

THE OCCURRENCE AND DISTRIBUTION OF INDICATOR BACTERIA IN CANYON LAKE

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The Santa Ana Regional Water Quality Control Board
3737 Main Street, Suite 500
Riverside, CA 92501-3339

and

The Lake Elsinore & San Jacinto Watersheds Authority
11615 Sterling Avenue
Riverside, CA 92503

Submitted by:

M.A. Anderson, K. Davis and M.V. Yates
Department of Environmental Sciences
University of California
Riverside, CA 92521

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Executive Summary

Canyon Lake was sampled weekly from August 2001 to August 2002 to quantify the concentrations of common water quality indicator bacteria in the lake and their spatial and temporal trends. The annual geometric mean total coliform bacteria concentration was 8445 cfu/100 mL, with a range across all sites, depths and sampling dates of 100-324,000 cfu/100 mL. The annual geometric mean fecal coliform bacteria concentration was 858 cfu/100 mL, with a range of 0-116,600 cfu/100 mL. The annual geometric mean enterococcus and *E. coli* concentrations were considerably lower than the total and fecal coliform bacteria (15 cfu/100 mL and 3 MPN/100 mL, respectively).

Bacteria concentrations were typically higher in East Bay and the other shallow embayments as compared to the main body of the lake. The highest bacteria concentrations were found in late February – early March 2002, although high concentrations were also found during the summer of 2001 and 2002. Canyon Lake also routinely possessed higher bacterial concentrations at the thermocline and bottom, as compared to the surface ($p < 0.05$).

Limited sampling in the watershed indicates a potentially large bacterial load to Canyon Lake in the event of heavy rainfall. Total and fecal coliform bacteria concentrations in the Perris Valley Storm Drain and Salt Creek were >8,000 to >242,000 cfu/100 mL. Enterococcus concentrations ranged from 3,130-15,400 cfu/100 mL, while *E. coli* concentrations ranged from 286-3,535 MPN/100 mL. Sampling of the storm drains surrounding the perimeter of the lake showed local nuisance runoff also possessed very high levels of bacteria, with total and fecal coliform bacteria concentrations of 10^5 - 10^6 cfu/100 mL. Enterococcus concentrations were also very high in the local runoff, and ranged from 4,900-190,000 cfu/100 mL. *E. coli* concentrations were lower than the other bacteria (110-2,400 MPN/100 mL).

Calculations made with a simple model that allowed for bacterial inputs due to summer nuisance runoff and losses due to inactivation yielded predicted concentrations of enterococci and *E. coli* in East Bay that were within a factor of about 2 of measured values (e.g., predicted concentrations of 4.7 cfu/100 mL vs. measured average concentrations of 10.9 cfu/100 mL). Greater deviations between

observed and predicted concentrations were witnessed for fecal and total coliform bacteria (observed concentrations were about 20x greater than predicted levels). While uncertainty in these calculations is fairly high, it appears that about 50% of the enterococci and *E. coli* in East Bay may be due to local summer runoff, although such sources apparently account for only ~5% of the total and fecal coliform bacteria present. Local nuisance runoff is thought to be less important for the main body of the lake.

A similar set of calculations was also made to account for direct waterfowl inputs of bacteria into the lake. Using information about the bacterial content of feces, the mass of feces per defecation, and an estimate of waterfowl density, the predicted enterococcus level was in surprisingly good agreement with measured geometric mean levels (14.9 vs. 15 cfu/100 mL), although predicted fecal coliform bacteria concentrations were again much lower than measured values (7.6 vs. 858 cfu/100 mL).

Results from these calculations suggest that the measured concentrations of enterococcus and *E. coli* in Canyon Lake for the study period (2001-2002) can be accounted for by considering these two sources (*i.e.*, nuisance runoff and waterfowl), although additional sources are needed to account for the high fecal and total coliform bacteria levels.

Leaking sewer lines and body-contact recreators might both be implicated, but several factors lead one to conclude that such inputs were relatively unimportant. First of all, fecal and total coliform concentrations were, for the most part, uniformly high across the lake. A leak in a sewer line would result in locally high concentrations near the leak, with concentrations that would decrease with increasing distance from the leak. This is especially true for East Bay, where the complex shoreline, very limited fetch, and high degree of wind sheltering would limit mixing. Analogously, higher concentrations would be expected near beach areas and in the ski area on the main body of the lake if body-contact recreation was an important source (very little body-contact recreational use was observed in East Bay). Secondly, the relative abundances of fecal coliform, enterococcus and *E. coli* are not consistent with a human (or non-human warm-blooded animal) source. Much higher enterococcus and *E. coli* concentrations would be expected, with concentration ratios of fecal coliform:enterococcus closer to 3:1 to 6:1, as compared

with the measured average value of 57.2. Similarly, inspection of the literature suggests that the fecal coliform:*E. coli* ratio in fecally-contaminated waters would approach ~1.2 (vs. the measured average value of 286).

Separate laboratory experiments indicate that Canyon Lake is able to support the growth of total and fecal coliform bacteria, but not enterococci. *E. coli* concentrations were consistently low throughout the year and apparently also do not reproduce in the lake. Thus, it is suggested that growth of coliform bacteria is the dominant source of total and fecal coliform bacteria in Canyon Lake. As a result, enterococci and *E. coli* appear to be better indicators of recent fecal contamination events; their use as water quality indicators for the lake is recommended.

Recreator health risks calculated using the measured enterococcus and *E. coli* concentrations with the relationships of Dufour (1984) were below the EPA acceptable rate of 8 cases of gastroenteritis per 1000 recreators. Given the low annual geometric mean concentrations for enterococci and *E. coli*, Canyon Lake may not pose the risk to recreator health that would be inferred from the high concentrations of total and fecal coliform bacteria.

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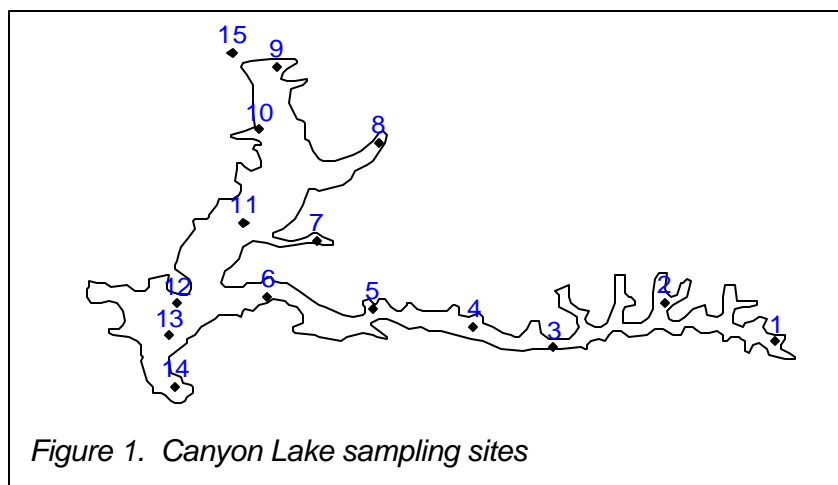
1. Introduction

Canyon Lake was constructed in 1928 as the Railroad Canyon Reservoir. It is about 1 mile upstream of Lake Elsinore and water spilled from Canyon Lake is a main source of water for Lake Elsinore. The beneficial uses of Canyon Lake include municipal and domestic water supply, agricultural supply, groundwater recharge, body contact recreation, non-body contact recreation, warm freshwater aquatic habitat, and wildlife habitat. Section 303 (d) of the Clean Water Act requires the State to identify surface water bodies that do not or are not expected to meet water quality standards (including beneficial uses, water quality objectives, and anti-degradation policy). The Santa Ana Regional Water Quality Control Board (Regional Board) has listed Canyon Lake as “impaired” due to excessive nutrients and pathogens. The Regional Board is required to develop a Total Maximum Daily Load (TMDL) for each of these pollutants.

The objectives of this study were to determine the concentrations of indicator bacteria and their sources and persistence within Canyon Lake.

2. Methodology

Canyon Lake was sampled weekly from August 2001-August 2002. Samples were collected weekly from up to 15 sites across the lake (Fig. 1). Sampling at the 15 sites was alternated weekly with detailed vertical sampling was conducted at sites 10 and 13 (Fig. 1). This sampling approach allowed us to quantify both the seasonal and spatial distribution of bacteria within the lake, including the lateral and detailed vertical bacterial distribution.



Samples were collected using a pneumatically triggered sampler that included a sterilized 500 mL bottle and stopper with tubing assembly. Once lowered to the appropriate depth, a pulse of air was released that opened the sampler, allowing water to enter the sterilized bottle. The sample bottle and associated assembly were then retrieved. The samples were sealed with autoclaved screw-cap lids and stored on ice for transport back to the laboratory.

In conjunction with the bacteria sampling, water column measurements of temperature, electrical conductance, dissolved oxygen, pH and turbidity were made using a Hydrolab DataSonde4 and Surveyor 4 display. Water samples were also periodically analyzed for dissolved organic carbon (DOC) and dissolved $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and soluble reactive phosphorus (SRP). DOC was measured using Shimadzu and Dohrmann total organic carbon analyzers. Dissolved $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and SRP were measured on samples filtered through a $0.45\ \mu\text{m}$ polycarbonate filter and acidified to $\text{pH}<2$ using H_2SO_4 using an Alpkem autoanalyzer following standard methods (APHA, 1998).

In addition to sampling of the water column, samples were collected at selected sites within the Canyon Lake watershed (Fig. 2). Canyon Lake receives flow from the San Jacinto River and, to a lesser extent, Salt Creek. The San Jacinto River watershed at Canyon Lake is approximately $720\ \text{mi}^2$ and includes an estimated $490\ \text{mi}^2$ of wildland, $108\ \text{mi}^2$ of urban/suburban development, and $122\ \text{mi}^2$ of agricultural land (Cindy Li, personal communication). The Salt Creek watershed encompasses about $127\ \text{mi}^2$ and includes principally wildland and urban/suburban development. Watershed samples for nutrient and bacterial analyses were collected on December 21st, 2001 and January 29th, 2002 following winter storm flow.

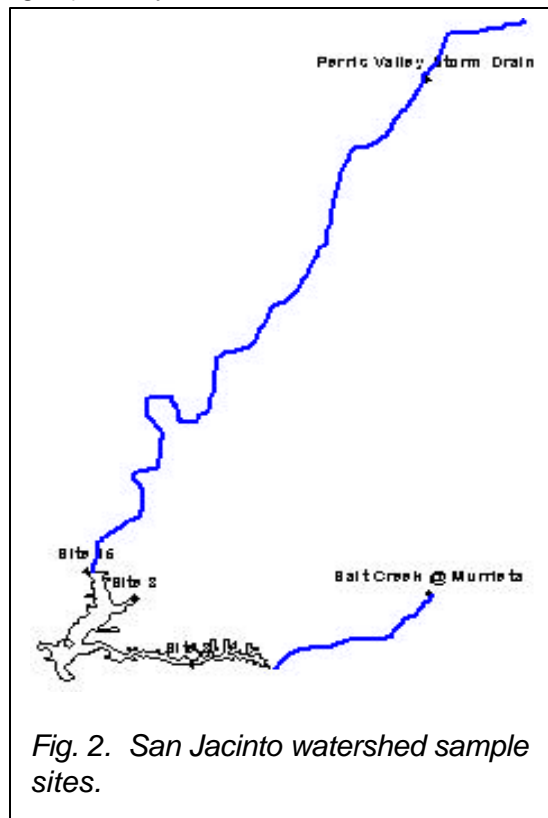
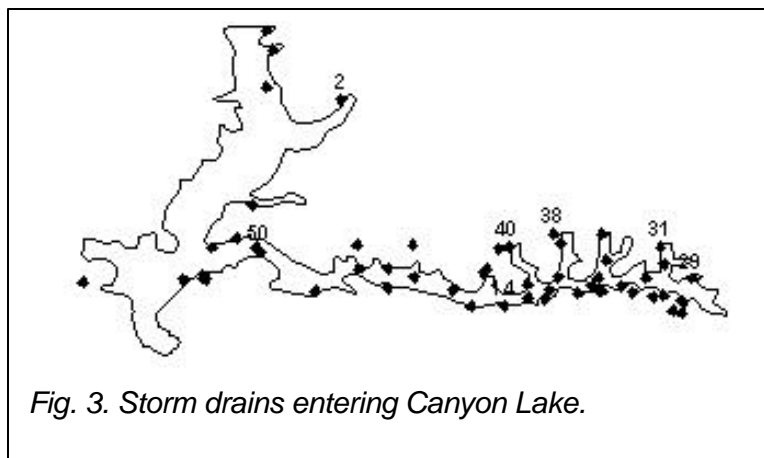


Fig. 2. San Jacinto watershed sample sites.

In addition to sampling of the San Jacinto and Salt Creek watersheds, the local watershed, specifically the storm drains entering the lake, were also mapped and sampled where possible (Fig. 3). The labeled sites were sampled on August 8, 2002.



Membrane filtration methods 9222B, 9222D, 9230C were used to analyze for total coliform bacteria, fecal coliform bacteria, and enterococcus concentrations, respectively. Methodologies were taken from Standard Methods for the Examination of Water and Wastewater 20th Edition. *E. coli* was analyzed for with the Colilert method (Eckner, 1998).

Total microbial and viral counts were obtained by use of the epifluorescent microscopy method (Porter, 1980; Suttle, 1997). 100 μ L samples were stained with DAPI and filtered onto 0.2 μ m pore size black polycarbonate filters for total microbial counts. Samples for total virus analysis were pre-filtered through 0.2 μ m pore size filters and then filtered onto 0.02 μ m pore size Al₂O₃ Anodisc 25 mm membrane filters, and placed in a petri dish with a Yo-Pro-1 sodium cyanide solution and incubated for two days. Stained samples were then mounted on microscope slides and viewed on a Nikon model Eclipse E600W epifluorescent microscope at a magnification of 1000X. Total microbial counts were viewed under an ultraviolet light at an excitation of 365 nm. Total viral counts were viewed with an acridine orange filter set at an excitation of <490 nm.

Lake bathymetry was determined using a Hummingbird depth finder and a Garmin eTrex GPS using the WGS-84 datum. Positional and depth data were used to develop a depth contour plot using Surfer 7.0 (Golden Software).

3. Results

3.1 Lake Bathymetry

Canyon Lake can be subdivided into 3 separate basins, the relatively shallow East Bay, the deeper main body of the reservoir, and the area north of the causeway that becomes the San Jacinto River. The area north of the causeway was not extensively sampled or mapped, but was routinely sampled near the culverts that connect the north basin and the main body of the reservoir. Bathymetry for the lake south of the causeway is provided in Fig. 4. Lake surface elevation at full pool is 1382 feet and at the time of the bathymetric measurements (August 2001) was approximately 1368 feet.

East Bay is a long, narrow and quite shallow embayment <10 feet deep when the lake is near full pool (Fig. 4). At the lake elevations present during much of 2001-2002 (~1364-1368'), a considerable area of East Bay was less than 6 feet in depth. In comparison, depths exceeding 40' were found near the dam (in the southern portion of the main body of the lake) (Fig. 4).

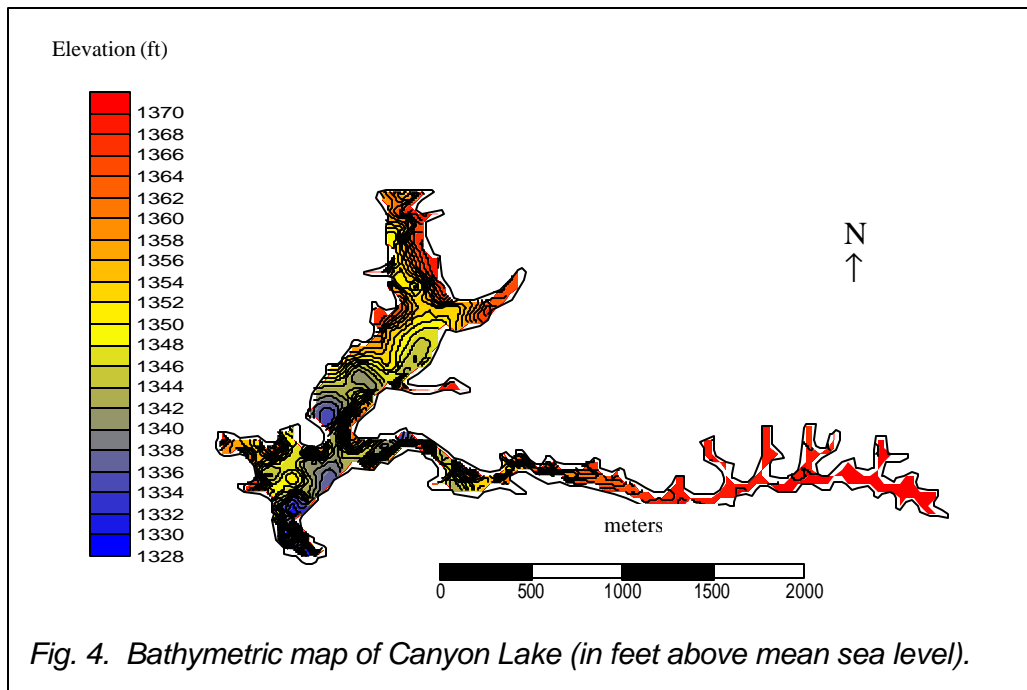
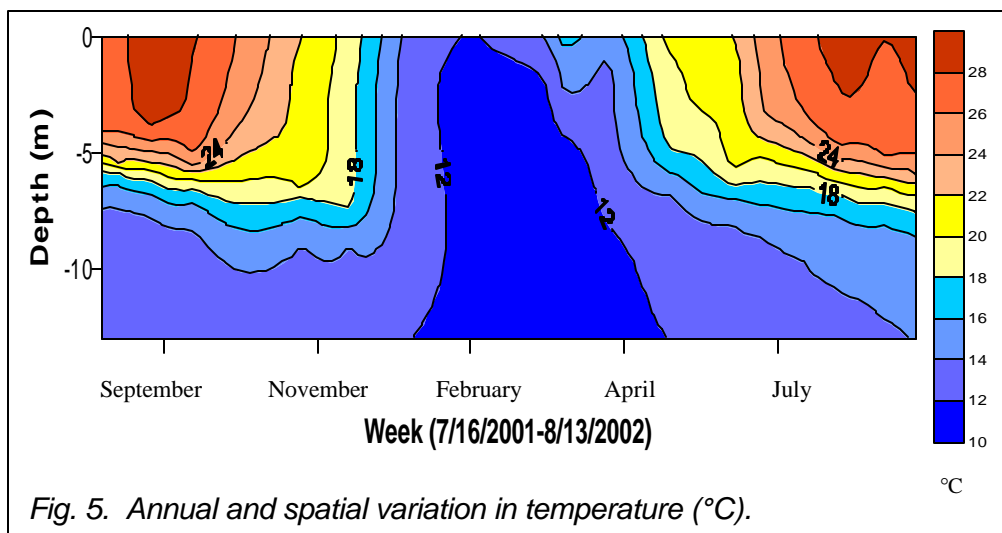


Fig. 4. Bathymetric map of Canyon Lake (in feet above mean sea level).

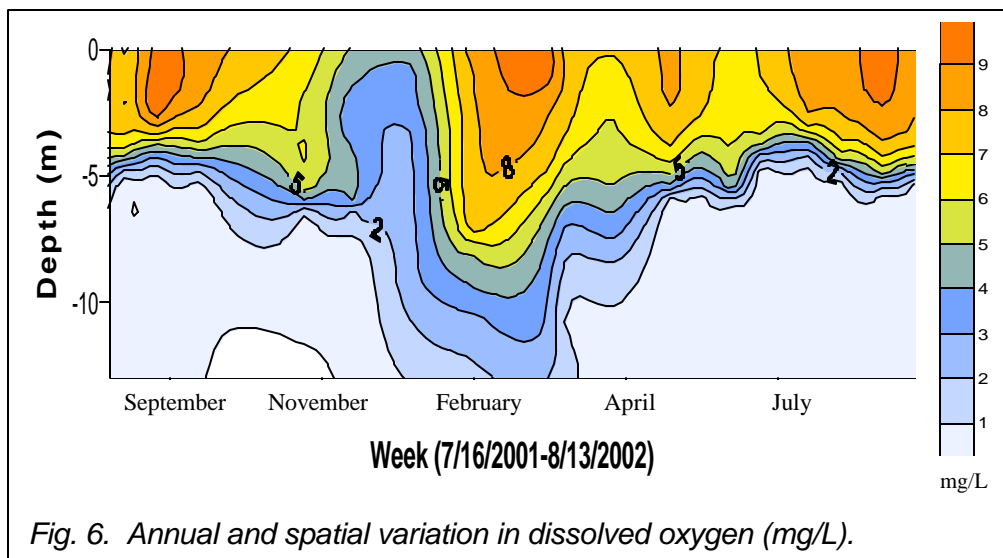
3.2 Limnological Characteristics

Water column measurements of temperature, dissolved oxygen and other important properties were made biweekly at sites 10 and 13 (on the main body of the lake). The temperature profiles collected at site 13 reveal relatively strong stratification present from May – October, mixing in late November, and essentially isothermal conditions present from December through early April (Fig. 5). Surface water temperatures often exceeded 26°C during the summer, while temperatures near the sediments were 10-12°C. The thermocline was present from approximately 5 m to 7 m, with some deepening over time (Fig. 5). Thus, Canyon Lake is a warm, monomictic lake, with an epilimnion that extends down to approximately 5 m depth.



Dissolved oxygen levels were generally high in the surface waters but low, even during the relatively well-mixed isothermal winter condition, near the sediments (Fig. 6). Notably, DO levels were <1 mg/L below about 5 m depth almost 75% of the year. Thus, anoxic conditions tend to dominate in the subsurface.

The pH of the lake varied from a mean value of 8.2 at the surface to 7.4 near the sediments. The electrical conductivity of the water was relatively low and did not change substantially with depth. Mean surface and bottom values were 1.139 $\mu\text{S}/\text{cm}$ and 1.134 $\mu\text{S}/\text{cm}$, respectively.



3.3 Microbiology

3.3.1 Annual and Seasonal Bacteria Concentrations

High concentrations of total and fecal coliform bacteria were found at Canyon Lake (Table 1). Total coliform bacteria concentrations ranged from 100-324,000 cfu/100 mL with a geometric mean across all sites, depths and sampling dates of 8445 cfu/100 mL. Fecal coliform bacteria levels were about one-order of magnitude lower (geometric mean concentration of 858 cfu/100 mL) (Table 1). Such levels exceed by a large margin the Basin plan levels of <100 for a single day sample for total coliform bacteria (Cindy Li, personal communication). Moreover, these geometric mean levels exceed DHS 30-day average recommended action levels of 1,000 and 200 for total and fecal coliform bacteria, respectively (CA DHS, 2001).

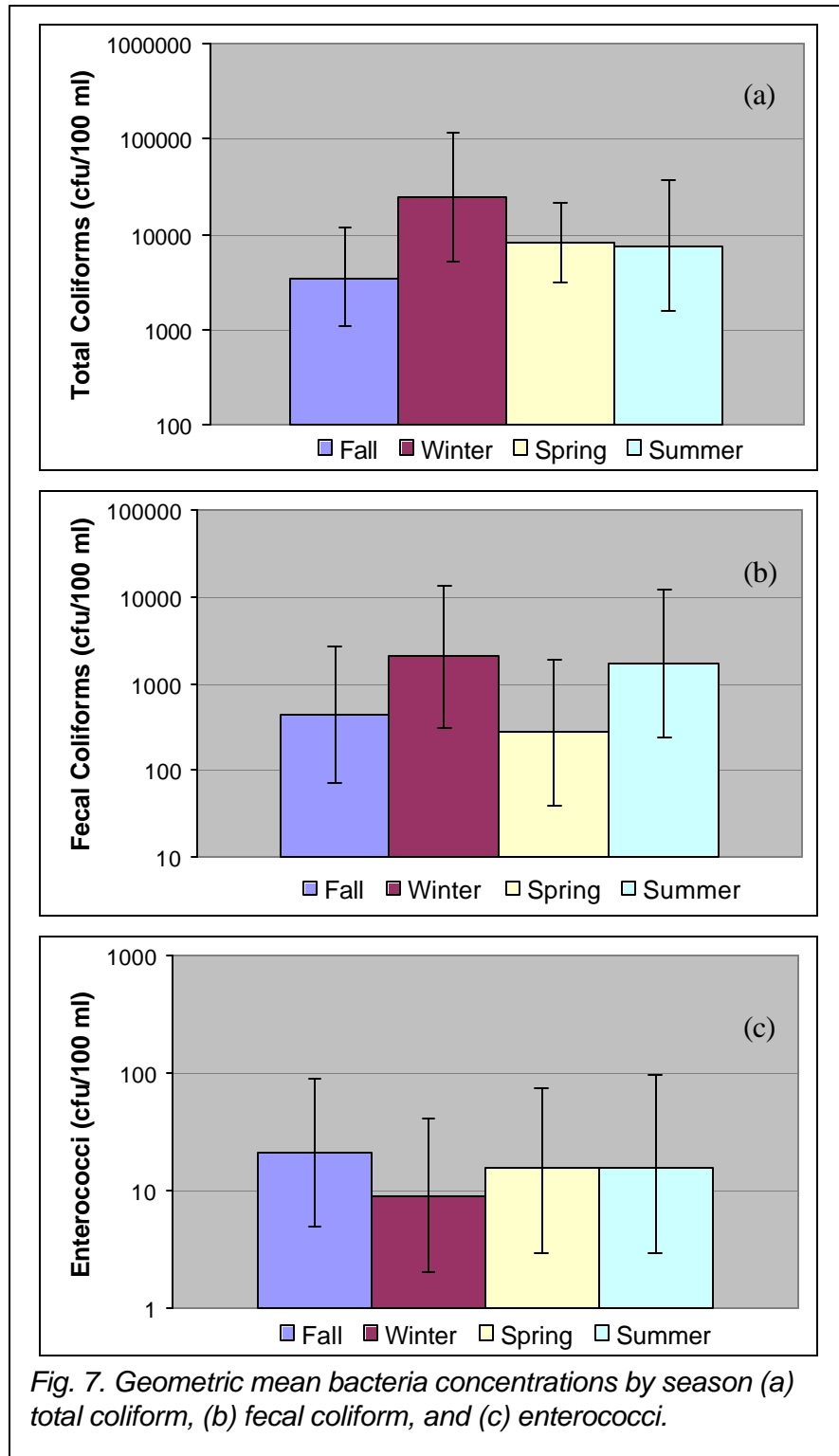
Geometric mean enterococcus and *E. coli* concentrations were markedly lower than the coliform bacteria, and within DHS 30-day average action levels for these indicators (33 and 126 cfu or MPN/100 mL, respectively). This is noteworthy because enterococci and *E. coli* are thought to be better indicators of human health than the coliform bacteria (DuFour, 1984).

	----- cfu/100 mL or MNP/100 mL -----			
Organism	Geometric Mean	Median	Range	N
Total Coliform	8445	7500	100 - 324000	797
Fecal Coliform	858	875	0 – 116600	845
Enterococcus	15	15	0 - 1080	846
<i>E. coli</i>	3	3	0 – 176	533

The annual geometric mean bacteria data were further broken down into seasonal data, defined by quarterly reporting periods (Fig. 7). The fall season consists of samples taken from October 17 to December 17, 2001, the winter season is from January 9 to March 26, 2002, the spring season is from April 9 to June 10, 2002, and the summer season includes samples taken in August and September of 2001 and July of 2002. Geometric mean values include an error bar of one standard deviation above and below the mean.

The geometric mean concentrations of total and fecal coliform bacteria were highest during the winter, although higher geometric mean fecal coliform concentrations were also calculated for the summer period. Geometric mean enterococcus and *E. coli* concentrations showed less variation throughout the year (data not shown for *E. coli*).

In addition to the annual and seasonal data that included all sampling sites, geometric mean concentrations were calculated for each individual site to help discern possible spatial variation in indicator bacteria levels within the lake (Figs. 8-11). In general, bacteria concentrations were higher in East Bay and the other two embayments (sites 7 and 8) than in the main body of the lake. Moreover, concentrations were typically higher at the thermocline and bottom than at the surface (Figs. 8-11).



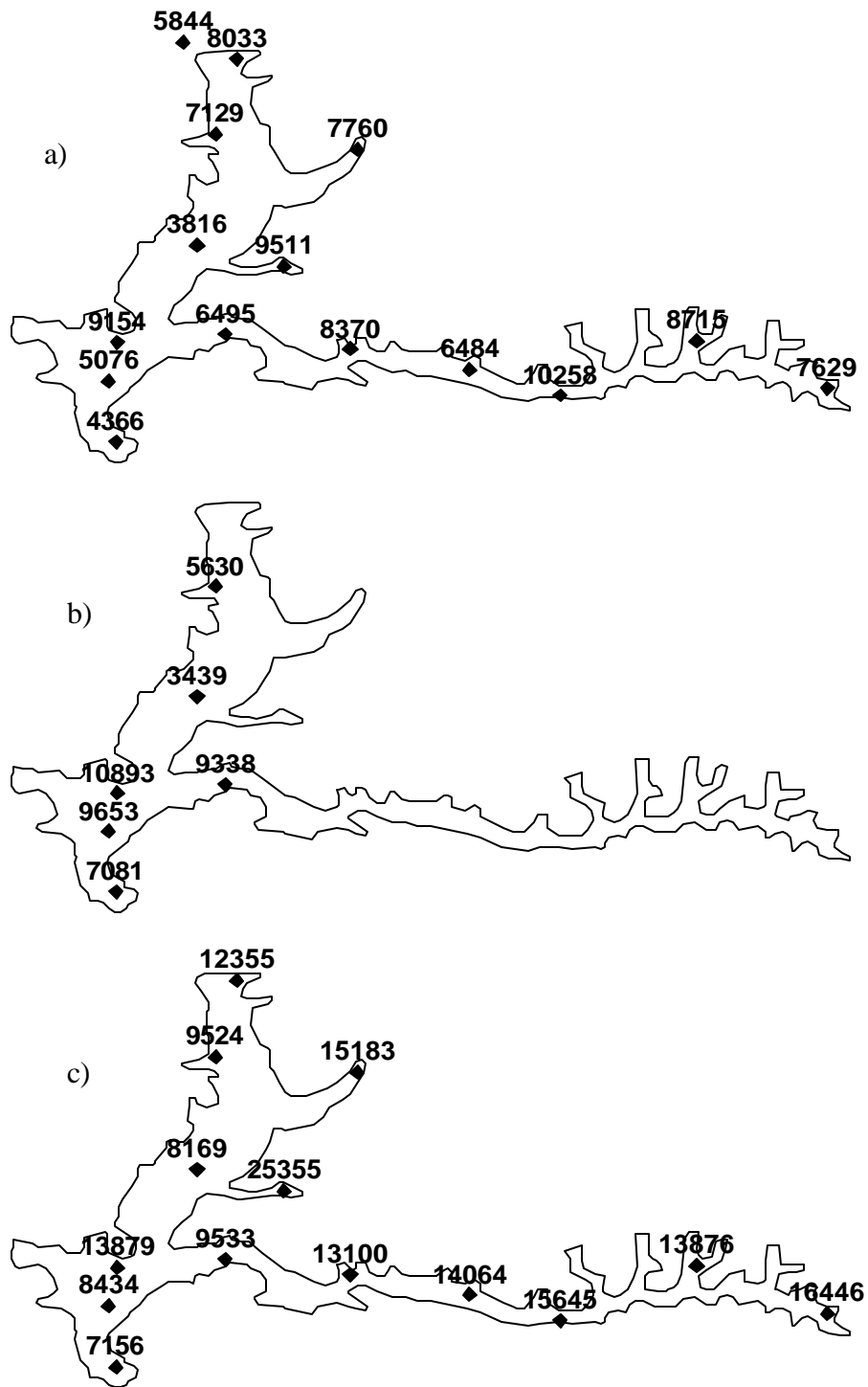
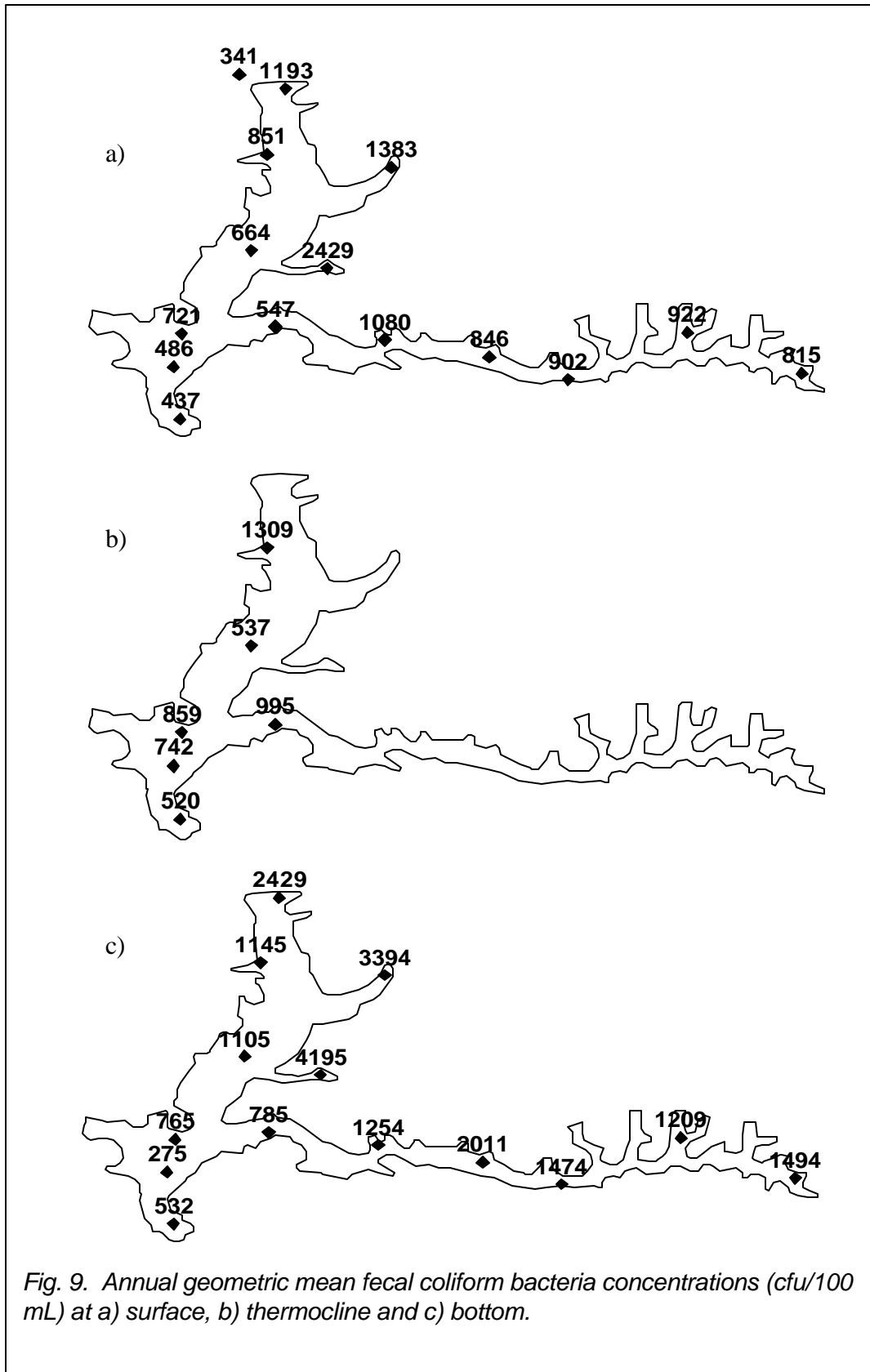
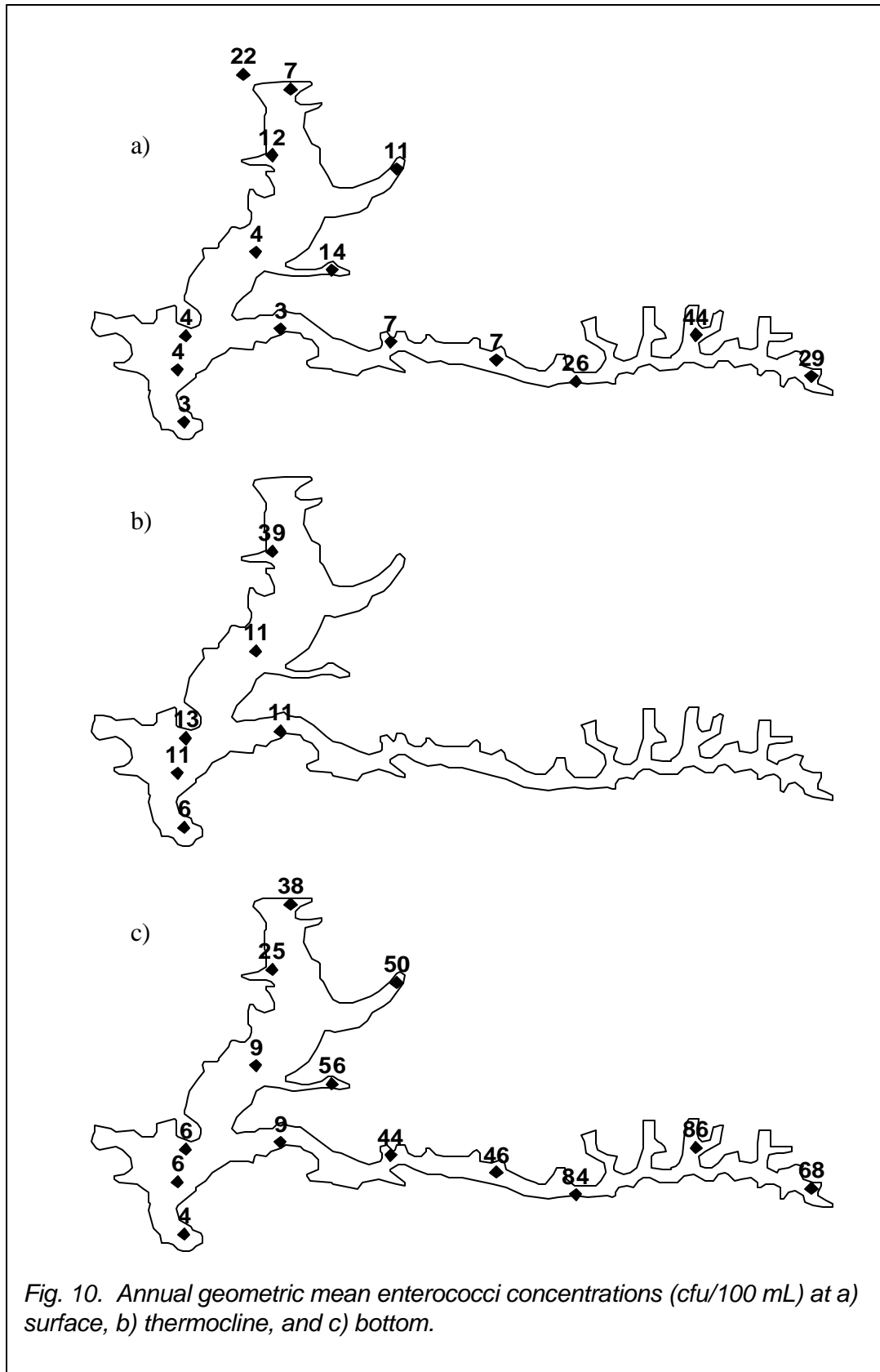
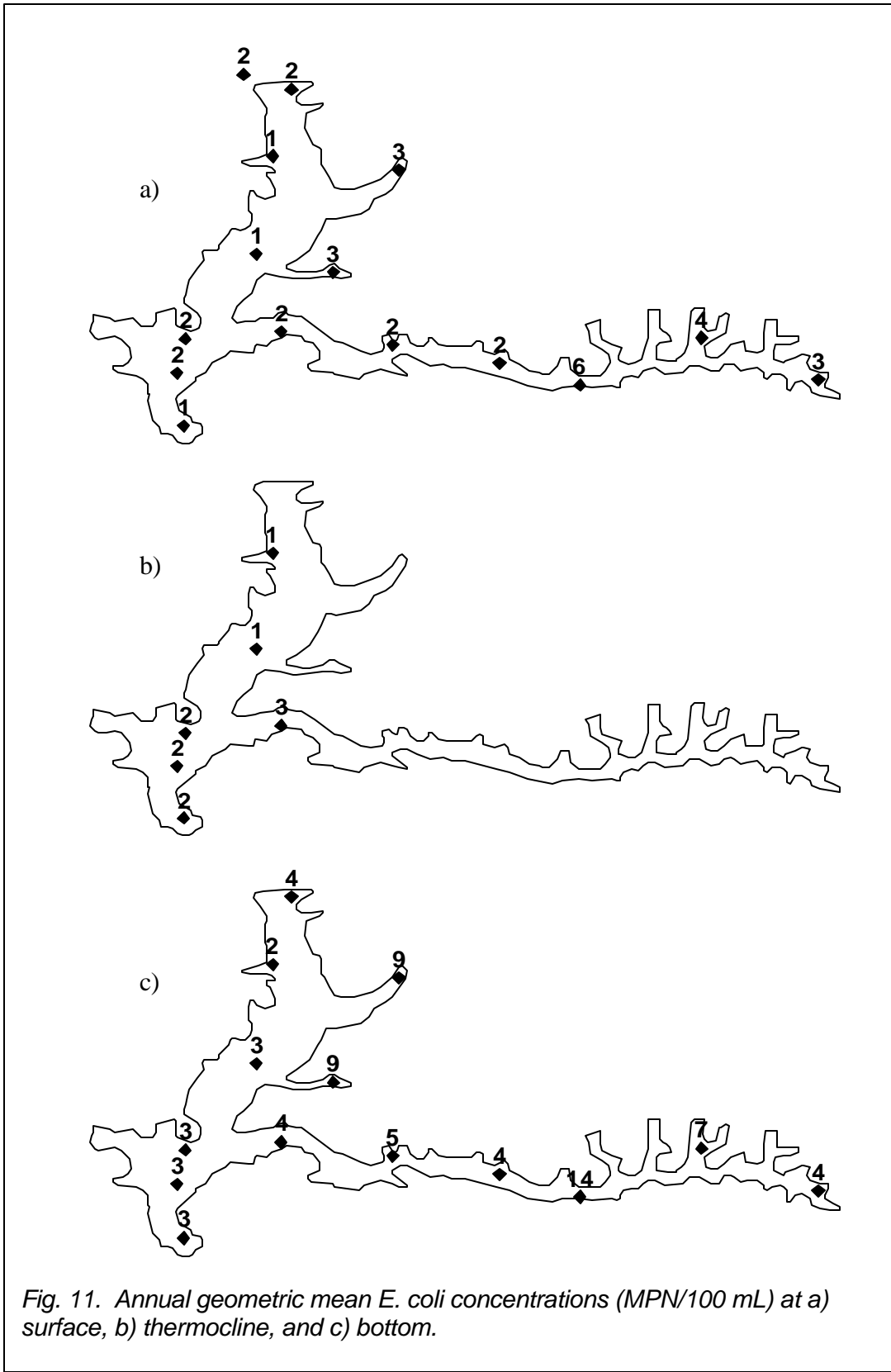


Fig. 8. Annual geometric mean total coliform bacteria concentrations (cfu/100 mL) at a) surface, b) thermocline and c) bottom.







The figures suggest that concentrations at any given site were often higher near the thermocline or bottom when compared with surface samples. Since bacterial populations are not normally distributed, parametric statistics are not appropriate for determining significant trends in bacterial concentrations (Weiskel *et al.*, 1996; Bergstein-Ben Dan and Stone, 1991). As a result, a nonparametric statistical test was conducted. Specifically, a sign test was employed (Daniel, 1990). This test is used to determine if the difference between two related pairs of data is significant. For Canyon Lake, concentrations for surface, thermocline and bottom samples were compared for each site and sampling date. The probability of a given sampling depth concentration being higher (or lower) than another depth is quantified. If there is no difference in their concentrations, then the frequency at which, *e.g.*, the measured bottom concentrations were higher than the surface concentrations, should be the same as the frequency at which the surface concentrations were higher than the bottom concentrations ($p = 0.5$). Frequencies that are much greater than (or much lower than) 0.5 indicates a statistically significant difference between the paired samples.

The probability, p , that the null hypothesis ($p = 0.5$) is true (*i.e.*, that there is no difference in concentrations between sample depths) can be calculated. Table 2 summarizes the p -value for total and fecal coliform bacteria and enterococcus concentrations at the lake bottom exceeding those at the surface, and those at the thermocline exceeding those at the surface and the bottom. The results of this test show that the difference between total and fecal coliform bacteria and enterococcus concentrations at the bottom and surface is statistically significant, with bottom concentrations being higher, at a p -value < 0.05 . This is true both for the shallow sites (1-5, 7-8) and the deeper sites (6, 9-14). Bacteria concentrations at the thermocline were also significantly higher than at the bottom and surface at a p -value < 0.05 , with the exception of total coliform bacteria concentrations at the bottom ($p = 0.37$).

Table 2. Results of sign test for samples collected from 8/8/2001-7/16/2002.			
	Total Coliforms	Fecal Coliforms	Enterococci
	p-value of bottom concentrations exceeding surface concentrations		
Shallow Sites (1-5, 7-8)	6.98E-18	6.97E-13	6.08E-25
Deep Sites (6, 9-14)	2.91E-06	3.57E-02	3.41E-06
	p-value of thermocline concentrations exceeding those at other depths		
Sites 6, 10-14; surface	2.25E-04	1.52E-04	8.46E-06
Sites 6, 10-14; bottom	3.66E-01	5.61E-05	1.28E-05

3.3.2 Temporal Trends in Bacterial Concentrations

Figures 12-15 show the measured temporal variation of log-transformed concentrations of total and fecal coliform bacteria, enterococcus, and *E. coli*, collected at the surface, thermocline, and bottom depths. Total coliform bacteria concentrations showed at all three depths the same general trend with time (Fig. 12). Specifically, bacteria concentrations reached their highest levels on 2/26/2002 and 7/9/2002. In February there was a large population of migratory waterfowl on the lake that might be considered responsible for these higher levels (considered further in Discussion). There is no obvious explanation for the high concentrations seen in July. The lowest concentrations were seen at the surface for site 11. This site is located in the middle of the lake and receives a lot of mechanical mixing of the surface layers from boating activities. There was very good agreement across all six sites at the thermocline, however, this is not seen at the surface or bottom across all fourteen sites. As previously seen, East Bay tends to have higher concentrations of coliform bacteria than on the main body of the lake. This would explain the observed variations in concentrations when all sites are plotted together. Perhaps the most striking feature of these figures is the large number of samples that exceeded the Department of Health Services (DHS) 30-day average recreational standard for total coliform bacteria, represented by the thick green line, of 1,000 cfu/100 mL (3 log units) and the single sample standard of 10,000 cfu/100 mL (4 log units), the thick blue line. Nearly all samples exceeded the 30-day average standard and about half the samples exceeded the single sample standard for total coliform bacteria (Fig. 12).

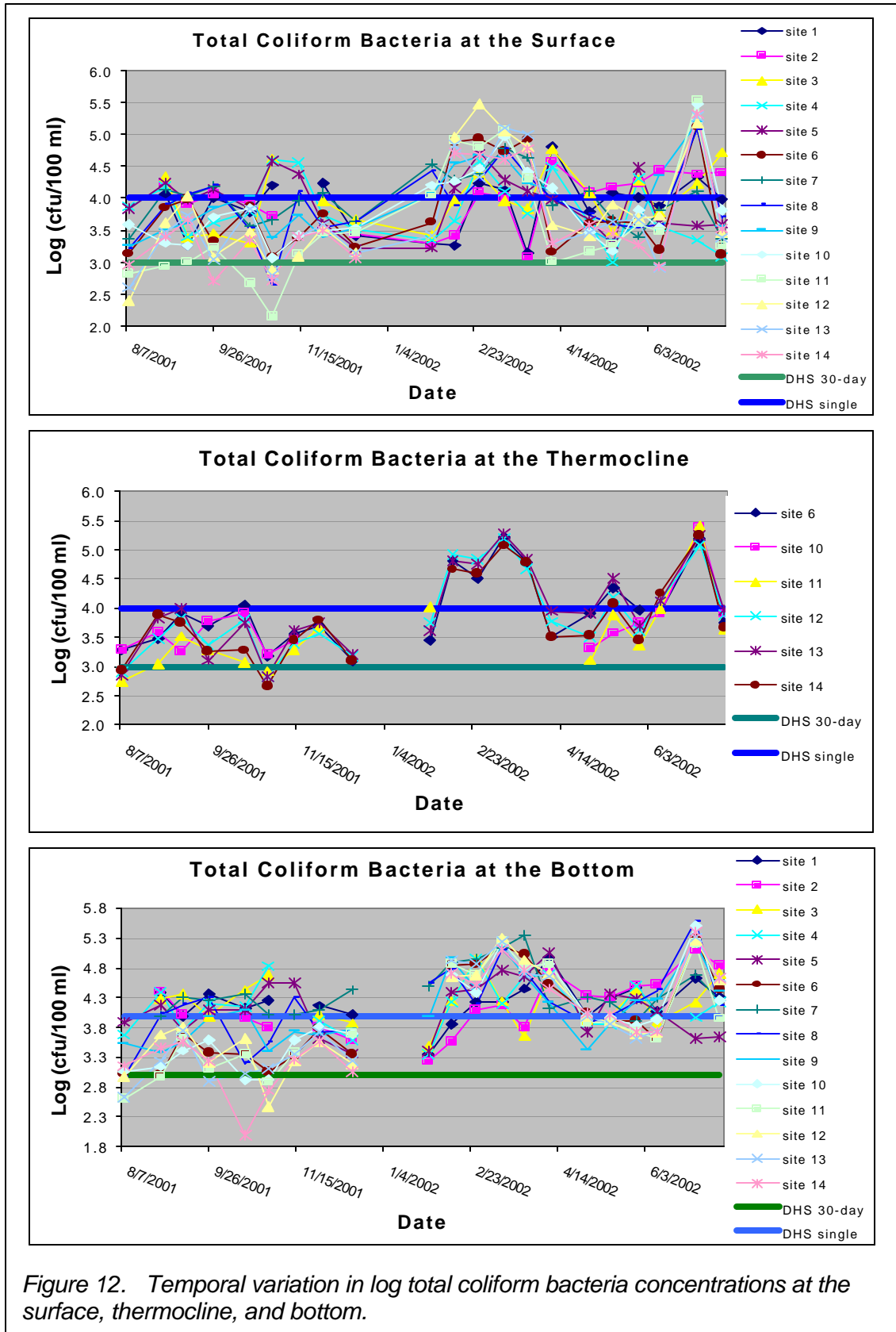


Figure 12. Temporal variation in log total coliform bacteria concentrations at the surface, thermocline, and bottom.

Fecal coliform bacteria concentrations were similar to total coliform bacteria concentrations in that they followed the same general trend at the three depths. Highest concentrations were also seen in late February - early March 2002 and in July, although concentrations were high throughout the summer of both 2001 and 2002 (Fig. 13). Bacteria levels were comparatively low from November – January, and at their lowest level in April. Once again, concentrations at the thermocline at all sites show good agreement in their annual variation (Fig. 13). There is a large amount of variation in the concentrations at the other two depths, especially at the bottom. A majority of the samples exceeded both the DHS 30-day average recreational standard of 200 cfu/100 mL (2.3 log units) and the single sample standard of 400 cfu/100 mL (2.6 log units) for fecal coliform bacteria (Fig 13).

Enterococcus and *E. coli* concentrations varied throughout the year without any prominent highs or lows. Most samples taken at the surface and thermocline for enterococci were below the DHS 30-day average recreational standard of 33 cfu/100 mL (1.5 log units) and the single sample standard of 61 cfu/100 mL (1.8 log units) (Fig. 14). However, about one-half of the bottom samples exceeded this standard. This appears to be due to the higher levels of bacteria associated with sediment particles, perhaps resuspended during boating and other recreational activity upon the lake. All *E. coli* samples were below the DHS 30-day average recreational standard of 126 cfu/100 mL (2.1 log units), except for one sample taken at the surface at site 4 on 12/17/2001, however, this sample does not exceed the single sample standard of 235 cfu/100 mL (2.4 log units) (Fig. 15).

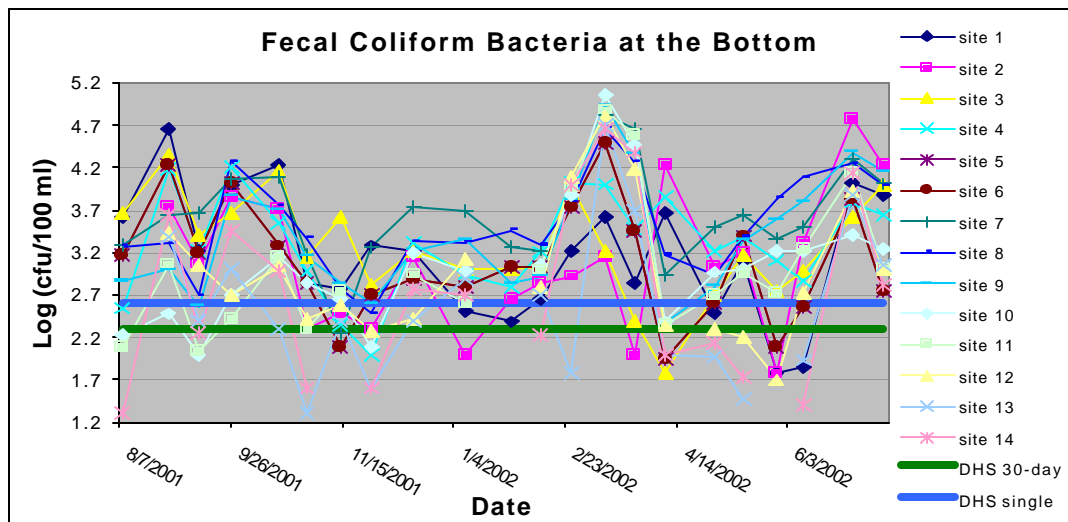
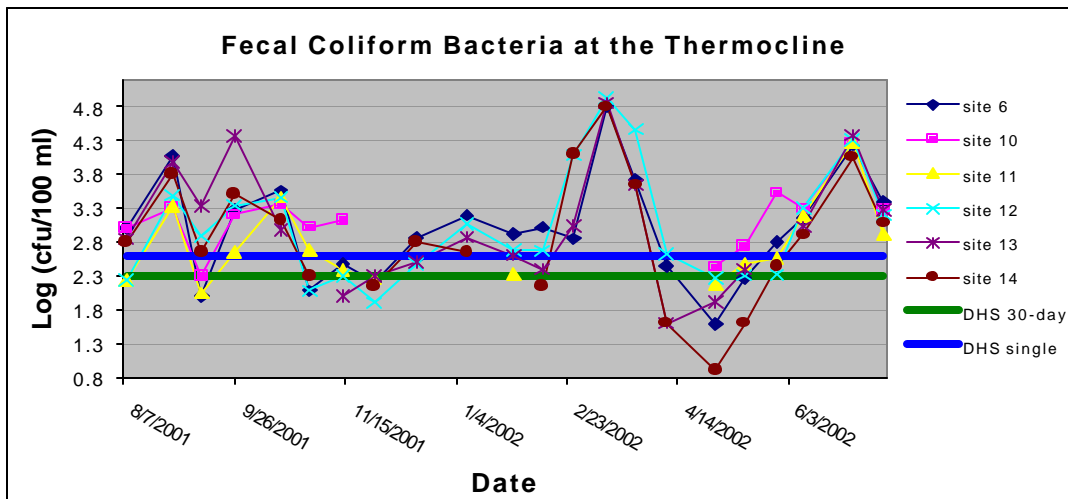
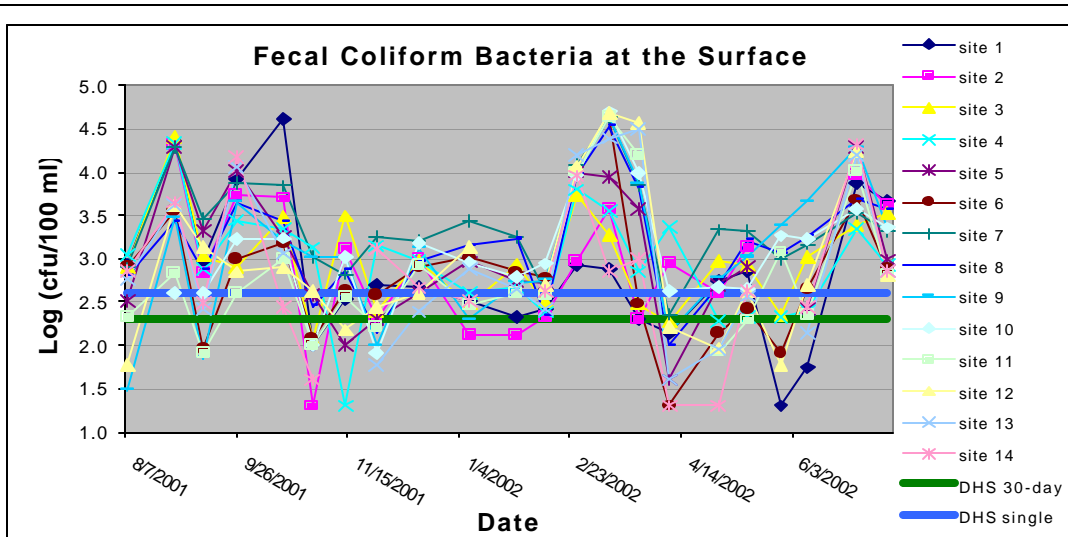
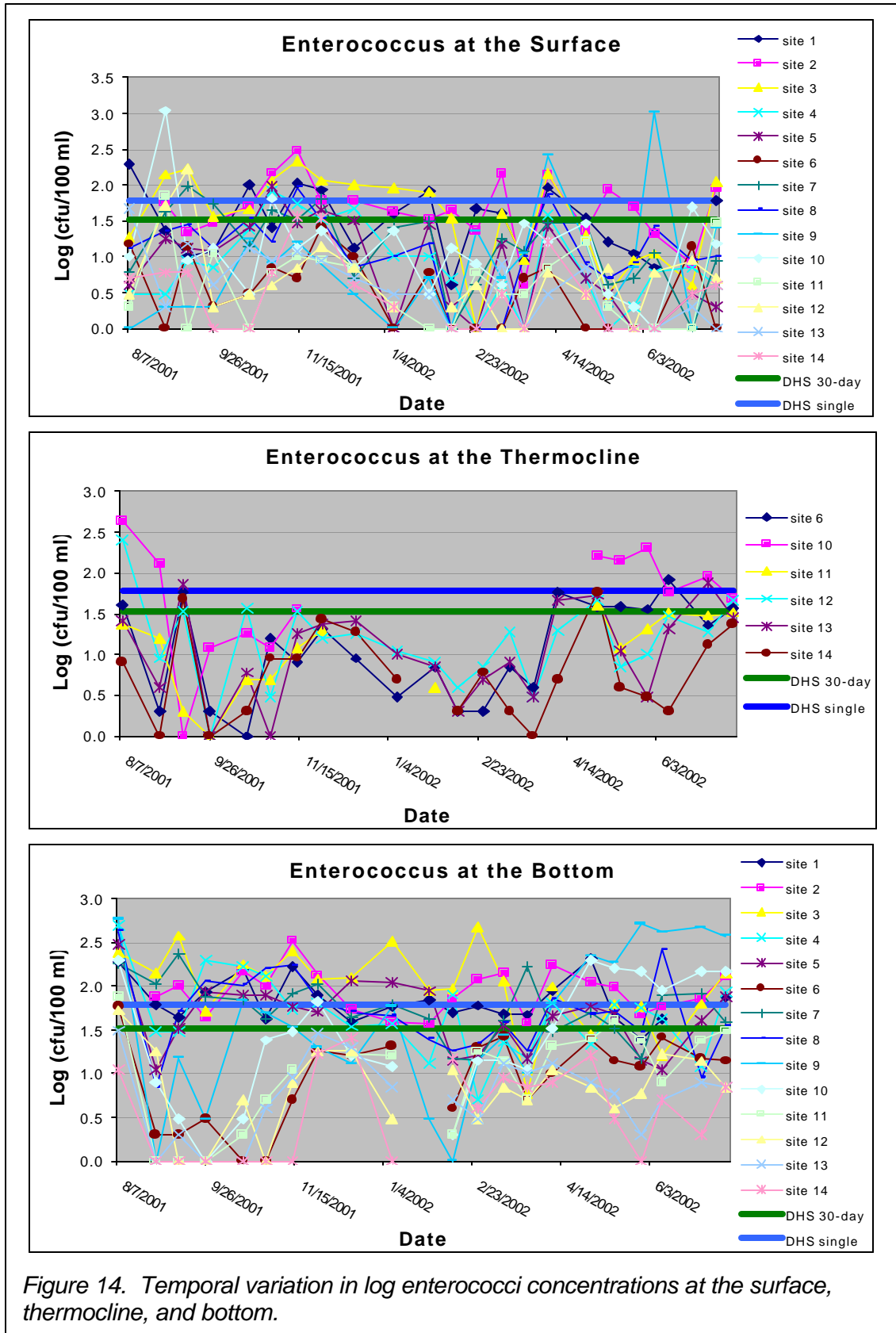


Figure 13. Temporal variation in log fecal coliform bacteria concentration at the surface, thermocline, and bottom.



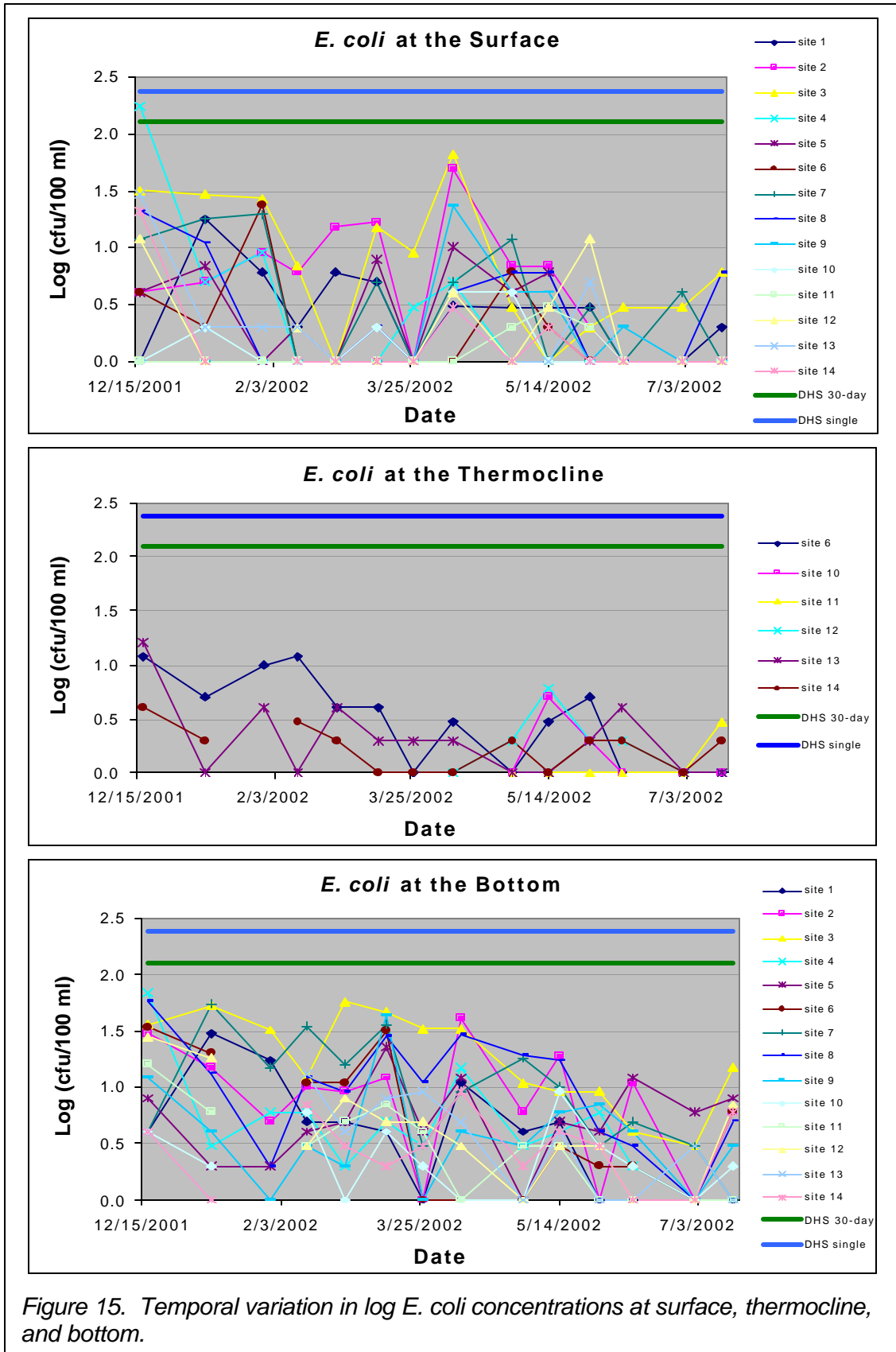


Figure 15. Temporal variation in log *E. coli* concentrations at surface, thermocline, and bottom.

In addition to the seasonal trends, an assessment was made of the diurnal variations in indicator bacteria concentrations at site 15. Samples were collected hourly for a 24 hour period beginning at 8 p.m. on March 5th, 2002.

While there was some sample-to-sample variation, total coliform bacteria levels remained relatively constant over the 24-hour sampling interval near 4×10^4 cfu/100 mL (Fig. 16a), although the data do suggest slightly lower measured concentrations in the afternoon (Fig. 16a). The effect was more dramatic for the 0 m (surface) sample as compared with the 2 m sample, consistent with the higher photon flux near the water surface. Sunlight, especially UV, is known to increase the rate of bacterial inactivation in natural waters. That being said, it is interesting to note that the fecal coliform bacterial concentrations exhibited rather different behavior, where levels were at a minimum near 2 a.m. and increased rather markedly toward dawn (Fig. 16b). Concentrations then appeared to decrease slightly near noon, although levels remained high, near 8000 cfu/100 mL, throughout the afternoon. Enterococcus concentrations remained low throughout the measurement period (typically <6 cfu/100 mL) and did not reveal an apparent diurnal trend (data not shown).

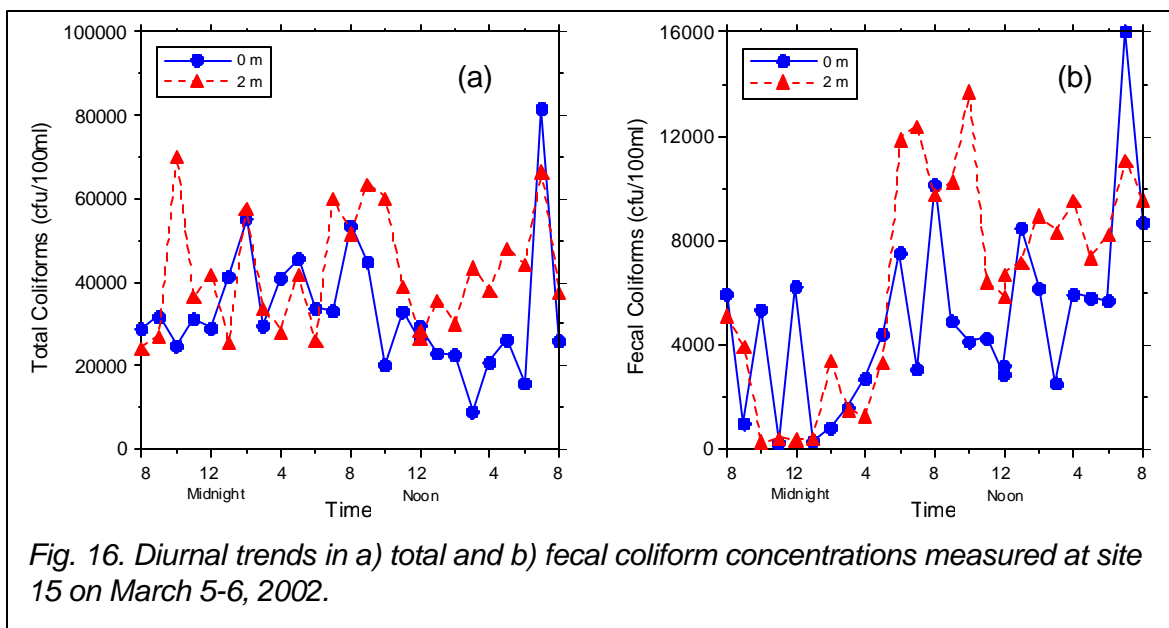
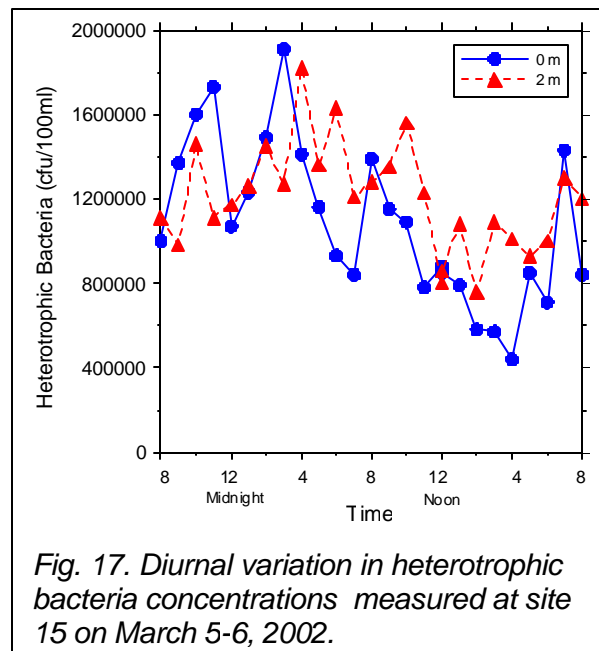


Fig. 16. Diurnal trends in a) total and b) fecal coliform concentrations measured at site 15 on March 5-6, 2002.

Measurements of heterotrophic bacteria revealed a behavior unlike either total coliform or fecal coliform bacteria, and in fact exhibited a trend almost exactly opposite that of the fecal coliform bacteria (Fig. 17). That is, heterotrophic bacterial

concentrations increased during the night, reached a maximum of 1.8×10^6 cfu/100 mL near 4 a.m., and then decreased for the next 12 hours to reach a minimum of about 8×10^5 cfu/100 mL in middle-to-late afternoon (Fig. 17). Such behavior is consistent with conventional wisdom about increased rates of bacterial inactivation in bright sunlight, and reduced inactivation rates and increased repair and reproduction during nighttime. Nevertheless, more research is needed to understand the different observed diurnal trends in bacterial concentrations in Canyon Lake.

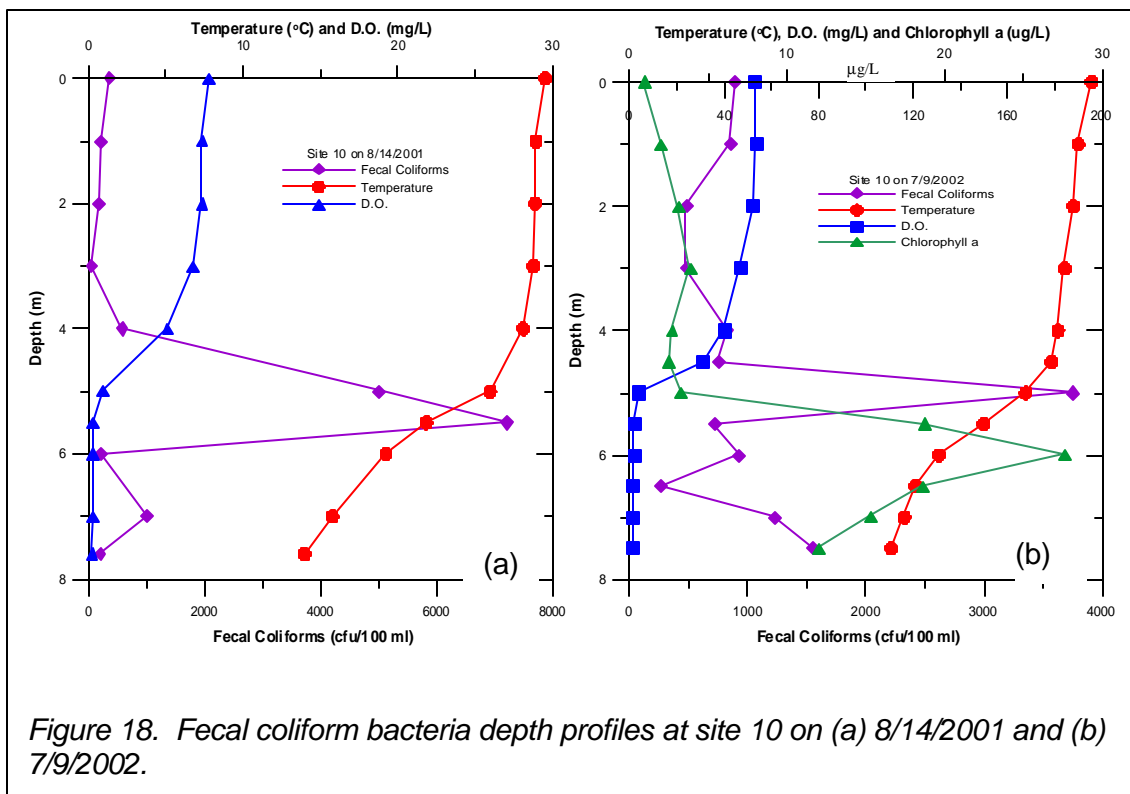


3.3.3 Vertical Distribution of Indicator Bacteria

As previously noted, bacteria concentrations near the thermocline were significantly higher than surface or bottom samples (except for total coliform bacteria at the deep water sites) (Table 2). Profiles collected in August 2001 and July 2002 at site 10 show this quite clearly (Fig. 18). As one can see, fecal coliform bacteria levels remained less than 500 cfu/100 mL in the uppermost 4 meters of the water column, and then sharply increased to over 7,000 cfu/100 mL at a depth of 5.5 meters (Fig. 18a). Fecal coliform bacteria levels then decreased dramatically, to levels less than 1000 cfu/100 mL, at 6-7.5 meters. This sharp increase in fecal coliform bacteria coincides with the thermocline where temperatures decreased from approximately 28°C to less than 15°C near the bottom (7.8 meters at this site).

A very similar trend was found the following summer (e.g., Fig. 18b). For example, during the July 9th 2002 sampling, fecal coliform bacteria levels greater than 3500 cfu/100 mL were found at 5 meters depth, while concentrations in the epilimnion above and the hypolimnion below were considerably lower (generally less

than 1000 cfu/100 mL). A strong gradient in dissolved oxygen concentrations was also present at the thermocline for both sampling dates (Fig. 18) (and other sampling dates and locations not shown). *In situ* chlorophyll a measurements also showed a dramatic increase near the thermocline (Fig. 18b).



Results from samplings at site 13 conducted during the late summer of 2001 and 2002 reveal similar trends as found at site 10, wherein fecal coliform bacteria concentrations near the thermocline were substantially higher than elsewhere in the water column (Fig. 19). Unlike site 10, which showed a single sharp increase in fecal coliform bacteria concentrations, a broader increase in concentration was found, however.

Higher concentrations of dissolved ammonium and soluble reactive phosphorus (SRP) were also found beginning at the thermocline, and increasing through the hypolimnion (Fig. 20). Dissolved nitrate concentrations remained constantly low throughout the profile.

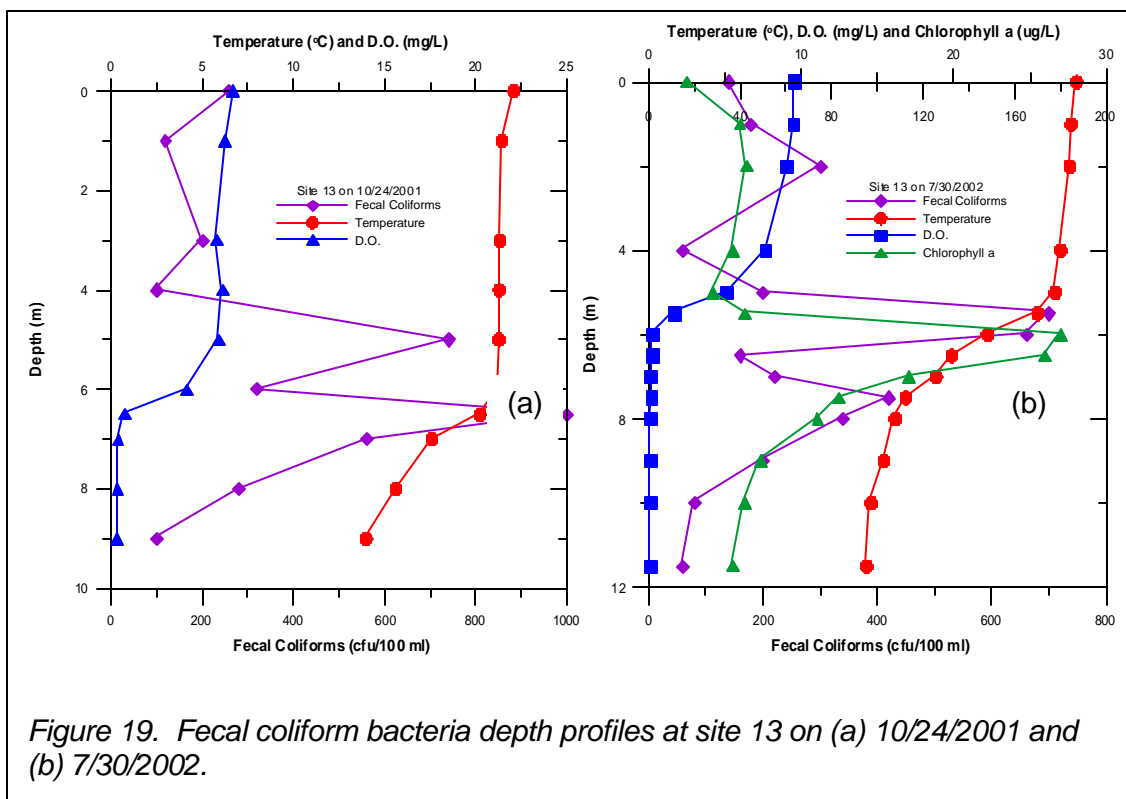


Figure 19. Fecal coliform bacteria depth profiles at site 13 on (a) 10/24/2001 and (b) 7/30/2002.

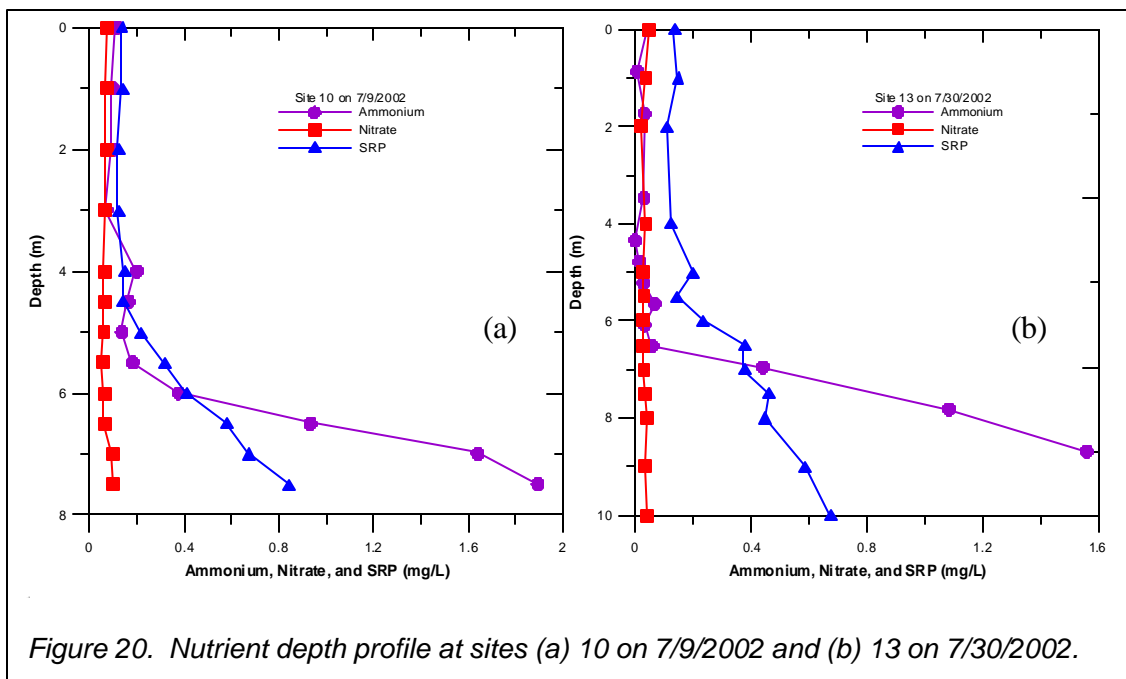


Figure 20. Nutrient depth profile at sites (a) 10 on 7/9/2002 and (b) 13 on 7/30/2002.

Enterococcus concentrations exhibited similar trends with depth as the fecal coliform bacteria, with higher levels near the thermocline (Figs. 21 and 22). Turbidity also showed an increase near the thermocline, although maximum turbidity levels

were reached at depths approximately one meter deeper than maximum enterococcus levels (Fig. 22).

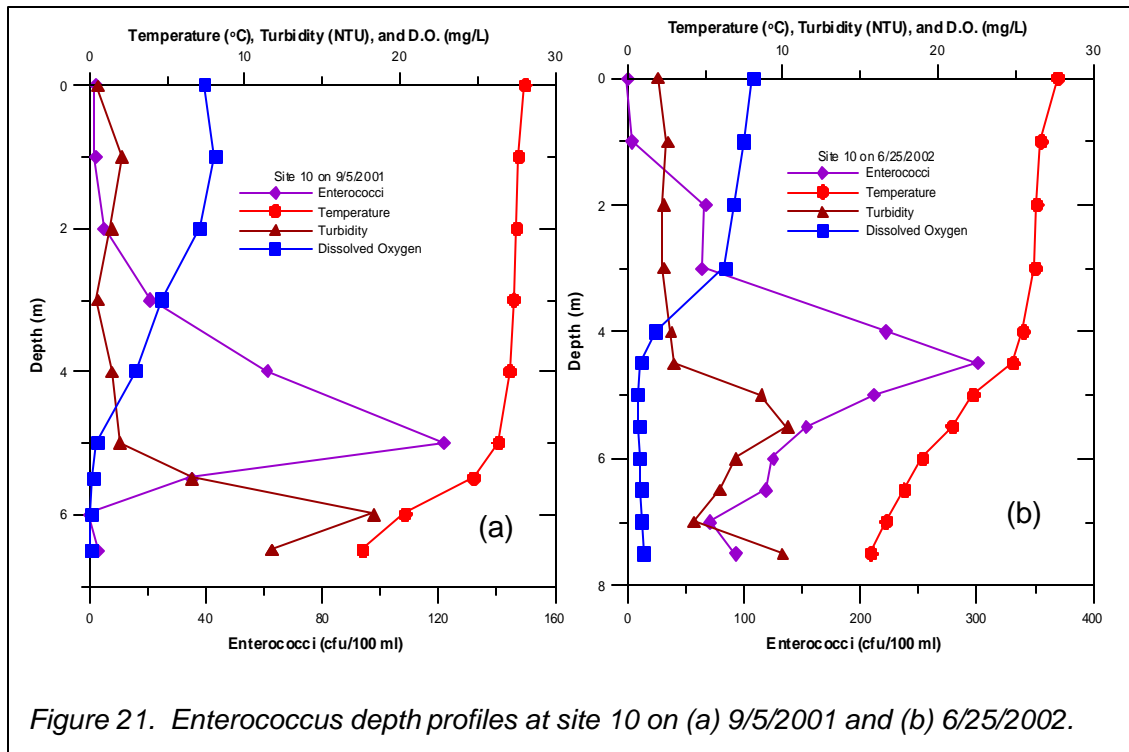


Figure 21. Enterococcus depth profiles at site 10 on (a) 9/5/2001 and (b) 6/25/2002.

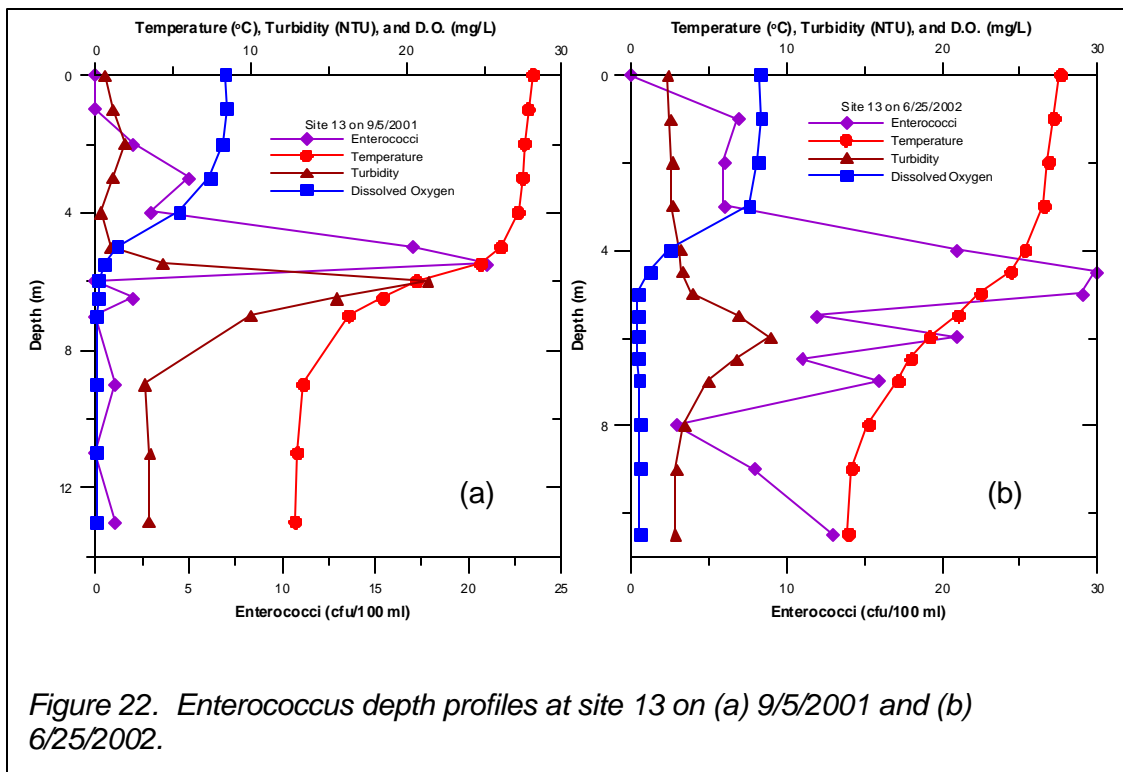
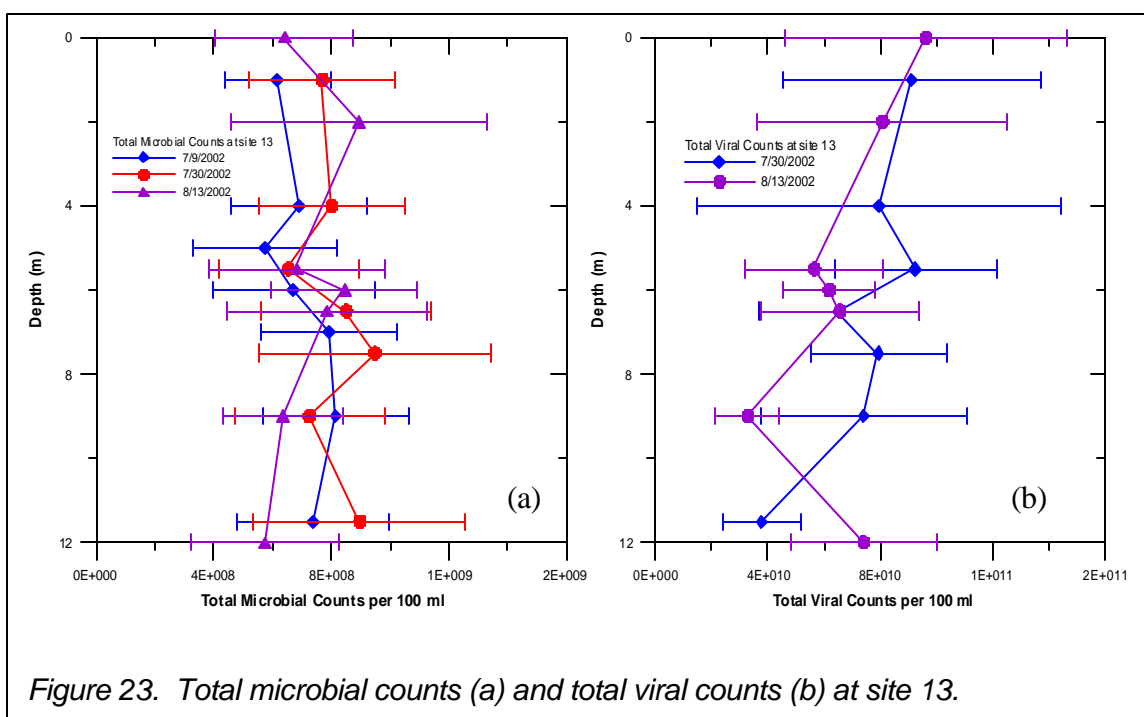


Figure 22. Enterococcus depth profiles at site 13 on (a) 9/5/2001 and (b) 6/25/2002.

The vertical distribution of total bacteria and total viruses did not show the elevated levels at the thermocline found for the indicator organisms, however (Fig. 23). Although analytical variation was relatively high, total bacteria and total virus counts did not appear to vary significantly with depth. This implies that the high bacterial concentrations found at the thermocline is unique to coliforms and enterococci, but not to the entire microbial population. Viruses can be responsible for a large degree of bacteria mortality (Bratbak *et al.*, 1994). However the results displayed in Fig. 23 suggest that bacterivory, or lack of, by viruses is not responsible for the vertical variability in indicator bacteria concentrations. The average total bacteria count is 7.4×10^8 bacterium per 100 mL and average total virus count is 7.1×10^{10} viruses per 100 mL. These values are typical for fresh water systems (Kalff, 2002).



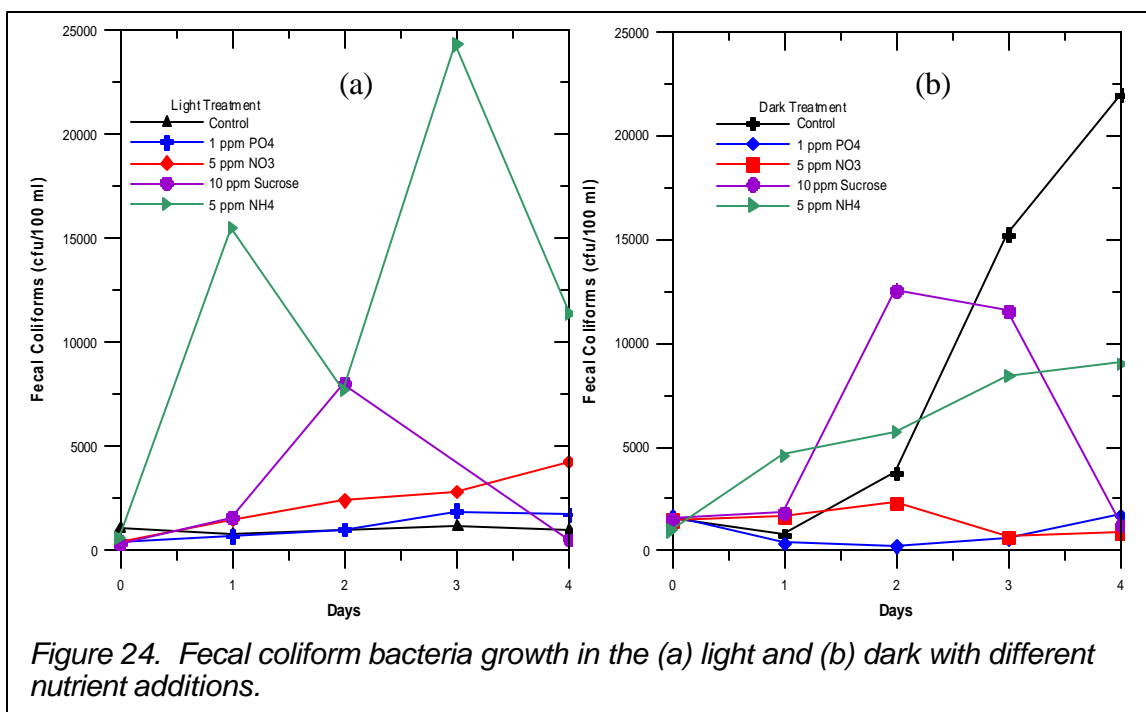
3.3.4 Bacterial Growth Experiments

The elevated concentrations of indicator bacteria at the thermocline may be a result of increased availability of nutrients at depth. To test this hypothesis, lab experiments were conducted in May of 2002 in which Canyon Lake water samples

were incubated at room temperature in the light and in the dark for four days. Samples were amended with ammonium, nitrate, phosphate, and sucrose.

Under a light regime mimicking natural conditions, fecal coliform bacteria levels in the control treatment remained low throughout the duration of the experiment (Fig. 24a). Addition of $\text{PO}_4\text{-P}$ did result in some increased growth. A discernable effect, although modest, on fecal coliform bacteria concentrations was found when samples were amended with 5 ppm $\text{NO}_3\text{-N}$ (Fig. 24a). There was a more significant increase in bacteria levels following addition of 10 ppm sucrose after 2 days, although levels then returned to control levels. Fecal coliform bacteria levels increased most dramatically when incubated in the light with 5 ppm $\text{NH}_4\text{-N}$, although analytical variability was high (Fig. 24a).

Rather different growth response to selected nutrient treatments was found when samples were incubated in the dark (Fig. 24b). Here the control treatment grew exponentially over time, and exceeded 20,000 cfu/100 mL after 4 days. $\text{PO}_4\text{-P}$ and $\text{NO}_3\text{-N}$ additions had no effect on bacteria levels over time, while $\text{NH}_4\text{-N}$ appeared to stimulate fecal coliform bacteria growth, albeit at a slower rate than found under illuminated conditions. Sucrose exhibited broadly similar behavior under both light and dark conditions (Fig. 24).



The specific growth rates (μ) for fecal coliform bacteria in Canyon Lake water with these different nutrient additions are summarized in Table 3. Hendricks (1972) reported coliform bacteria in Oconee River water had a mean specific growth rate of 0.144 d^{-1} . Camper *et al.* (1991) found coliforms isolated from a municipal drinking water distribution system to have a specific growth rate of $0.96\text{-}2.88 \text{ d}^{-1}$ when grown on a mineral salt medium. The specific growth rates of fecal coliform bacteria found for most treatments exceed that found for coliforms in Oconee River water, but all were less than those found for coliforms in water from a distribution system, with the exception of the sucrose treatments after two days of growth. Rice *et al.* (1991) define a substrate as being able to support or moderately support microbial growth if it has a coliform growth response (CGR) greater than 0.51 log units (*i.e.*, can yield a concentration increase of at least 3.2x over 5 days). Based on the experiment described above, Canyon Lake water is capable of supporting microbial growth in the dark without any additional treatment, as well as when supplied with $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$.

Elevated levels of total coliform bacteria were regularly observed at the thermocline and they were also found to grow exponentially in laboratory experiments (*e.g.*, μ of 1.35 and 2.40 d^{-1} for N+P nutrients in the light and dark, respectively), but because they are not as much of a concern from a human health perspective, they were not the primary focus of the growth experiments. *E. coli* were also not included in the growth experiments because of their continued low concentrations in the lake throughout the year.

	Control	PO₄	NO₃	NH₄	Sucrose*	Sucrose**
Light	-0.023	0.362	0.579	0.745	0.128	1.642
Dark	0.663	0.009	-0.130	0.557	-0.051	1.070

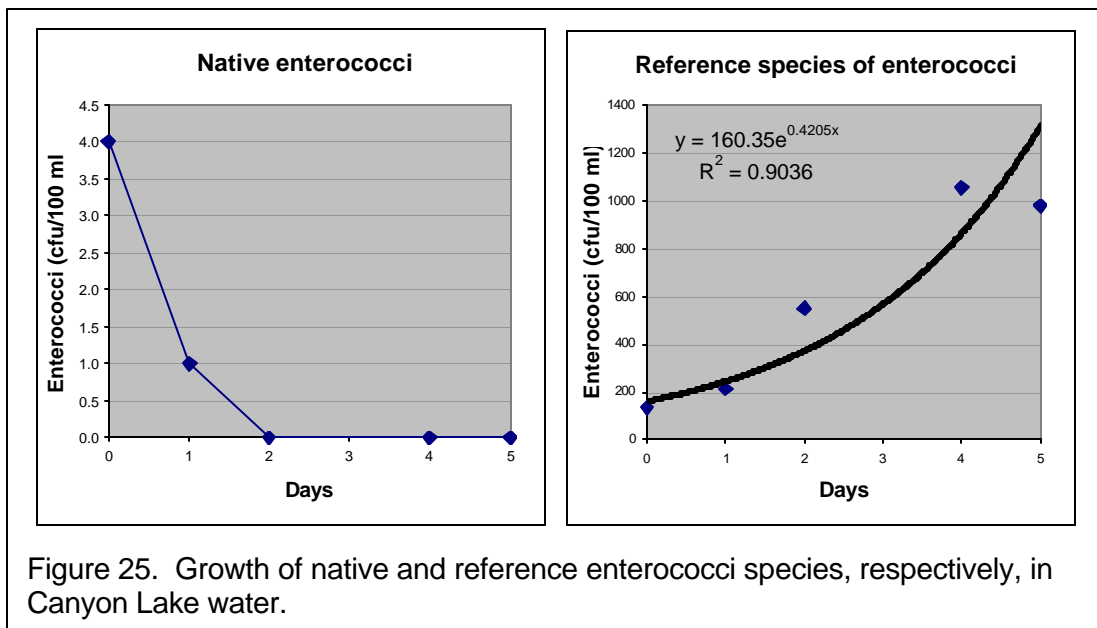
* growth rate for sucrose addition after four days, as reported for other treatments.

**growth rate for sucrose addition after two days.

While it has been shown that fecal coliform bacteria grow in the environment, this has not been observed with enterococci, except in extremely nutrient-rich water (Kenner, 1978). An experiment was conducted to ascertain if indigenous enterococcus species have the ability to grow in Canyon Lake. Four liters of water

was collected from Canyon Lake near site 6. Two liters were filter sterilized through a 0.2 μm filter and inoculated with a laboratory reference species of enterococcus obtained from the ATCC. Two additional liters were not treated and served as an experimental control.

Fig. 25 summarizes the results of this experiment. In the control sample the native enterococci did not grow and, rather, their populations decreased below detection on the second day. The disappearance rate or effective inactivation rate is often used to describe declining bacterial densities because it includes factors such as, sedimentation, predation, dilution and death, without attributing the decline to only one factor (Gannon *et al.*, 1983). The native enterococci had a disappearance rate of 1.39 d^{-1} . Mitchell and Chamberlin (1978) reported a median enterococcus disappearance rate of 0.96 d^{-1} for freshwater systems. In the filter-sterilized sample inoculated with the reference organism, enterococci grew exponentially over a five-day period with a specific growth rate of 0.42 d^{-1} . Thus, in the absence of predation, competition for resources, and other ecological constraints, the reference enterococcus strain was able to grow in the lake water. These results demonstrate that under favorable conditions, some strains of enterococci have the ability to grow in the environment, although under conditions found in Canyon Lake, the native population does not appear to reproduce significantly.



3.3.5 Sediment Resuspension Experiment

As seen in previous figures, East Bay and other shallow embayments tend to have higher bacteria concentrations in comparison to the main body of the lake. One possible source of these bacteria is from the sediments that are resuspended by boating activity, specifically, by prop turbulence. In order to assess the potential contribution of sediments to the bacterial load of the water column, three different amounts of sediment, collected from site 5 using an Ekman dredge, were added to water taken from the same site at three meters below the surface. Samples were left at ambient conditions and mixed twice daily. Table 4 summarizes the results of this experiment. Bacteria concentrations were quite variable for the three organisms tested. Only enterococci had levels higher than that of the control throughout the course of the experiment.

Table 4. Results of sediment resuspension experiment (cfu/100 mL).					
Total Coliforms	Day 0	Day 1	Day 2	Day 3	Day 4
Control	13500	11700	36200	17400	13200
1 gram of soil	13500	7200	16233	9700	5000
10 grams	13500	3600	14200	16600	6750
100 grams	13500	2000	810	2240	1400
Fecal Coliforms	Day 0	Day 1	Day 2	Day 3	Day 4
Control	3825	7050	17133	10800	23000
1 gram of soil	3825	1550	3450	4050	8600
10 grams	3825	1000	940	7800	4000
100 grams	3825	300	1940	8400	10450
Enterococci	Day 0	Day 1	Day 2	Day 3	Day 4
Control	56	35	10	1	2
1 gram of soil	56	53	19	6	12
10 grams	56	50	28	45	407
100 grams	56	100	3	125	329

These results indicate that the lake sediments may contribute to enterococcus concentrations, but are inconclusive as to the sediment's contribution to coliform bacteria concentrations. Nevertheless, bacteria are known to thrive in sediments. Sediments can provide a source of nutrients to bacteria and serve as a protective habitat in aquatic systems (Fish and Pettibone, 1995; Bergstein-Ben Dan and Stone, 1991). Grimes (1980) has demonstrated the resuspension of sediment-bound cells to contribute detectable levels of coliform bacteria to the water column, and thus, their presence at high concentrations are not necessarily indicative a recent fecal contamination event.

3.3.6 Bacteria Concentrations in Watershed

Significant levels of indicator bacteria may also be input from the surrounding watershed (Roll and Fujioka, 1997). At Canyon Lake, these waters can enter both from the San Jacinto and Salt Creek watersheds and through the storm drains surrounding the lake. The community of Canyon Lake was designed such that all runoff eventually flows into the lake. Along the way these waters can pick up bacteria from animal waste, vegetation, and sediments. Table 5 shows indicator bacteria concentrations in local runoff collected from seven storm drains (Fig. 3). Bacteria levels were very high across all drains with the organisms' concentrations (Table 1) about two orders of magnitude higher than corresponding measured lake concentrations (Table 5).

Storm Drain ID	Total Coliforms (cfu/100 mL)	Fecal Coliforms (cfu/100 mL)	Enterococcus (cfu/100 mL)	<i>E. coli</i> (MPN/100 mL)
2	7.8×10^6	5.0×10^6	1.9×10^5	
14	3.7×10^6	1.5×10^5	1.7×10^4	2.4×10^3
29	5.7×10^5	1.2×10^5	1.3×10^4	
31	3.2×10^6	2.2×10^5	4.9×10^3	
38	1.4×10^6	1.3×10^5	5.1×10^3	1.1×10^2
40	4.2×10^6	9.8×10^5	5.8×10^4	
50	1.7×10^7	1.7×10^6	1.1×10^5	

The potential importance of local storm drain flows to bacteria levels in East Bay was estimated using the data in Table 5 in conjunction with some estimates of flow. Assuming inputs of bacteria from local runoff and loss due to inactivation, a simple mass balance equation that states that the change in the number of bacteria, N , over time, t , in East Bay (assumed here to be completely mixed both vertically and laterally) can be written:

$$\frac{dN}{dt} = V \frac{dC}{dt} = Q_{in}C_{in} - kCV \quad (1)$$

where V is the volume of East Bay, Q_{in} is the storm drain flow, C_{in} is the bacteria concentrations in the storm drain flow, k is the first-order net disappearance rate constant, and C is the bacteria concentration in East Bay.

Under steady-state conditions (*i.e.*, $dC/dt = 0$), eq 1 reduces to:

$$C_{pred} = \frac{Q_{in}C_{in}}{kV} \quad (2)$$

where C_{pred} is the predicted steady-state bacterial concentration. For example, substituting the average enterococcus concentration in storm drain flow (5.6×10^4 cfu/100 mL) into eq 2, along with an estimate of the total daily volumetric discharge from these drains ($95 \text{ m}^3/\text{d}$), the volume of East Bay ($1.18 \times 10^6 \text{ m}^3$) and the lab-measured disappearance rate (1.39 d^{-1}), one calculates a steady-state enterococcus concentration of 3.2 cfu/100 mL. Using the median inactivation rate constant of 0.96 d^{-1} reported by Mitchell and Chamberlin (1978), one calculates a steady-state concentration of 4.7 cfu/100 mL (Table 6). Results from calculations for the other indicator bacteria are provided in Table 6.

Organism	C_{in} (cfu/100 mL)	k (d^{-1})	C_{pred} (cfu/100 mL)	C_{obsd} (cfu/100 mL)
Total Coliform	5.4×10^6	1.0^a	435	8236
Fecal Coliform	1.2×10^6	1.15^b	84	1684
Enterococcus	5.6×10^4	0.96^a	4.7	10.9
<i>E. coli</i>	1.3×10^3	0.3^c	0.3	0.8

^aMitchell and Chamberlin, 1978; ^bBordalo et al., 2002; ^cNasser and Oman, 1999

Predicted concentrations of indicator bacteria in East Bay due to summer storm drain flows were below the measured mean summer surface values (Table 6). Predicted concentrations of total and fecal coliform bacteria were only about 5 % of the measured values, while the predicted enterococcus concentration was about 50% of the measured geometric mean summer concentration (Table 6). The limited nuisance runoff concentration data for *E. coli* places a substantial uncertainty in the predicted levels based upon external loading from local runoff. In fact, it should be recognized that a relatively large uncertainty exists for all of the predicted concentrations in Table 6. The above predicted concentrations are based upon storm drain flow estimates made on a single sampling date for the 7 drains in Table 5. While these were the primary drains identified as typically flowing (or having shown signs of recently flowed) during routine sampling of East Bay, other drains may also contribute to the loading of bacteria in East Bay. Moreover, some uncertainty surrounds the estimates of daily flow for the drains, especially those that flow only intermittently, e.g., during nearby home sprinkler operation.

Essentially no information is available about storm drain flow to the main body of the lake; nevertheless, simple calculations suggest that storm drain inputs are relatively less important of the main body of the lake. As shown in Fig. 3, only a handful of storm drains were identified as entering the main body of the lake. Nevertheless, assuming cumulative daily flows and concentrations comparable to those in East Bay, the larger mixed volume of the main body (summer epilimnetic volume of about $3.7 \times 10^6 \text{ m}^3$) would reduce the predicted bacteria levels by about 70 %. Thus, a comparable analysis for the main body would predict, e.g., summer fecal coliform and enterococcus concentrations of about 27 and 1.5 cfu/100 mL, respectively.

Notwithstanding the uncertainty in these calculations, it seems clear that local runoff can not be the only source of bacteria to the lake, especially for total and fecal coliform bacteria. Since waterfowl have been identified as a source of bacteria in some surface waters, further assessment may also be in order. Toward that end, fecal material from resident waterfowl were collected on 11/18/01 and analyzed for indicator bacteria (Table 7).

Species	Total Coliform (cfu/g feces)	Fecal Coliform (cfu/g feces)	Enterococcus (cfu/g feces)	Fecal Coliform/Enterococcus
<i>Branta canadensis</i>	5.4x10 ⁵	1.0x10 ⁵	2.1x10 ⁵	0.48
<i>Anas platyrhynchos</i> ^a	8.0x10 ³	4.3x10 ³	9.4x10 ³	0.46

^afecal material was partially dehydrated (i.e., not particularly fresh)

Waterfowl feces are a potentially significant source of indicator bacteria to Canyon Lake as indicated by the high bacterial content of avian feces (Table 7). The Mallard duck feces (*Anas platyrhynchos*) were partially desiccated, with the measured bacterial content well below that reported in other studies (e.g., Geldrich *et al.*, 1962). While a firm population estimate for these waterfowl at the lake is not available, casual observation suggests that perhaps 100 waterfowl are residents during the summer. Manny *et al.* (1994) measured defecation rates of Canada geese and found that geese defecate an average of 1.96 times per hour during the day and 0.37 times per hour at night, with an average mass (M) of 6.3 g per event. Assuming 14 hours of light per day, this translates to a defecation frequency (F) of 31.1 per day and a total fecal loading of 197 g per bird.

Assuming that all of this fecal material is directly or indirectly introduced into the water and that the fecal material disaggregate sufficiently to release all bacteria into the water column, one can write an equation like eq 2 to estimate the concentration of bacteria in the lake due to waterfowl:

$$C_{pred}^{bird} = \frac{N F M C_{feces}}{k V} \quad (3)$$

Using the fecal bacterial contents for Canada geese (*Branta Canadensis*) in Table 7, along with inactivation rate constants from Table 6, and assuming 100 birds (all Canada geese for this calculation) colonize the lake (50 individuals on the main body and 50 on East Bay), one estimates that <1 cfu/100 mL of either fecal coliform or enterococcus bacteria could be attributed to direct waterfowl inputs. Using the higher fecal coliform and enterococcus bacteria concentrations in waterfowl feces reported by Geldrich *et al.* (1962) (3.3x10⁷ and 5.4x10⁷, respectively), one predicts a volume-averaged steady-state fecal coliform concentration in the main body of 7.6 cfu/100 mL. Given the higher relative enterococcus concentration in the feces (Table

5; Geldrich *et al.*, 1962) and slightly lower inactivation rate (Table 5), one estimates an enterococcus concentration of 14.9 cfu/100 mL. What is notable in these calculations is that, while the predicted enterococcus concentration is fortuitously close to the measured level found in the lake (14.9 vs. 15 cfu/100 mL geometric mean concentration), predicted fecal coliform levels remain <1% of the geometric mean concentration found in the study (Table 1). Thus, while nuisance runoff (which may convey bacteria derived from animal waste), as well as direct inputs from waterfowl appear to account for observed levels of enterococcus bacteria found in Canyon Lake, such inputs can not account for the high fecal coliform bacteria levels in the lake.

In addition to the local storm drains that discharge into the lake following sprinkler runoff and rainfall, sites in the upper watershed may also be an input source of indicator bacteria. Table 8 shows the bacteria concentrations measured at the Perris Valley storm drain and on Salt Creek at Murrieta in the San Jacinto Watershed (Fig. 2). During high rainfall events, water from these sites flows into Canyon Lake, although, that did not occur during 2001-2002. These concentrations are thus representative of potential bacterial load in the watershed and appear to be very similar to concentrations found in local runoff (Table 5).

	Total Coliforms (MPN/100mL)		Fecal Coliforms (cfu/100mL)		Enterococci (MPN/100mL)		<i>E. coli</i> (MPN/100mL)	
	12/21/01	1/29/02	12/21/01	1/29/02	12/21/01	1/29/02	12/21/01	1/29/02
Salt Creek at Murrieta	>9677	>241920	>8000	>16000	>3226	3130	1741	1150
Perris Valley Storm Drain	>9677	>241920	>8000	>16000	>3226	15400	286	3535

3.3.7 Predicted Recreator Risk

The California Department of Health Services (DHS) has developed numeric standards and guidance for indicator bacteria in freshwater beaches to protect recreator health. Beach posting or closure is recommended when indicator organism levels exceed any of the following single-sample levels (Table 9):

Organism	Concentration (cfu or MPN/100 mL)	
	Single-Sample	Thirty-Day Avg
Total coliform	10,000	1,000
Fecal coliform	400	200
Enterococcus	61	33
<i>E. coli</i>	235	126

Thirty-day averages provide clues about natural variations in the bacterial levels, and with longer-term sampling, can provide valuable information about background levels, point and non-point sources of bacteria, and other factors important for a particular recreational area.

It was noted in Section 3.3.2 that the total and fecal coliform bacteria levels in Canyon Lake routinely exceeded both the single-sample and 30-day limits (e.g., Figs.12 and 13), although enterococcus and *E. coli* levels were generally below DHS guidance values (Fig. 14 and 15).

It has been previously noted that fecal and total coliform bacteria are not particularly useful indicators of fecal contaminations of surface waters. For example, in a comprehensive epidemiological study, DuFour (1984) found no statistically significant correlation between highly-credible gastrointestinal illness and fecal coliform bacteria concentration ($R=0.081$), which led him to conclude that bacteria from other sources were sufficiently high to eliminate their usefulness as an indicator of fecal contamination. *Klebsiella*, a member of the fecal coliform group, has been found to grow to high densities in pulp mill wastes, textile processing plant wastes and other waste streams. DuFour (1984) reported *Klebsiella* accounted for 17-73% of the fecal coliform bacteria found in Lake Erie.

In contrast to fecal coliform bacteria, however, DuFour (1984) reported a strong correlation between *E. coli* concentrations and swimming-associated gastroenteritis ($R=0.804$). Enterococcus concentrations were also significantly correlated with highly-credible gastrointestinal illness ($R=0.744$). The results of this comprehensive epidemiological study allow one to estimate the rate of swimming-associated gastroenteritis among body-contact recreators. Specifically, the incidence of gastroenteritis, Y (cases/1000 swimmers) was related to *E. coli* concentration, X (cfu/100 mL) by the relationship (Dufour, 1984):

$$Y = 9.397 \log X - 11.74 \quad (3)$$

Similarly, gastrointestinal illness (Y) was related to the enterococcus concentration, Z (cfu/100 mL) by:

$$Y = 9.40 \log Z - 6.278 \quad (4)$$

These relationships were used with the previously presented monitoring data to calculate the risk of gastrointestinal illness resulting from body-contact recreation on Canyon Lake (Table 10).

Organism	Annual	Summer '01	Fall '01	Winter '02	Spring '02
Enterococcus	4.8	4.8	6.5	2.7	5.0
<i>E. coli</i>	<0.1	NA	<0.1	<0.1	<0.1

The geometric mean enterococcus concentration of 15 cfu/100 mL (Table 1) yielded a predicted recreator risk of 4.8 illnesses per 1000 swimmers (Table 10). Data split into the summer, fall, winter and spring seasons suggest slightly higher risk of infection during the fall (6.5 illnesses per 1000 recreators) than the winter (2.7 illnesses per 1000 recreators).

A similar analysis conducted using the measured *E. coli* concentrations suggests much lower risk levels (<0.1 cases per 1000 body-contact recreators) than predicted based upon geometric mean enterococcus concentrations (Table 8). While it is difficult to reconcile the differences in predicted recreator risk levels using these 2 organisms, these risk levels are nevertheless below the acceptable gastroenteritis rate of 8 cases per 1000 for the EPA target.

While geometric mean concentrations represent the average risk levels over the appropriate temporal and/or spatial scale, it is useful to also consider the data (e.g., Figs. 14 and 15) in more detail. For example, surface water samples from Canyon Lake exceeded the single-sample limit for enterococci 35 times, or 12% of the time, with 24 excursions above the limit associated with samples collected from East Bay. As previously noted, however, *E. coli* numbers were consistently below the corresponding single-sample limit of 235 cfu/100 mL.

4. Discussion

Annual geometric mean concentrations for total and fecal coliform bacteria were very high at 8445 cfu/100 mL and 858 cfu/100 mL, respectively. Conversely, enterococcus and *E. coli* annual geometric mean concentrations were quite low (15 cfu/100 mL and 3 cfu/100 mL, respectively). Bacteria concentrations were consistently higher in East Bay and embayments off of the main body when compared with sites near the middle of the main body of the lake.

Although total and fecal coliform bacteria concentrations were high throughout the year, they did exhibit some temporal trends, with noticeably higher levels at all sites on the February 26, 2002 and July 9, 2002 sampling dates (Figs. 12 and 13). The high levels found in February might be attributed to rainfall and runoff into the lake, although the meteorological record did not show any substantial rainfall immediately preceding this sampling period. In fact, weather records for Temecula and UCR meteorological stations indicated no rainfall had fallen since February 17th (9 days prior) (CIMIS, 2002). Given the high rate of disappearance of bacteria in most waters, any fecal coliform bacteria washed into the lake would, in theory, have been reduced to 0.1 – 1 % of their initial concentrations (assuming a winter disappearance rate of about 0.5 – 0.7 d⁻¹). This implies an alternate source of total and fecal coliform bacteria is responsible for the high levels found on this date.

Leaking sewage lines or pump stations are one possible source, although it is notable that fecal and total coliform levels were unusually high across essentially all monitoring stations (Figs. 12 and 13), while enterococcus and *E. coli* concentrations remained low (Figs. 14 and 15). A leak would presumably result in high concentrations in area(s) nearest the source area, with concentrations decreasing with increasing distance from the source. This would be particularly true for East Bay, where the complex shoreline, very limited fetch, and high degree of wind sheltering, would limit mixing.

Moreover, a sewage leak would be expected to increase concentrations of all the indicator bacteria, including *E. coli* and enterococcus. In human waste, *E. coli* comprise a large portion of the fecal coliform bacteria, while enterococcus levels are generally found at slightly lower concentrations. For example, Baggi *et al.* (2001) reported fecal coliform concentrations of 1.6×10^7 cfu/100 mL and enterococcus

concentrations of 5.0×10^6 cfu/100 mL in raw sewage. Tyrrel *et al.* (1995) found somewhat lower levels of the organisms in secondary effluent (approximately 6×10^4 and 1×10^4 cfu/100 mL for fecal coliform and enterococcus, respectively). Nevertheless, fecal coliform:enterococcus ratios of 3:1 (Baggi *et al.*, 2001) to 6:1 (Tyrrel *et al.*, 1995) are much lower than found in Canyon Lake, which more typically averaged about 60:1. In a contaminated bathing beach, Calderon *et al.* (1991) found *E. coli* to account for about 80% of the fecal coliform, offering further indirect evidence for a non-fecal source of bacteria in Canyon Lake, since *E. coli* routinely accounted for less than 0.5% of the fecal coliform found in the lake. Calderon *et al.* (1991) also reported an average fecal coliform:enterococcus ratio of approximately 4:1, in good agreement with found by Baggi *et al.* (2001) and Tyrrel *et al.* (1995). Based upon these considerations, a sewage leak does not appear to be responsible for the high levels found in February 2002.

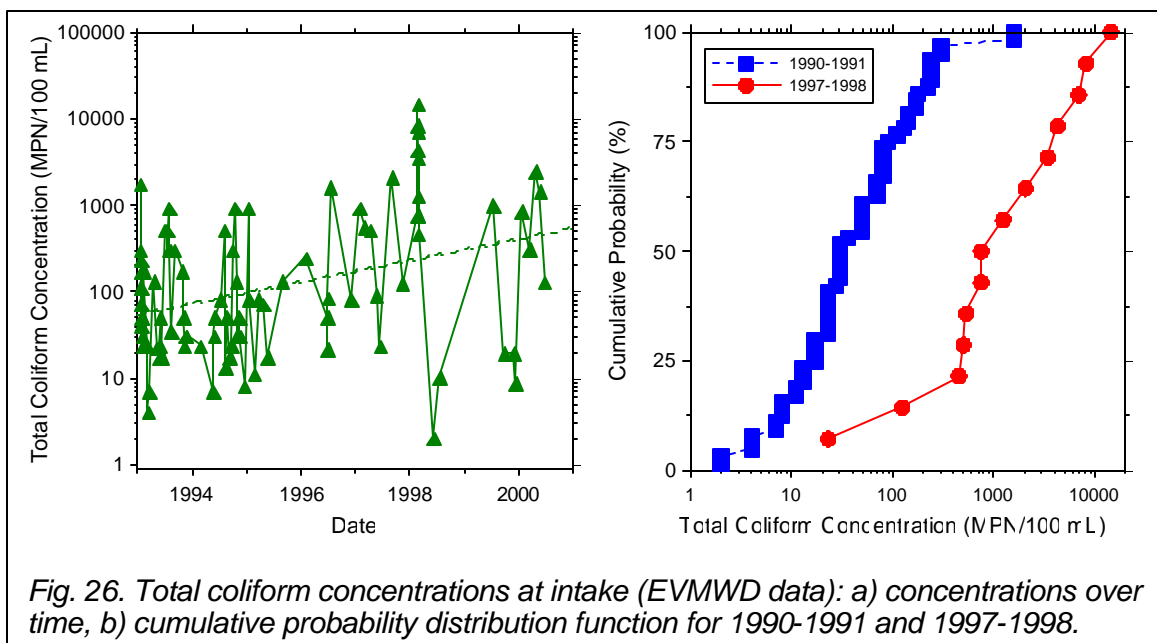
A large number of waterfowl were found on the lake during this sampling time, although as previously discussed, one would expect higher enterococcus levels if the bacteria were derived from an avian source. While waterfowl may be a source of enterococcus bacteria, it appears that growth of total and fecal coliform bacteria within the lake is principally responsible for their consistently high levels.

High levels of total and fecal coliform bacteria were also found on the July 9, 2002 sampling date, although concentrations were also elevated in August-September of 2001 (Figs. 12 and 13). For the same reasons as articulated above (*i.e.*, high levels found at all sites, and bacterial ratios not consistent with human sewage contamination), sewage leaks or spills are not considered likely sources of bacteria to the lake over this time period. Although limited numbers of waterfowl were present during the summer months, body-contact recreational use is comparatively high and might be considered a source of bacteria. As discussed above, however, the low numbers of *E. coli* and enterococcus relative to fecal coliform are not consistent with fecal contamination (Calderon *et al.*, 1991). One is again led to conclude that ecological conditions within the lake promote the proliferation of high populations of total and fecal coliform bacteria. It is specifically hypothesized that non-fecally derived *Klebsiella* is a major component of the coliform bacterial community in Canyon Lake, although other organisms may also be present.

Since conditions at the lake can change over time, it is helpful to review the available historical bacterial data collected by EVMWD. Data provided by D. Neiter of the Santa An RWQCB in the form of a spreadsheet entitled Canyon Lake Coliform.xls served as the basis for this analysis.

The available records provide data about total coliform and *E. coli* bacteria concentrations from a number of sites across the lake. Concentrations at the plant intake have been measured most frequently, with a continuous (weekly to monthly) record of total coliform since 1990 and *E. coli* since 1993. A continuous record for the other sites does not start until March, 1998. Since the intake site has the most extensive bacteriological record, analysis will largely focus on this site. It bears noting up front that total coliform levels periodically exceeded the EVMWD maximum detection limit (>200.5, >1600, or >2419 MPN/100 mL) depending upon measurement date. Since the numeric value for a concentration above the maximum detection limit is not known, they are not included in subsequent time-series plots and thus reduces the data content of the figures. *E. coli* concentrations were always within the detection range, however, so more credence is placed upon this data.

Total coliform bacteria levels earlier in the decade typically varied between 20 and 400 MPN/100 mL, although higher levels, in some instances exceeding the 1600 MPN/100 mL, were occasionally witnessed (Fig. 26a).



Concentrations have increased since then, with the best-fit line putting recent levels at least 1-order of magnitude higher than the 1993 level. Again, the limited data, especially past 1998, is due to the frequent excursions above the maximum detection level (>200 MPN/100 mL for most of this time period). Thus, Fig. 26 under-represents recent total coliform levels in the lake.

A detection level of 1600 MPN/100 mL was in place in 1997 to early 1998, however, so this interval was compared with the 1990-1991 period; specifically, cumulative probability distribution functions (cdf) were developed for both monitoring periods (Fig. 26b). As one can see, the cdf was shifted to significantly higher total coliform levels in 1997-1998 relative to the 1990-1991 period. The median concentration (*i.e.*, the concentration coinciding with the 50% cumulative probability) increased from 30 MPN/100 mL to 750 MPN over this interval. Peak levels were also correspondingly higher. This analysis thus clearly indicates that total coliform bacteria levels in the lake have increased significantly over the past decade.

In contrast, available monitoring data from EVMWD indicate that *E. coli* levels have not changed substantively over the past decade, with the best-fit line having negligible slope (Fig. 27).

Nevertheless, high levels of *E. coli* in the lake were periodically found (Fig. 27). Rainfall data shows that high *E. coli* levels were often associated with rainfall events (Fig. 27b). For example, the highest *E. coli* levels found (>1000 MPN/100 mL) were associated with the El Niño of 1998. High levels were also found during the 1993 El Niño period, although in nearly all cases, *E. coli* concentrations increased markedly from low summertime levels (often <1 MPN/100 mL) to high wintertime concentrations (Fig. 27). Thus, it appears that loading from the upper watershed during periods of average to high runoff tends to dominate the *E. coli* levels in the lake, although storm sewer overflows and other sources closer to the lake may also be operating under such conditions. Importantly, however, irreversible loss processes rather rapidly remove *E. coli* from the lake, so unlike nutrients, which are capable of being recycled, bacterial contaminants represent a comparatively short-lived water quality concern. The loss of indicator bacteria can mask human health risks, however, since pathogens such as *Cryptosporidium* can be quite long-lived in aquatic systems, often surviving weeks to months (Carrington and Ransome, 1994).

Profile data have shown a significantly higher concentration of coliform bacteria and enterococci at the thermocline. Subsequent studies have also confirmed that total and fecal coliform bacteria are capable of growth in Canyon Lake water. At the thermocline, which behaves as a barrier to the mixing of the waters above and below, concentrations of inorganic nutrients and dissolved organic carbon tend to build up and may support the growth of coliform bacteria. This was seen in Figure 19, where ammonium and phosphate concentrations increase starting at the thermocline. The availability of nutrients would also explain the high algal production,

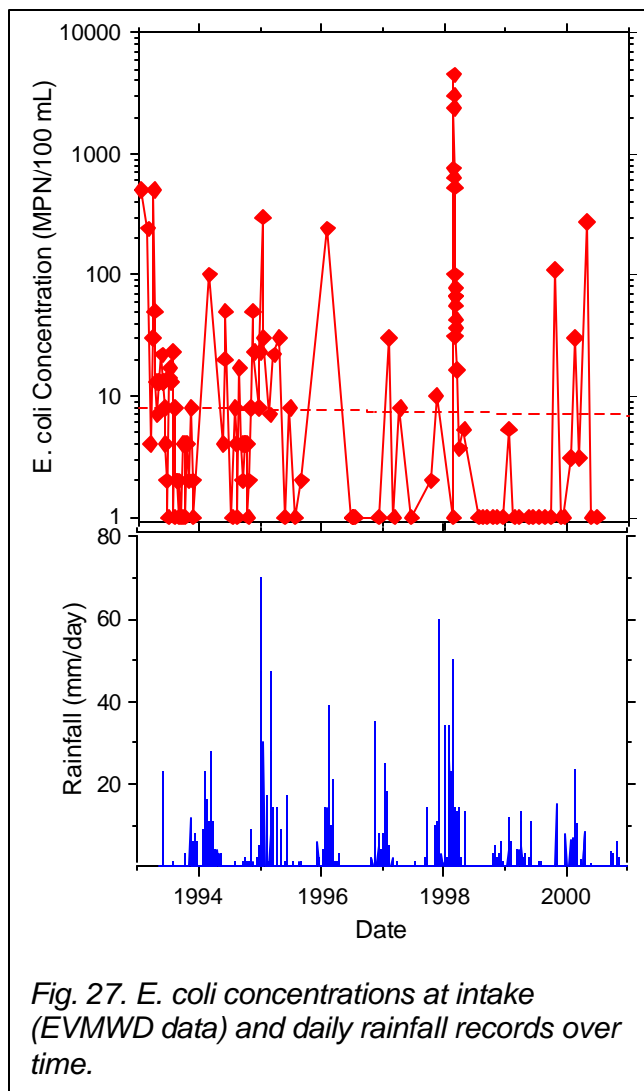


Fig. 27. *E. coli* concentrations at intake (EVMWD data) and daily rainfall records over time.

as measured by chlorophyll *a*, observed at the thermocline. Studies have shown a positive correlation between bacteria and chlorophyll *a* in freshwater systems (Weinbauer and Hofle, 1998; Silverman *et al.*, 1983). This occurs, in part, because of dying algal cells that release dissolved organic carbon and other nutrients back into the water column. Low levels of dissolved oxygen at the thermocline may also give the facultative anaerobic coliform bacteria a selective advantage over other strict aerobes in the epilimnion and strict anaerobes in the hypolimnion. Below this zone of elevated metabolic activity, nutrient concentrations increased and chlorophyll *a* and bacteria levels decreased.

Suspended particles also settle at the thermocline, as reflected in the turbidity measurements. Laboratory experiments have shown that the native enterococcus species do not grow in Canyon Lake water; therefore, the observed phenomenon of

increased enterococcus concentrations at the thermocline cannot be attributed to growth and reproduction. However, bacteria are often associated with soil particles and other particulate material (Weiskel *et al.*, 1996; Roll and Fujioka, 1997; Bergstein-Ben Dan and Stone, 1991), so the elevated enterococcus concentrations may be due to the trapping of suspended material at the thermocline. Such processes are probably also at least partially responsible for the elevated fecal coliform levels found there.

Bacterial loading from nuisance runoff is another important mechanism contributing to Canyon Lake's elevated bacterial levels; nuisance runoff is thought to be a particularly important source of enterococcus and *E. coli*, where it may account for 50% or more of these bacteria in East Bay. Model calculations indicate that nuisance runoff probably accounts for only about 5% of the measured total and fecal coliform bacteria in East Bay, however, and <2% of these organisms in the main body of the lake. The higher levels of bacteria in East Bay relative to the main body of the lake is attributed in part to the fact that a majority of the storm drains surrounding Canyon Lake are found in East Bay (Fig. 3). East Bay also has a higher house density per unit shoreline than the main body of the lake, so it can be inferred that there is more runoff being generated and more animal waste and other sources of bacteria present.

5. Conclusions

Canyon Lake was characterized by high levels of total and fecal coliform bacteria throughout the year, although enterococcus and *E. coli* concentrations remained low. Thus, these 4 commonly used bacterial indicators provide contradictory representations of water quality in the lake. Simple model calculations indicate that nuisance runoff and waterfowl were the dominant sources of enterococcus and *E. coli* over the study period. Nuisance runoff and waterfowl were also identified as sources of coliform bacteria to the lake, although such inputs are thought to be small in comparison to internal production of bacteria. Specifically, the corpus of data supports the notion that growth of bacteria within the total and fecal coliform groups is maintaining high levels of these bacteria in Canyon Lake. It is

postulated that non-fecally derived *Klebsiella* are an important component of the coliform community within the lake, although other organisms may also be responsible. Leaking sewer lines and body-contact recreators do not appear to have been important sources of bacteria in 2001-2002, given the observed broadly uniform distribution of indicator bacteria across the lake and the low measured levels of enterococci and *E. coli* relative to the high total and fecal coliform bacteria concentrations found. As a result, it is concluded that total and fecal coliform bacteria are not particularly useful indicators of water quality in Canyon Lake. Use of enterococcus and *E. coli* is recommended.

6. Acknowledgments

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8. Appendices

Table A-1 shows the results of field splits with EVMWD on three dates. Overall there was good agreement between the two laboratories with the exception of the total coliform bacteria analysis on July 16, 2002. On this date the samples were not analyzed by EVMWD, but by Babcock Laboratories.

Site	October 30, 2001		February 12, 2002				July 16, 2002			
	Total Coliforms (cfu or MPN/100 mL)		Total Coliforms (MPN/100 mL)		<i>E. coli</i> (MPN/100 mL)		Total Coliforms (cfu or MPN/100 mL)		<i>E. coli</i> (MPN/100 mL)	
	UCR	EVMWD	UCR	EVMWD	UCR	EVMWD	UCR	EVMWD	UCR	EVMWD
1	15,600	17,329	866	855	2	3	8000	30	2	7
3	40,000	14,080	17,329	10,462	8.5	8.5	56,000	170	6	8
8	440	2,920	>2,419	14,136	<1	3	5,000	70	6	23
14	520	4,160	>2,419	>2,419	1	4.1	3,000	14	1	<2
15	480	1,789	1,300	921	1	<1	37,000	130	2	4

Tables A2-A5 summarize the annual analysis of duplicates. Out of 354 duplicate pairs for total and fecal coliforms, enterococci and *E. coli*, twenty one pairs were found to be outside of the acceptable range of variance for an acceptance range >94%.

Table A-2. Total coliform bacteria duplicate analysis from biweekly spatial sampling.

Site I.D.	Date	Depth (m)	Duplicate Analyses		Logarithms of Counts		Range of Logarithms (L1-L2)	Acceptance of Range (A or U)
			D1	D2	L1	L2		
3	08/29/01	0.0	214	185	2.330	2.267	0.063	A
3	08/29/01	1.8	188	192	2.274	2.283	0.009	A
3	09/11/01	0.0	24	28	1.380	1.447	0.067	A
3	09/11/01	1.5	166	225	2.220	2.352	0.132	A
3	09/26/01	0.0	28	18	1.447	1.255	0.192	A
3	09/26/01	1.5	77	96	1.886	1.982	0.096	A
12	08/29/01	0.0	49	41	1.690	1.613	0.077	A
12	08/29/01	5.5	205	205	2.312	2.312	0.000	A
12	08/29/01	6.1	279	241	2.446	2.382	0.064	A
12	09/11/01	0.0	109	54	2.037	1.732	0.305	A
12	09/11/01	6.0	50	70	1.699	1.845	0.146	A
12	09/11/01	7.5	66	43	1.820	1.633	0.186	A
12	09/26/01	0.0	12	17	1.079	1.230	0.151	A
12	09/26/01	6.0	17	23	1.230	1.362	0.131	A
12	09/26/01	7.5	14	16	1.146	1.204	0.058	A
3	10/17/2001	0.0	2000	1960	3.301	3.292	0.009	A
3	10/30/2001	0.0	41600	39100	4.619	4.592	0.027	A
3	11/28/2001	0.0	9800	8200	3.991	3.914	0.077	A
3	12/17/2001	0.0	5300	3800	3.724	3.580	0.144	A
3	10/17/2001	1.4	22800	29600	4.358	4.471	0.113	A
3	10/30/2001	1.5	49100	45300	4.691	4.656	0.035	A
3	11/28/2001	1.0	11000	9400	4.041	3.973	0.068	A
3	12/17/2001	1.5	7800	6900	3.892	3.839	0.053	A
12	10/17/2001	0.0	2500	3380	3.398	3.529	0.131	A
12	10/30/2001	0.0	700	800	2.845	2.903	0.058	A
12	11/14/2001	0.0	1100	1360	3.041	3.134	0.092	A
12	11/28/2001	0.0	4300	2700	3.633	3.431	0.202	A
12	12/17/2001	0.0	1400	1440	3.146	3.158	0.012	A
12	10/17/2001	6.0	6600	300	3.820	2.477	1.342	U
12	10/30/2001	6.5	660	720	2.820	2.857	0.038	A
12	11/14/2001	7.5	2500	2400	3.398	3.380	0.018	A
12	11/28/2001	7.5	2600	4900	3.415	3.690	0.275	A
12	12/17/2001	6.0	1640	1380	3.215	3.140	0.075	A
12	10/17/2001	6.8	4100	100	3.613	2.000	1.613	U
12	10/30/2001	9.0	420	160	2.623	2.204	0.419	A
12	11/14/2001	9.0	2020	1440	3.305	3.158	0.147	A
12	11/28/2001	9.0	4800	2300	3.681	3.362	0.320	A
12	12/17/2001	9.0	1480	1540	3.170	3.188	0.017	A
3	1/30/2002	0.0	2400	2800	3.380	3.447	0.067	A
3	2/26/2002	0.0	21000	28000	4.322	4.447	0.125	A
3	3/13/2002	0.0	12400	5600	4.093	3.748	0.345	A
3	1/30/2002	1.5	3100	3000	3.491	3.477	0.014	A
3	2/12/2002	1.5	16700	17700	4.223	4.248	0.025	A
3	2/26/2002	1.5	74000	108000	4.869	5.033	0.164	A
3	3/13/2002	1.5	18200	16200	4.260	4.210	0.051	A
3	3/26/2002	1.5	8000	1000	3.903	3.000	0.903	U
12	2/12/2002	0.0	87000	92000	4.940	4.964	0.024	A
12	2/26/2002	0.0	266000	324000	5.425	5.511	0.086	A
12	3/13/2002	0.0	114000	111000	5.057	5.045	0.012	A
12	3/26/2002	0.0	67000	61000	4.826	4.785	0.041	A
12	1/30/2002	3.0	5900	5200	3.771	3.716	0.055	A
12	2/12/2002	6.0	80000	85000	4.903	4.929	0.026	A
12	2/26/2002	6.0	108000	32000	5.033	4.505	0.528	U
12	3/13/2002	6.0	156000	154000	5.193	5.188	0.006	A
12	3/26/2002	6.0	44000	49000	4.643	4.690	0.047	A
12	2/12/2002	9.0	55000	36000	4.740	4.556	0.184	A
12	2/26/2002	9.0	33000	64000	4.519	4.806	0.288	A
12	3/13/2002	9.0	174000	232000	5.241	5.365	0.125	A
12	3/26/2002	9.0	97000	72000	4.987	4.857	0.129	A
3	4/9/2002	0.0	62200	52000	4.794	4.716	0.078	A
3	4/9/2002	2.0	49700	48400	4.696	4.685	0.012	A
12	4/9/2002	0.0	4600	3000	3.663	3.477	0.186	A
12	4/9/2002	5.0	6500	5200	3.813	3.716	0.097	A
12	4/9/2002	9.0	46600	54000	4.668	4.732	0.064	A
3	5/1/2002	0.0	7000	17250	3.845	4.237	0.392	A
3	5/1/2002	1.5	8700	8500	3.940	3.929	0.010	A
12	5/1/2002	0.0	2500	2550	3.398	3.407	0.009	A
12	5/1/2002	6.0	2900	3500	3.462	3.544	0.082	A
12	5/1/2002	10.0	8550	10400	3.932	4.017	0.085	A
3	5/14/2002	0.0	3050	2900	3.484	3.462	0.022	A
3	5/14/2002	2.0	9300	10250	3.968	4.011	0.042	A
12	5/14/2002	0.0	8450	7500	3.927	3.875	0.052	A
12	5/14/2002	5.0	15900	14800	4.201	4.170	0.031	A
12	5/14/2002	10.0	6600	9100	3.820	3.959	0.139	A
3	5/29/2002	0.0	18400	19750	4.265	4.296	0.031	A
3	5/29/2002	2.0	25500	29950	4.407	4.476	0.070	A
12	5/29/2002	0.0	5350	4400	3.728	3.643	0.085	A
12	5/29/2002	5.0	3250	5050	3.512	3.703	0.191	A
12	5/29/2002	9.0	4350	5500	3.638	3.740	0.102	A
3	6/10/2002	0.0	5800	5850	3.763	3.767	0.004	A
3	6/10/2002	1.5	7500	7950	3.875	3.900	0.025	A
12	6/10/2002	0.0	5650	4850	3.752	3.686	0.066	A
12	6/10/2002	5.0	14200	12200	4.152	4.086	0.066	A
12	6/10/2002	10.0	6000	4300	3.778	3.633	0.145	A
3	7/2/2002	0.0	14700	19500	4.167	4.290	0.123	A
3	7/2/2002	1.5	19600	13300	4.292	4.124	0.168	A
12	7/2/2002	0.0	167000	132000	5.223	5.121	0.102	A
12	7/2/2002	5.0	112000	127000	5.049	5.104	0.055	A
12	7/2/2002	9.5	209000	153000	5.320	5.185	0.135	A
3	7/16/2002	0.0	57300	44400	4.758	4.647	0.111	A
3	7/16/2002	2.0	57000	45100	4.756	4.654	0.102	A
12	7/16/2002	0.0	2100	3500	3.322	3.544	0.222	A
12	7/16/2002	5.0	9100	6100	3.959	3.785	0.174	A
12	7/16/2002	9.0	46900	32700	4.671	4.515	0.157	A
					Range mean:		0.145	
					Precision Criteria:		0.475	

Table A-3. Fecal coliform bacteria duplicate analysis from biweekly spatial sampling.

Site I.D.	Date	Depth (m)	Duplicate Analyses		Logarithms of Counts		Range of Logarithms (L1-L2)	Acceptance of Range (A or U)
			D1	D2	L1	L2		
3	08/29/01	0	254	232	2.405	2.365	0.039	A
3	08/29/01	1.8	72	226	1.857	2.354	0.497	A
3	09/11/01	0	107	118	2.029	2.072	0.042	A
3	09/11/01	1.5	70	25	1.845	1.398	0.447	A
3	09/26/01	0	8	12	0.903	1.079	0.176	A
3	09/26/01	1.5	33	47	1.519	1.672	0.154	A
12	08/29/01	0	464	423	2.667	2.626	0.040	A
12	08/29/01	5.5	307	283	2.487	2.452	0.035	A
12	08/29/01	6.1	274	244	2.438	2.387	0.050	A
12	09/11/01	0	4	4	0.602	0.602	0.000	A
12	09/11/01	6.0	1	13	0.000	1.114	1.114	U
12	09/11/01	7.5	10	1	1.000	0.000	1.000	U
12	09/26/01	0	7	43	0.845	1.633	0.788	A
12	09/26/01	6.0	308	197	2.489	2.294	0.194	A
12	09/26/01	7.5	8	5	0.903	0.699	0.204	A
3	10/17/2001	0.0	3560	2580	3.551	3.412	0.140	A
3	10/30/2001	0.0	20	180	1.301	2.255	0.954	U
3	11/14/2001	0.0	3120	140	3.494	2.146	1.348	U
3	11/28/2001	0.0	300	200	2.477	2.301	0.176	A
3	12/17/2001	0.0	1000	880	3.000	2.944	0.056	A
3	10/17/2001	1.4	14400	14700	4.158	4.167	0.009	A
3	10/30/2001	1.5	1580	1040	3.199	3.017	0.182	A
3	11/14/2001	1.5	5900	2480	3.771	3.394	0.376	A
3	11/28/2001	1.0	500	800	2.699	2.903	0.204	A
3	12/17/2001	1.5	2140	1200	3.330	3.079	0.251	A
12	10/17/2001	0.0	640	920	2.806	2.964	0.158	A
12	10/30/2001	0.0	520	340	2.716	2.531	0.185	A
12	11/14/2001	0.0	100	200	2.000	2.301	0.301	A
12	11/28/2001	0.0	300	260	2.477	2.415	0.062	A
12	12/17/2001	0.0	460	340	2.663	2.531	0.131	A
12	10/17/2001	6.0	3500	2300	3.544	3.362	0.182	A
12	10/30/2001	6.5	120	120	2.079	2.079	0.000	A
12	11/14/2001	7.5	120	280	2.079	2.447	0.368	A
12	11/28/2001	7.5	120	40	2.079	1.602	0.477	A
12	12/17/2001	6.0	235	250	2.371	2.398	0.027	A
12	10/17/2001	6.8	1600	620	3.204	2.792	0.412	A
12	10/30/2001	9.0	380	100	2.580	2.000	0.580	A
12	11/14/2001	9.0	600	180	2.778	2.255	0.523	A
12	11/28/2001	9.0	240	140	2.380	2.146	0.234	A
12	12/17/2001	9.0	280	220	2.447	2.342	0.105	A
3	1/9/2002	0.0	270	330	2.431	2.519	0.087	A
3	1/30/2002	0.0	920	810	2.964	2.908	0.055	A
3	2/12/2002	0.0	380	250	2.580	2.398	0.182	A
3	2/26/2002	0.0	6560	4220	3.817	3.625	0.192	A
3	3/13/2002	0.0	1800	2000	3.255	3.301	0.046	A
3	3/26/2002	0.0	100	500	2.000	2.699	0.699	A
3	1/9/2002	1.5	880	1100	2.944	3.041	0.097	A
3	1/30/2002	1.5	1070	990	3.029	2.996	0.034	A
3	2/12/2002	1.5	900	1240	2.954	3.093	0.139	A
3	2/26/2002	1.5	10000	9760	4.000	3.989	0.011	A
3	3/13/2002	1.5	1360	1920	3.134	3.283	0.150	A
3	3/26/2002	1.5	400	100	2.602	2.000	0.602	A
12	1/30/2002	0.0	150	280	2.176	2.447	0.271	A
12	2/12/2002	0.0	480	520	2.681	2.716	0.035	A
12	2/26/2002	0.0	10000	13400	4.000	4.127	0.127	A
12	3/13/2002	0.0	40900	55400	4.612	4.744	0.132	A
12	1/30/2002	3.0	470	480	2.672	2.681	0.009	A
12	2/12/2002	6.0	430	510	2.633	2.708	0.074	A
12	2/26/2002	6.0	11000	13000	4.041	4.114	0.073	A
12	3/13/2002	6.0	82200	87800	4.915	4.943	0.029	A
12	3/26/2002	6.0	36000	22300	4.556	4.348	0.208	A
12	2/12/2002	9.0	510	740	2.708	2.869	0.162	A
12	2/26/2002	9.0	13600	11000	4.134	4.041	0.092	A
12	3/13/2002	9.0	68800	61000	4.838	4.785	0.052	A
12	3/26/2002	9.0	6000	24700	3.778	4.393	0.615	A
3	4/9/2002	0.0	200	170	2.301	2.230	0.071	A
3	4/9/2002	2.0	40	80	1.602	1.903	0.301	A
12	4/9/2002	0.0	20	300	1.301	2.477	1.176	U
12	4/9/2002	5.0	20	810	1.301	2.908	1.607	U
12	4/9/2002	9.0	60	370	1.778	2.568	0.790	A
3	5/1/2002	0.0	351	1560	2.545	3.193	0.648	A
3	5/1/2002	1.5	383	626	2.583	2.797	0.213	A
12	5/1/2002	0.0	39	146	1.591	2.164	0.573	A
12	5/1/2002	6.0	92	272	1.964	2.435	0.471	A
12	5/1/2002	10.0	155	239	2.190	2.378	0.188	A
3	5/14/2002	0.0	730	975	2.863	2.989	0.126	A
3	5/14/2002	2.0	1400	1615	3.146	3.208	0.062	A
12	5/14/2002	0.0	525	305	2.720	2.484	0.236	A
12	5/14/2002	5.0	95	310	1.978	2.491	0.514	A
12	5/14/2002	10.0	135	185	2.130	2.267	0.137	A
3	5/29/2002	2.0	380	720	2.580	2.857	0.278	A
12	5/29/2002	0.0	60	60	1.778	1.778	0.000	A
12	5/29/2002	5.0	180	230	2.255	2.362	0.106	A
12	5/29/2002	9.0	60	40	1.778	1.602	0.176	A
3	6/10/2002	0.0	975	1135	2.989	3.055	0.065	A
3	6/10/2002	1.5	1010	955	3.004	2.980	0.024	A
12	6/10/2002	0.0	35	960	1.544	2.982	1.438	U
12	6/10/2002	5.0	2660	1275	3.425	3.106	0.319	A
12	6/10/2002	10.0	870	165	2.940	2.217	0.722	A
3	7/2/2002	0.0	3010	1900	3.479	3.279	0.200	A
3	7/2/2002	1.5	2350	5870	3.371	3.769	0.398	A
12	7/2/2002	0.0	16100	17500	4.258	4.243	0.015	A
12	7/2/2002	9.5	8500	8600	3.929	3.934	0.005	A
3	7/16/2002	0.0	3830	2970	3.583	3.473	0.110	A
3	7/16/2002	2.0	11400	8300	4.057	3.919	0.138	A
12	7/16/2002	0.0	890	620	2.839	2.792	0.046	A
12	7/16/2002	5.0	1440	1740	3.158	3.241	0.082	A
12	7/16/2002	9.0	1280	750	3.107	2.875	0.232	A
					Range mean:		0.284	
					Precision Criteria:		0.930	

Table A-4. Enterococci duplicate analysis from biweekly spatial sampling.

Site I.D.	Date	Depth (m)	Duplicate Analyses		Logarithms of Counts		Range of Logarithms (L1-L2)	Acceptance of Range (A or U)
			D1	D2	L1	L2		
3	08/29/01	0	140	128	2.146	2.107	0.039	A
3	08/29/01	1.8	156	144	2.193	2.158	0.035	A
3	09/11/01	0	172	105	2.236	2.021	0.214	A
3	09/11/01	1.5	332	380	2.521	2.580	0.059	A
3	09/26/01	0	36	16	1.556	1.204	0.352	A
3	09/26/01	1.5	61	52	1.785	1.716	0.069	A
12	08/29/01	0	1	52	0.000	1.716	1.716	U
12	08/29/01	5.5	9	1	0.954	0.000	0.954	U
12	08/29/01	6.1	18	21	1.255	1.322	0.067	A
12	09/11/01	0	170	109	2.230	2.037	0.193	A
12	09/11/01	6.0	18	34	1.255	1.531	0.276	A
12	09/11/01	7.5	1	1	0.000	0.000	0.000	A
12	09/26/01	0	2	1	0.301	0.000	0.301	A
12	09/26/01	6.0	1	1	0.000	0.000	0.000	A
12	09/26/01	7.5	1	1	0.000	0.000	0.000	A
3	10/17/2001	0.0	36	56	1.556	1.748	0.192	A
3	10/30/2001	0.0	48	160	1.681	2.204	0.523	A
3	11/14/2001	0.0	208	230	2.318	2.362	0.044	A
3	11/28/2001	0.0	115	112	2.061	2.049	0.011	A
3	12/17/2001	0.0	108	92	2.033	1.964	0.070	A
3	10/17/2001	1.4	158	198	2.199	2.297	0.098	A
3	10/30/2001	1.5	111	143	2.045	2.155	0.110	A
3	11/14/2001	1.5	253	251	2.403	2.400	0.003	A
3	11/28/2001	1.0	121	123	2.083	2.090	0.007	A
3	12/17/2001	1.5	112	138	2.049	2.140	0.091	A
12	10/17/2001	0.0	3	3	0.477	0.477	0.000	A
12	10/30/2001	0.0	3	4	0.477	0.602	0.125	A
12	11/14/2001	0.0	6	8	0.778	0.903	0.125	A
12	11/28/2001	0.0	14	13	1.146	1.114	0.032	A
12	12/17/2001	0.0	6	7	0.778	0.845	0.067	A
12	10/17/2001	6.0	34	39	1.531	1.591	0.060	A
12	10/30/2001	6.5	3	2	0.477	0.301	0.176	A
12	11/14/2001	7.5	37	30	1.568	1.477	0.091	A
12	11/28/2001	7.5	16	16	1.204	1.204	0.000	A
12	12/17/2001	6.0	17	19	1.230	1.279	0.048	A
12	10/17/2001	6.8	4	7	0.602	0.845	0.243	A
12	10/30/2001	9.0	1	1	0.000	0.000	0.000	A
12	11/14/2001	9.0	6	9	0.778	0.954	0.176	A
12	11/28/2001	9.0	21	14	1.322	1.146	0.176	A
12	12/17/2001	9.0	20	16	1.301	1.204	0.097	A
3	1/9/2002	0.0	89	90	1.949	1.954	0.005	A
3	1/30/2002	0.0	78	82	1.892	1.914	0.022	A
3	2/12/2002	0.0	32	38	1.505	1.580	0.075	A
3	2/26/2002	0.0	1	1	0.000	0.000	0.000	A
3	3/13/2002	0.0	34	48	1.531	1.681	0.150	A
3	3/26/2002	0.0	0	17	0.000	1.230	1.230	U
3	1/9/2002	1.5	325	322	2.512	2.508	0.004	A
3	1/30/2002	1.5	78	103	1.892	2.013	0.121	A
3	2/12/2002	1.5	64	123	1.806	2.090	0.284	A
3	2/26/2002	1.5	460	505	2.663	2.703	0.041	A
3	3/13/2002	1.5	124	106	2.093	2.025	0.068	A
3	3/26/2002	1.5	11	1	1.041	0.000	1.041	U
12	1/30/2002	0.0	5	6	0.699	0.778	0.079	A
12	2/12/2002	0.0	2	2	0.301	0.301	0.000	A
12	2/26/2002	0.0	4	4	0.602	0.602	0.000	A
12	1/30/2002	3.0	9	6	0.954	0.778	0.176	A
12	2/12/2002	6.0	3	4	0.477	0.602	0.125	A
12	2/26/2002	6.0	5	9	0.699	0.954	0.255	A
12	3/13/2002	6.0	2	36	0.301	1.556	1.255	U
12	3/26/2002	6.0	3	3	0.477	0.477	0.000	A
12	2/12/2002	9.0	13	8	1.114	0.903	0.211	A
12	2/26/2002	9.0	4	1	0.602	0.000	0.602	A
12	3/13/2002	9.0	7	6	0.845	0.778	0.067	A
3	4/9/2002	0.0	177	108	2.248	2.033	0.215	A
3	4/9/2002	2.0	100	97	2.000	1.987	0.013	A
12	4/9/2002	0.0	6	6	0.778	0.778	0.000	A
12	4/9/2002	5.0	16	24	1.204	1.380	0.176	A
12	4/9/2002	9.0	12	10	1.079	1.000	0.079	A
3	5/1/2002	0.0	19	20	1.279	1.301	0.022	A
3	5/1/2002	1.5	16	40	1.204	1.602	0.398	A
12	5/1/2002	0.0	3	3	0.477	0.477	0.000	A
12	5/1/2002	6.0	40	51	1.602	1.708	0.106	A
12	5/1/2002	10.0	6	8	0.778	0.903	0.125	A
3	5/14/2002	0.0	2	4	0.301	0.602	0.301	A
3	5/14/2002	2.0	82	43	1.914	1.633	0.280	A
12	5/14/2002	0.0	0	14	0.000	1.146	1.146	U
12	5/14/2002	5.0	4	9	0.602	0.954	0.352	A
12	5/14/2002	10.0	2	6	0.301	0.778	0.477	A
3	5/29/2002	0.0	5	12	0.699	1.079	0.380	A
3	5/29/2002	2.0	44	74	1.643	1.869	0.226	A
12	5/29/2002	0.0	1	1	0.000	0.000	0.000	A
12	5/29/2002	5.0	10	9	1.000	0.954	0.046	A
12	5/29/2002	9.0	8	3	0.903	0.477	0.426	A
3	6/10/2002	0.0	15	6	1.176	0.778	0.398	A
3	6/10/2002	1.5	15	17	1.176	1.230	0.054	A
12	6/10/2002	0.0	4	7	0.602	0.845	0.243	A
12	6/10/2002	5.0	25	34	1.398	1.531	0.134	A
12	6/10/2002	10.0	18	15	1.255	1.176	0.079	A
3	7/2/2002	0.0	6	2	0.778	0.301	0.477	A
3	7/2/2002	1.5	60	66	1.778	1.820	0.041	A
12	7/2/2002	5.0	11	26	1.041	1.415	0.374	A
12	7/2/2002	9.5	17	11	1.230	1.041	0.189	A
3	7/16/2002	0.0	114	112	2.057	2.049	0.008	A
3	7/16/2002	2.0	107	175	2.029	2.243	0.214	A
12	7/16/2002	0.0	1	8	0.000	0.903	0.903	U
12	7/16/2002	5.0	40	54	1.602	1.732	0.130	A
12	7/16/2002	9.0	8	6	0.903	0.778	0.125	A
					Range mean:		0.214	
					Precision Criteria:		0.701	

Table A-5. *E. coli* duplicate analysis from biweekly spatial sampling.

Site I.D.	Date	Depth (m)	Duplicate Analyses		Logarithms of Counts		Range of Logarithms (L1-L2)	Acceptance of Range (A or U)
			D1	D2	L1	L2		
3	12/17/2001	0.0	44	21	1.643	1.322	0.321	A
3	12/17/2001	1.5	39	34	1.591	1.531	0.060	A
12	12/17/2001	0.0	21	4	1.322	0.602	0.720	A
12	12/17/2001	6.0	43	34	1.633	1.531	0.102	A
12	12/17/2001	9.0	25	30	1.398	1.477	0.079	A
3	1/9/2002	0.0	31	28	1.491	1.447	0.044	A
3	1/30/2002	0.0	20	33	1.301	1.519	0.217	A
3	2/12/2002	0.0	9	5	0.954	0.699	0.255	A
3	2/26/2002	0.0	2	0	0.301	0.000	0.301	A
3	3/13/2002	0.0	12	17	1.079	1.230	0.151	A
3	3/26/2002	0.0	1	16	0.000	1.204	1.204	U
3	1/9/2002	1.5	53	77	1.724	1.886	0.162	A
3	1/30/2002	1.5	32	30	1.505	1.477	0.028	A
3	2/12/2002	1.5	12	20	1.079	1.301	0.222	A
3	2/26/2002	1.5	58	35	1.763	1.544	0.219	A
3	3/13/2002	1.5	47	27	1.672	1.431	0.241	A
3	3/26/2002	1.5	33	0	1.519	0.000	1.519	U
12	1/30/2002	0.0	13	7	1.114	0.845	0.269	A
12	2/12/2002	0.0	3	0	0.477	0.000	0.477	A
12	2/26/2002	0.0	0	0	0.000	0.000	0.000	A
12	3/13/2002	0.0	0	0	0.000	0.000	0.000	A
12	3/26/2002	0.0	0	1	0.000	0.000	0.000	A
12	1/30/2002	3.0	16	12	1.204	1.079	0.125	A
12	2/12/2002	6.0	7	5	0.845	0.699	0.146	A
12	2/26/2002	6.0	2	4	0.301	0.602	0.301	A
12	3/13/2002	6.0	3	3	0.477	0.477	0.000	A
12	3/26/2002	6.0	0	0	0.000	0.000	0.000	A
12	2/12/2002	9.0	3	3	0.477	0.477	0.000	A
12	2/26/2002	9.0	10	5	1.000	0.699	0.301	A
12	3/13/2002	9.0	6	3	0.778	0.477	0.301	A
12	3/26/2002	9.0	5	4	0.699	0.602	0.097	A
3	4/9/2002	0	86	45	1.934	1.653	0.281	A
3	4/9/2002	2	36	29	1.556	1.462	0.094	A
12	4/9/2002	0	3	5	0.477	0.699	0.222	A
12	4/9/2002	5	1	1	0.000	0.000	0.000	A
12	4/9/2002	9	2	3	0.301	0.477	0.176	A
3	5/1/2002	0	5	0	0.699	0.000	0.699	A
3	5/1/2002	1.5	15	6	1.176	0.778	0.398	A
12	5/1/2002	6	1	2	0.000	0.301	0.301	A
12	5/1/2002	10	2	0	0.301	0.000	0.301	A
3	5/14/2002	0	1	1	0.000	0.000	0.000	A
3	5/14/2002	2	5	12	0.699	1.079	0.380	A
12	5/14/2002	0	4	1	0.602	0.000	0.602	A
12	5/14/2002	5	1	11	0.000	1.041	1.041	U
12	5/14/2002	10	0	6	0.000	0.778	0.778	A
3	5/29/2002	0.0	1	3	0.000	0.477	0.477	A
3	5/29/2002	2.0	10	7	1.000	0.845	0.155	A
12	5/29/2002	0.0	10	13	1.000	1.114	0.114	A
12	5/29/2002	5.0	2	1	0.301	0.000	0.301	A
12	5/29/2002	9.0	3	2	0.477	0.301	0.176	A
3	6/10/2002	0.0	4	1	0.602	0.000	0.602	A
3	6/10/2002	1.5	4	4	0.602	0.602	0.000	A
12	6/10/2002	0.0	0	1	0.000	0.000	0.000	A
12	6/10/2002	5.0	2	1	0.301	0.000	0.301	A
12	6/10/2002	10.0	1	1	0.000	0.000	0.000	A
3	7/2/2002	0.0	3	3	0.477	0.477	0.000	A
3	7/2/2002	1.5	1	5	0.000	0.699	0.699	A
12	7/2/2002	0.0	0	1	0.000	0.000	0.000	A
12	7/2/2002	5.0	0	0	0.000	0.000	0.000	A
12	7/2/2002	9.5	1	0	0.000	0.000	0.000	A
3	7/16/2002	0.0	7	5	0.845	0.699	0.146	A
3	7/16/2002	2.0	15	14	1.176	1.146	0.030	A
12	7/16/2002	0.0	1	1	0.000	0.000	0.000	A
12	7/16/2002	5.0	0	0	0.000	0.000	0.000	A
12	7/16/2002	9.0	6	7	0.778	0.845	0.067	A
					Range mean:		0.249	
					Precision Criteria:		0.815	

Table A-6. Bacteria annual mean and standard deviation at three depths.

Site I.D.	Average Depth (m)	Total Coliforms		Fecal Coliforms		Enterococci		<i>E. coli</i>	
		log (cfu/100 ml)		log (cfu/100 ml)		log (cfu/100 ml)		log (MPN/100 ml)	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
1	0.0	3.88	0.43	2.91	0.90	1.46	0.44	0.43	0.37
2	0.0	3.94	0.43	2.96	0.75	1.64	0.43	0.65	0.53
3	0.0	4.01	0.46	2.96	0.54	1.41	0.71	0.76	0.61
4	0.0	3.81	0.49	2.93	0.64	0.87	0.57	0.36	0.64
5	0.0	3.92	0.44	3.03	0.75	0.84	0.64	0.36	0.41
6	0.0	3.81	0.69	2.74	0.71	0.48	0.50	0.24	0.42
7	0.0	3.98	0.41	3.39	0.54	1.14	0.55	0.51	0.52
8	0.0	3.89	0.53	3.14	0.61	1.05	0.53	0.40	0.47
9	0.0	3.90	0.53	3.08	0.80	0.84	0.77	0.20	0.40
10	0.0	3.85	0.61	2.93	0.91	1.09	0.63	0.13	0.23
11	0.0	3.58	0.87	2.82	0.77	0.57	0.54	0.08	0.16
12	0.0	3.96	0.82	2.86	0.95	0.58	0.51	0.30	0.43
13	0.0	3.71	0.77	2.69	1.25	0.55	0.49	0.25	0.42
14	0.0	3.64	0.75	2.64	1.03	0.49	0.50	0.16	0.38
15	0.0	3.77	0.53	2.53	0.94	1.35	0.88	0.23	0.30
6	5.8	3.97	0.63	3.00	0.78	1.05	0.59	0.48	0.42
10	5.3	3.75	0.55	3.12	0.48	1.59	0.74	0.14	0.27
11	5.6	3.54	0.65	2.73	0.61	1.05	0.49	0.17	0.29
12	5.5	4.04	0.68	2.93	1.04	1.10	0.51	0.37	0.46
13	5.7	3.98	0.71	2.87	1.08	1.02	0.57	0.30	0.35
14	5.9	3.85	0.72	2.72	1.12	0.76	0.54	0.22	0.20
1	1.1	4.22	0.33	3.17	0.75	1.83	0.25	0.55	0.49
2	1.7	4.14	0.48	3.08	0.80	1.94	0.25	0.85	0.53
3	1.6	4.19	0.44	3.17	0.63	1.92	0.53	1.16	0.50
4	3.0	4.15	0.42	3.30	0.59	1.66	0.45	0.62	0.47
5	4.5	4.12	0.47	3.10	0.68	1.64	0.38	0.71	0.36
6	9.6	3.98	0.75	2.89	0.77	0.94	0.50	0.64	0.59
7	1.7	4.40	0.40	3.62	0.58	1.75	0.34	0.94	0.50
8	2.5	4.18	0.59	3.53	0.57	1.70	0.45	0.96	0.49
9	5.4	4.09	0.56	3.39	0.68	1.58	0.86	0.56	0.45
10	7.1	3.98	0.75	3.06	0.74	1.39	0.71	0.36	0.32
11	7.9	3.91	0.81	3.04	0.79	0.96	0.57	0.43	0.40
12	8.8	4.14	0.76	2.88	1.01	0.81	0.42	0.51	0.41
13	10.6	3.93	0.82	2.44	1.04	0.75	0.45	0.46	0.41
14	12.3	3.85	0.85	2.73	1.06	0.56	0.51	0.45	0.32