	10	0	5	6	6
3-2-1	1	0	4	2	1	1
3-2-2	0	0	1	1	0	2
3-2-3	1	0	2	1	6	3
AVG	0.5	4.17	1.5	4.83	3.3	4
4-1-1	31	20	22	19	5	12
4-1-2	29	15	33	14	8	8
4-1-3	36	14	27	20	3	8
4-2-1	4	3	30	10	6	10
4-2-2	9	3	40	10	12	12
4-2-3	9	3	21	5	6	8
AVG	19.667	9.67	28.83	13	6.67	9.67
5-1-1	26	59	22	51	8	15
5-1-2	25	52	22	42	7	2
5-1-3	15	47	18	46	3	9
5-2-1	27	67	4	34	6	6
5-2-2	29	94	4	31	8	2
5-2-3	37	94	4	32	10	3
AVG	26.5	68.83	12.3	39.3	7	6.17
6-1-1	6	1	5	5	18	18
6-1-2	3	2	11	5	18	16
6-1-3	4	1	5	5	16	15
6-2-1	0	0	1	7	3	0
6-2-2	5	1	1	5	0	2
6-2-3	4	0	0	4	2	2
AVG	3.67	0.83	3.83	5.17	9.5	8.83

Table A9. 2001 Fecal coliform data (cfu) from Smith Mountain Lake (cont.)

7-1-1	2	1	3	4	1	0
7-1-2	1	3	0	3	1	6
7-1-3	0	2	0	5	1	3
7-2-1	0	0	0	0	0	1
7-2-2	0	0	0	1	0	0
7-2-3	1	0	0	0	0	1
AVG	0.67	1	0.5	2.167	0.5	1.83
8-1-1	184	34	14	4	0	3
8-1-2	143	30	22	6	1	2
8-1-3	180	27	12	8	0	3
8-2-1	7	1	1	3	0	4
8-2-2	8	3	2	3	0	1
8-2-3	7	0	3	2	1	3
AVG	88.17	15.83	9	4.3	0.3	2.67
9-1-1	46	13	39	68	12	8
9-1-2	60	6	30	69	16	11
9-1-3	45	10	30	74	12	12
9-2-1	25	9	66	77	31	126
9-2-2	25	9	22	84	27	65
9-2-3	27	8	14	83	25	38
AVG	38	9.17	33.5	75.83	20.5	43.33
10-1-1	0	1	0	1	0	2
10-1-2	0	0	0	0	1	4
10-1-3	1	0	0	0	1	2
10-2-1	0	0	0	1	1	0
10-2-2	3	0	0	1	1	0
10-2-3	1	0	0	2	0	0
AVG	0.83	0.17	0	0.83	0.67	1.33
11-1-1	8	39	37	109	27	2
11-1-2	3	25	36	100	25	6
11-1-3	1	36	38	118	25	2
11-2-1	7	6	156	99	7	28
11-2-2	10	3	201	90	9	20
11-2-3	7	2	182	104	7	24
AVG	6	18.5	108.3	103.33	16.667	13.67
12-1-1	6	8	1	14	2	2
12-1-2	4	6	9	21	0	2
12-1-3	7	6	5	8	3	0
12-2-1	0	0	0	5	0	0
12-2-2	1	1	0	3	0	0
12-2-3	0	0	1	4	0	0
AVG	3	3.5	2. 7	9.17	0.83	0.67
13-1-1	5	0	3	4	4	1
13-1-2	1	1	4	3	7	3
13-1-3	2	2	3	3	3	0
13-2-1	1	0	0	6	1	0

Table A9. 2001 Fecal coliform data (cfu) from Smith Mountain Lake (cont.)

13-2-2	2	0	0	4	0	1
13-2-3	5	0	0	4	0	0
AVG	2.7	0.5	1. 7	4	2.5	0.83
14-1-1	40	12	1	5	3	3
14-1-2	33	11	1	8	9	1
14-1-3	42	14	2	6	6	0
14-2-1	54	14	4	7	2	15
14-2-2	37	14	1	2	5	30
14-2-3	48	17	4	8	2	29
AVG	42.3	13. 7	2.17	6	4.5	13
week	1	3	5	7	9	11
Mean/week	23.8	12.0	14.9	19.6	5.5	8.4
std/week	40.3	19.2	33.9	31.1	7.2	15.9