Water Quality Assessment of Lake Texoma Beaches, 1999-2001

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A biological and inorganic assessment of five beaches on Lake Texoma was conducted from September 1999 through July 2001. Water samples from each beach site were divided into two groups, swimming season and non-swimming season. Water properties, such as temperature, alkalinity, and sulfates, were slightly higher in the swimming season, while dissolved oxygen and total suspended sediments were slightly higher in the non-swimming season. Constituents, such as pH, conductivity, chloride, and nutrients, showed no difference between the swimming season and the non-swimming season. A predictive model based on the geometric mean for *Escherichia coli* was used to measure the gastrointestinal illness rate per 1,000 swimmers during the swimming season. The model results showed an extremely low probability that someone would become sick from swimming at any of the five beaches. A comparative analysis was done that measured the probability that *E. coli* and total coliform concentrations were statistically different during the swimming and non-swimming seasons. Evidence from the comparative analysis suggested that total coliform concentrations at four beaches were significantly higher in the swimming season than in the non-swimming season. There was no evidence suggesting that *E. coli* concentrations were statistically different during the two seasons.

INTRODUCTION

Lake Texoma reservoir (Fig. 1) is a large (37,652 surface ha) and economically important man-made impoundment of the Red and Washita Rivers in southern Oklahoma and northern Texas. The drainage area for Lake Texoma is approximately 102,828 Km^2 extending into the Texas Panhandle and parts of eastern New Mexico. The Red River and the Washita River are the major inflows into Lake Texoma. U.S. Geological Survey gaging stations "Red River near Gainesville, Texas" and "Washita River near Dickson, Oklahoma" reported annual mean streamflows of 94 m^3/s and 54 m^3/s, respectively (Blazs 2000). The primary land use within drainage basin consists of 37.7% upland grasses and forbs and 36.2% cultivated agriculture (NLCD 2000). Lake Texoma was built by the U.S. Army Corps of Engineers beginning in 1939 and completed in 1944 primarily for flood control, water supply, and hydroelectric power (OWRB 1990). Other uses of Lake Texoma include recreation, real estate, and farming, all of which may have an effect on the water quality of the reservoir.

The U.S. Army Corps of Engineers reported 5.8 million people visited Lake Texoma in 1997 making it the most visited U.S. Army Corps lake west of the Mississippi River (Wingfield 2002 personal communication). Although, the Oklahoma Water Resources Board routinely collects samples for analysis of water properties, nutrients, and chlorophyll information as part of the Beneficial Use Monitoring

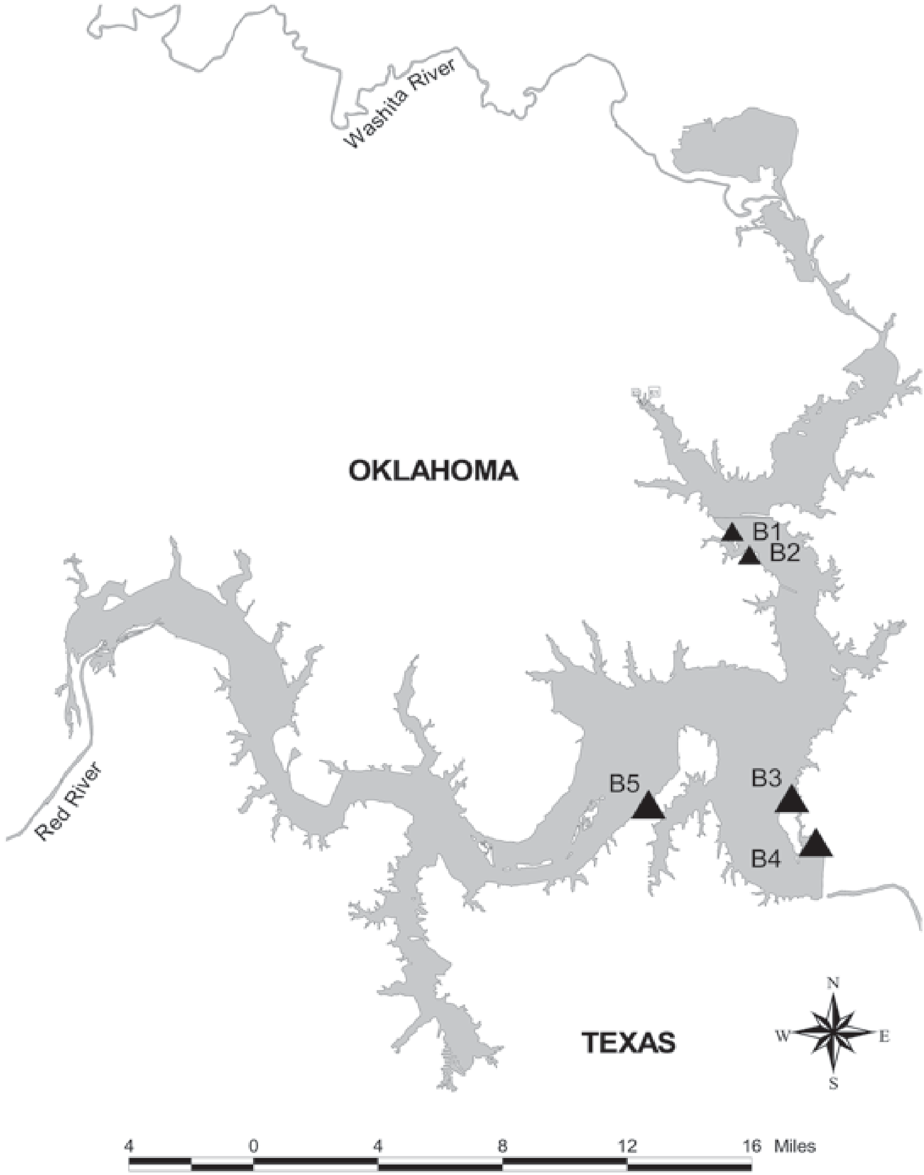

Figure 1. Sampling locations at beach sites in Lake Texoma, on the border of southern Oklahoma and northern Texas.

Program (BUMP), there is no routine monitoring for total and fecal coliform contamination in the reservoir. Consequently, there is limited data available to assess the safety of the water for swimming and other recreational activities.

Some potential sources of infectious agents in recreational water include runoff from agricultural operations, drainage from streams, beach users, houseboats, septic systems, and fecal matter of domestic and wild animals (Clesceri et al 1998). Also, fecal coliform concentrations generally show a positive correlation to discharge due to surface runoff from pastures, feed lots, and urban areas (Smith et al 1993, Wilhelm and Maluk 1998, Clark and Norris 2000). Fecal pollution impairs the quality of water for recreational use and adversely affects fish and aquatic life (Hoos et al 2002). Studies have shown that *Escherichia coli* (*E. coli*) is the most specific indicator of contamination by fecal material from warm-blooded animals and is present in the feces of warm-blooded animals at densities of 10^8 to 10^9 /g (Edberg et al 1994, Elmund et al 1999). Cabelli (1981) also found a cause-effect relation between the concentration of enterococci and the rate of swimming-associated gastroenteritis at marine beaches. Similarly, Dufour (1984), in a freshwater study, reported a strong correlation between the rate of illness, gastroenteritis, occurring in swimmers and the concentrations of *E. coli* and enterococci, but not with fecal-coliform bacteria. *E. coli* typically are not disease causing (pathogenic) bacteria, but can be correlated to the presence of human enteric pathogens and can be used as a measure of water safety for recreational contact (Hoos et al 2002).

In 1986 the U.S. Environmental Protection Agency recommended new recreational water-quality criteria for *E. coli* in fresh water based on a predictive model that assessed the gastrointestinal illness rate per 1,000 swimmers. The regression equation Y= -11.74 + 9.40 (log x), where Y is the swimming-associated gastrointestinal illness rate per 1,000 swimmers, and x is the concentration of *E. coli* colonies per 100 mL (Dufour 1984). Also, the U.S. Environmental Protection Agency established water-quality criteria for *E. coli* and enterococci. The criteria are based on a geometric-mean standard for bathing waters of 126 colonies/ 100 mL for *E. coli* and 33 colonies/100 mL for enterococci, indicating an illness rate of 8/1,000 people (U.S. EPA 1986).

This study will (1) assess and characterize water quality at five designated swimming beaches in Lake Texoma reservoir during the swimming and non-swimming seasons, (2) use a predictive model to assess the probability of a swimmer becoming sick based on sampled *E. coli* concentrations, and (3) compare concentrations of total coliform and *E. coli* during the swimming and non-swimming season. Water properties, nutrients, total coliform, and *E. coli* bacteria were the water-quality constituents included in the characterization. This article is based on data collected from September 1999 through July 2001.

MATERIALS and METHODS

Water-quality samples were collected at five beach sites (Fig. 1) on a seasonal basis from September 1999 through July 2001. Samples were obtained at 0.305 m depth intervals from each beach site through a 6.4 mm diameter polyethylene tube connected to a peristaltic pump and placed in clean 500 mL vessels. Water samples for total coliform and *E. coli* were collected in sterile 100 mL vessels with sodium thiosulphate (0.1 mL of a 1.8 % solution per 100 mL capacity). All samples were stored on ice until returned to the laboratory. Ten percent or more of the samples were collected in duplicates.

Water properties were measured following U.S. Environmental Protection Agency (EPA) methods 150.1 for pH, 120.1 for conductivity, 310.1 for alkalinity, and method 2540D from *Standard Methods for Water and Wastewater*, 17th ed. for total suspended solids (TSS). Dissolved oxygen (DO) concentrations were measured with an Orion (Model 842) DO meter (Orion Research, Inc., Beverly, MA). Methods used for inorganic analyses were waters capillary electrophoresis method N-601 for sulfate (SO_4^{2-}) and chloride (Cl^-); Lachat FIA methods (Lachat Instruments, Inc., Milwaukee, WI), 10-107-04-2-A for nitrite (NO_2^-) plus nitrate (NO_3^-), 100107-05-1-A for nitrite (NO_2^-), 10-115-01-1 for ortho-phospate (PO_4^{3-}), and 10-107-06-1-A for ammonia (NH_3). Quality assurance measures performed included spikes, duplicates, known analytical quality control (AQC) samples, check standards, and blanks. Total coliform and *E. coli* were determined by using the Quanti-Tray® Colilert Method (IDEXX Laboratories, Inc., Westbrook, Maine) that can simultaneously detect and enumerate both organisms (Edberg et al 1990, Eaton et al 1995). Reverse Osmosis (RO) purified water was used as a negative control and RO water with one drop of a log phase culture of *E. coli* ATTC strain 15597 was used as a positive control. The content of one IDEXX reagent was added to 100 mL of each sample, and the samples were shaken and allowed to sit until all reagent was dissolved. Each sample was poured into a plastic Quanti-Tray that consisted of 49 large wells and 48 smaller wells. Trays were sealed using an IDEXX Quanti-Tray sealer and incubated for 24 h at 35 ± 0.5°C. The wells that changed to yellow were counted positive for total coliform. Wells that changed to yellow and fluoresced when placed in a 6 W, 365 nm, ultra violet (UV) light box were counted positive for *E. coli*. The density units are expressed as most probable number (MPN) per 100 mL.

The geometric means for *E. coli* were used in a predictive model by Dufour (1984), Y= -11.74 + 9.40 (log x) to measure the probability of the gastrointestinal illness rate per 1,000 swimmers. When computing geometric means, observations reported below the detection limit were set to a value one half of the detection limit. The Wilcoxon Rank-Sum statistical test was used to determine if total coliform and *E. coli* distributions were statistically different during the swimming and non-swimming seasons (MathSoft 1999). The Wilcoxon Rank-Sum test is a non-parametric test that measures the probability of two independent sample groups are similar in median or central value under the null hypothesis. A *P*-value or significance level of 0.1 or less suggests the null hypothesis be rejected in favor of the alternate hypothesis. A *P*-value of 0.1 is reference to a 10% maximum risk the null hypothesis would incorrectly be rejected, suggesting that the distribution of total coliform or *E. coli* during the swimming season is greater during the swimming season.

RESULTS and DISCUSSION

Water samples collected for each beach site were split into two groups, a non-swimming season group and a swimming season group. Samples for the swimming season group were collected from April through September, while samples for the non-swimming group were collected from October through March. The beaches sampled were officially open from April 1 through September 30. Each beach used was reported as a high use beach from May 15 through August 15, with extremely high use from Memorial Day to the weekend of July 4 (Wingfield 2002 personal communication). Tables 1 and 2 provide summary statistics for water properties, inorganics, total coliforms, and *E. coli* bacteria.

The measured water temperatures were highest during the swimming season, with median temperature ranging from 26.6°C at Lake Texoma Lodge 1 (B1) to 28.6°C at Lake Texoma Lodge 2 (B2). In the non-swimming season, the median temperature ranged from 18.7°C at B5 to 20.3°C at B1. Median pH measurements ranged from 7.70 at B1 and 8.12 at Island View (B5), with no significant difference between the swimming and non-swimming season. Median conductivity concentrations ranged from 1665 μmhos cm^{-1} at B1 to 2065 μmhos cm^{-1} at B5, with no significant difference between the swimming and non-swimming season. Median alkalinity concentrations were slightly higher in the swimming season, ranging from 98.4 mg L^{-1} at B1 and B2 to 104.0 mg L^{-1} at Burn Run East (B4), than in the non-swimming season. During the non-swimming season, alkalinity concentrations ranged from 93.3 mg L^{-1} at B2 to 95.5 mg L^{-1} at Burn Run West (B3). The median DO and TSS concentrations were both higher in the non-swimming season than in the swimming season. Dissolved oxygen concentrations in the swimming season ranged from 7.9 mg L^{-1} at B5 to 8.4 mg L^{-1} at B1, while DO concentrations in the non-swimming season ranged from 8.4 mg L^{-1} at B3 to 10.3 mg L^{-1} at B5. Total suspended sediment concentrations in the swimming season ranged from 1.0 mg L^{-1} at B3 to 9.0 mg L^{-1} at B5, while TSS concentrations in the non-swimming season ranged from 4.0 mg L^{-1} at B4 to 15.0 mg L^{-1} at B1.

Median SO_4^{2-} concentrations were slightly higher during the swimming season, ranging from 370 mg L^{-1} at B2 to 427 mg L^{-1} at B1. The SO_4^{2-} concentrations in the non-swimming season ranged from 351 mg L^{-1} B1 to 384 mg L^{-1} at B5. There was little difference in Cl^- concentrations in the swimming season than in the non-swimming season. The median Cl^- concentrations during the swimming season ranged from 252 mg L^{-1} at B2 to 370 mg L^{-1} at B5, while Cl^- concentrations in the non-swimming season 290 mg L^{-1} at B1 and B2 to 359 mg L^{-1} at B5. There was no difference in nutrient concentrations during the swimming and non-swimming seasons. When computing summary statistics for nutrients, sample observations reported below the detection limit were set to a value one half of the maximum detection limit (MDL). All NO_3^- samples were reported as

TABLE 1. Summary statistics for concentrations of selected water-quality constituents in samples collected during the non-swimming season at various beach sites on Lake Texoma Reservoir.

	Sites																								
	B1					B2					B3					B4					B5				
NAME	n	Min[1]	Med	Max	Geom	n	Min	Med	Max	Geom	n	Min	Med	Max	Geom	n	Min	Med	Max	Geom	n	Min	Med	Max	Geom
Temp (°C)	3	9.6	20.3	21.9	16.2	3	9.7	20.3	21.7	16.1	3	10.3	19.5	21.7	12.7	3	8.7	19.4	20.8	15.2	3	8.8	18.7	19.8	14.8
pH (su)	3	7.8	7.9	8.0	7.9	5	7.7	8.0	8.3	8.0	6	7.6	7.9	8.3	7.5	5	7.9	8.1	8.3	8.0	5	7.7	8.0	8.3	8.0
Conductivity[2]	3	1610	1702	1790	1699	5	941	1700	2080	1572	6	20	1940	2200	325	5	1110	1970	2240	1795	5	1150	2020	2300	1856
Alkalinity[3]	3	92.6	93.2	117.0	100.3	5	90.2	93.1	144.0	105.0	6	82.2	95.5	116.0	61.1	5	90.6	93.5	115.0	98.6	5	88.5	93.7	105.0	94.3
DO	3	7.5	9.6	11.1	9.3	3	7.1	10.0	11.0	9.2	6	7.4	8.4	9.5	7.7	3	8.2	8.6	10.4	9.0	3	7.4	10.3	10.7	9.3
TSS	3	1.0	15.0	16.0	6.2	5	4.0	7.0	19.0	8.6	6	4.0	8.5	15.0	6.9	5	1.0	4.0	17.0	4.4	5	1.0	14.0	17.0	8.4
SO_4^{-2}	3	267	351	365	325	5	197	365	541	357	6	170	363	420	145	5	177	366	416	325	5	132	384	460	322
CL^-	3	249	290	371	299	5	86	290	369	232	6	37	336	412	77	5	175	338	407	306	5	217	359	416	335
NO_2^-	3	0.05	0.05	0.05	0.05	5	0.05	0.05	0.05	0.05	6	0.05	0.05	0.05	0.11	5	0.05	0.05	0.05	0.05	5	0.05	0.05	0.05	0.05
NO_3	3	0.05	0.05	0.16	0.07	5	0.05	0.11	0.58	0.12	6	0.05	0.13	0.59	0.40	5	0.05	0.11	0.57	0.11	5	0.05	0.05	0.59	0.10
NH_3	3	0.05	0.05	0.13	0.07	5	0.05	0.05	0.20	0.17	6	0.05	0.05	0.20	0.17	5	0.05	0.05	0.11	0.06	5	0.05	0.05	0.16	0.06
O-P	3	0.01	0.01	0.01	0.01	5	0.01	0.01	0.01	0.01	6	0.01	0.01	0.01	0.01	5	0.01	0.01	0.01	0.01	5	0.01	0.01	0.01	0.01
Total Coliform (MPN/100 mL)	2	191	196	200	196	4	145	477	4260	611	5	147	435	14830	776	5	85	461	10460	653	6	17.3	237	6836	301
E. coli (MPN/100 mL)	3	0.50	0.50	1.00	0.63	5	0.50	0.50	3.10	0.83	6	0.50	1.25	3.00	1.07	5	0.50	0.50	31.10	1.14	6	0.05	0.50	3.00	0.67

[1]Min = minimum concentration, Med = median concentration, Max = maximum concentration, Geom = geometric mean concentration.
[2]Conductivity in µmhos cm^{-1}.
[3]Alkalinity, DO, TSS, SO_4^{-2}, CL^-, NO_2^-, NO_3, NH_3, O-P in mg L^{-1}.

TABLE 2. Summary statistics for concentrations of selected water-quality constituents in samples collected during the swimming season at various beach sites on Lake Texoma Reservoir.

	Sites																								
	B1					B2					B3					B4					B5				
NAME	n	Min[1]	Med	Max	Geom	n	Min	Med	Max	Geom	n	Min	Med	Max	Geom	n	Min	Med	Max	Geom	n	Min	Med	Max	Geom
Temp (°C)	3	24.1	26.6	32.6	27.5	6	16.1	28.6	32.0	20.3	7	19.2	27.3	31.4	26.8	7	21.3	28.0	31.0	27.1	6	20.3	27.1	28.5	25.9
pH (su)	3	7.5	7.7	8.2	7.8	8	7.6	8.1	8.5	8.1	9	7.7	8.0	8.5	8.0	9	7.8	7.9	8.6	8.1	8	7.7	8.0	8.7	8.0
Conductivity[2]	3	1650	1665	1710	1675	8	1420	1670	1990	799	9	1200	1960	2200	1818	9	1110	1970	2240	1795	8	1150	2020	2300	1856
Alkalinity[3]	3	89.0	98.4	120.0	101.7	8	85.2	98.4	140.0	77.8	9	89.5	103.0	172.0	109.1	9	85.0	104.0	123.0	102.6	8	76.9	98.5	110.0	98.8
DO	3	8.0	8.4	9.8	8.7	6	7.1	8.2	9.1	7.3	7	6.5	7.9	8.5	7.7	7	6.0	7.9	8.4	7.6	6	5.6	7.4	10.4	7.3
TSS	3	4.0	8.0	11.0	7.1	8	0.5	3.0	18.0	2.8	9	0.5	1.0	16.0	2.1	9	0.5	2.0	17.0	2.5	8	0.5	9.0	40.0	4.9
SO_4^{-2}	3	360	427	429	404	8	317	370	414	202	9	181	387	413	336	9	185	380	410	335	8	175	390	427	325
CL^-	3	239	263	287	262	8	185	252	345	144	9	177	328	406	307	9	179	329	439	311	8	192	370	419	315
NO_2^-	3	0.05	0.05	0.05	0.05	8	0.05	0.05	0.05	0.05	9	0.05	0.05	0.05	0.11	9	0.05	0.05	0.05	0.05	8	0.05	0.05	0.05	0.05
NO_3	3	0.05	0.05	0.13	0.07	8	0.05	0.05	0.17	0.13	9	0.05	0.05	0.48	0.08	9	0.05	0.05	0.51	0.07	8	0.05	0.05	0.38	0.06
NH_3	3	0.05	0.05	4.06	0.22	8	0.05	0.05	0.27	0.14	9	0.05	0.05	0.18	0.06	9	0.05	0.05	0.15	0.06	8	0.05	0.05	0.18	0.07
O-P	3	0.01	0.02	0.02	0.02	8	0.01	0.02	0.08	0.04	9	0.01	0.01	0.02	0.01	9	0.01	0.01	0.02	0.01	8	0.01	0.01	0.02	0.01
Total Coliform (MPN/100 mL)	2	2419	2475	2530	2474	5	579	3100	9768	3247	8	1733	2419	16328	2950	8	43.2	2827	19863	2549	9	75.9	3000	19608	2950
E. coli (MPN/100 mL)	3	0.50	2.00	3.10	1.46	7	0.50	0.50	5.20	1.00	8	0.50	0.50	2.00	0.65	9	0.50	0.50	9.70	0.75	9	0.50	0.50	1.00	0.58

[1]Min = minimum concentration, Med = median concentration, Max = maximum concentration, Geom = geometric mean concentration.
[2]Conductivity in μmhos cm^{-1}.
[3]Alkalinity, DO, TSS, SO_4^{-2}, CL^-, NO_2^-, NO_3, NH_3, O-P in mg L^{-1}.

being below the MDL of <0.10 mg L^{-1}. Sixty-two percent of all NO_2^- samples and 79% of all NH_3 samples were reported below the MDL of <0.10 mg L^{-1}. The maximum NO_2^- observation was 0.59 mg L^{-1} at B3 and B5. There was one NH_3 concentration at B1 during the swimming season that was 4.06 mg L^{-1}. The next highest NH_3 concentration was 0.20 mg L^{-1} at B2, which was also during the swimming season. There was no significant difference between PO_4^{3-} concentrations during the swimming and non-swimming seasons. Forty-three percent of all PO_4^{3-} concentrations were reported as below the MDL of <0.02 mg L^{-1}. The maximum PO_4^{3-} observation was 0.08 mg L^{-1} at site B2.

The geometric mean and median values for total coliform and *E. coli* for beach sites B1-B5 are shown in Figure 2. Median

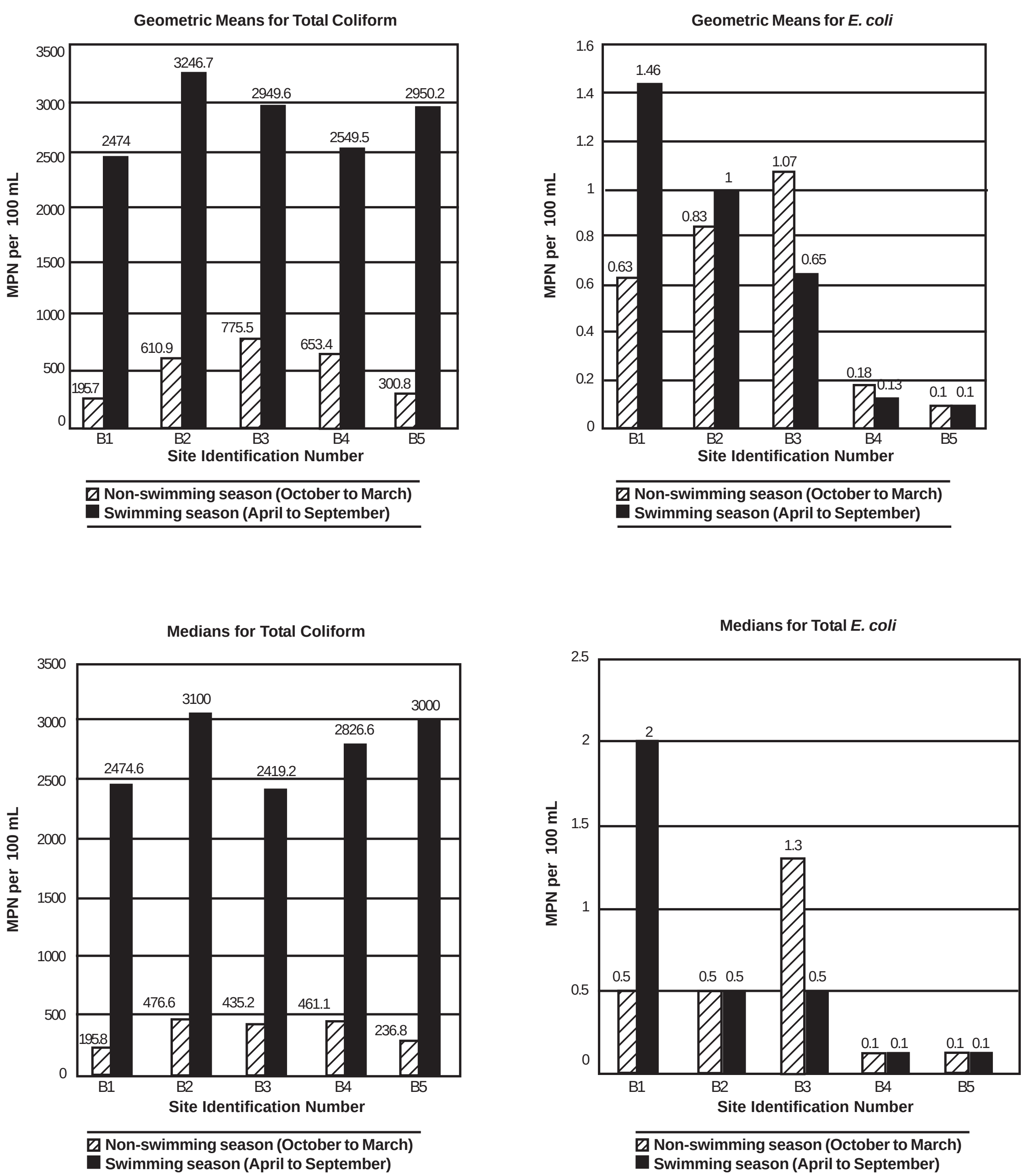

Figure 2. Geometric means and median concentration for total coliforms and *E. coli* during non-swimming and swimming season.

values for total coliform were higher during the swimming season than in the non-swimming season. During the swimming season, median concentrations ranged from 2,429 MPN/100 mL at B3 to 3,100 MPN/100 mL at B2. The maximum total coliform concentration was reported at B4 with a value of 19,863 MPN/100 mL during the swimming season (Table 2). Median concentrations during the non-swimming season ranged from 196 MPN/100 mL at B1 to 477 MPN/100†mL at B2. The maximum total coliform concentration reported during the non-swimming season was 14,830 MPN/100 mL at site B3 (Table 1).

There was little difference in median *E. coli* concentrations in the swimming season and in *E. coli* concentrations in the non-swimming season. Sixty-nine percent of *E. coli* observations in the swimming season and 68% of *E. coli* observations in the non-swimming season were below the detection limit of <1 MPN/100 mL. The highest *E. coli* observation in the swimming season was 9.7 MPN/100 mL at B4 (Table 2). The highest *E. coli* observation in the non-swimming season was 31.0 MPN/100 mL at B4 (Table 1).

The predictive model developed by Dufour (1984) was used to assess the probability that a swimmer would become sick based on the geometric mean for each of the five beaches during the swimming season. Results from the predictive model showed negative probabilities that a swimmer would become sick from swimming at any of the five beaches. The *E. coli* breaking point concentration needed to attain a positive probability is 19 MPN/100 mL, which is well above the highest value of 1.46 MPN/100 mL reported at B1. The U.S. EPA has set a criterion of 235 MPN/100 mL for a single freshwater sample taken at a designated site (EPA 2002). The maximum observation reported at B4 was 9.70 MPN/100 mL, which is below the U.S. EPA criterion for a single sample.

A Wilcoxon Rank-Sum test was used to compare total coliform and *E. coli* concentrations during the swimming and non-swimming season. Table 3 provides *P*-values attained while comparing total coliform and *E. coli* concentrations for each beach during the non-swimming and swimming season. A second Wilcoxon Rank-Sum test was performed by grouping all data collected at B1, B2, B3, B4, and B5 and dividing the sum into two groups, a swimming season and non-swimming season. Evidence from the first comparison test suggested that total coliform concentrations from beach sites B1, B2, B3, and B5 were significantly higher in the swimming season than in the non-swimming season. Conversely, evidence for beach site B4 did not suggest any differences in total coliform concentrations between the swimming season and the non-swimming season. The second comparison test showed that concentrations of total coliform were significantly higher ($P<0.0005$) in the swimming season than in the non-swimming season. The higher total coliform is expected during the swimming season due to elevated temperature, cattle grazing and recreational activities. The first comparison test between *E. coli* concentrations showed no significant difference between the two seasons (Table 3). The second comparison also indicated that there was no significant difference between *E. coli* concentrations during the swimming and non-swimming season. The occurring of *E. coli* during swimming and non-swimming season is probably due to wildlife and resuspension of sediment by recreational activities.

TABLE 3. Exact one-tailed attained significance level for individual beach sites using the Wilcoxin-Rank Sum test comparing Total Coliform and *E. coli* concentrations in non-swimming and swimming seasons.

Site ID	*P*-value	
	Total coliform	*E.Coli*
B1	0.082	0.177
B2	0.058	0.428
B3	0.053	0.900
B4	0.128	0.574
B5	0.043	0.500

CONCLUSION

The water quality at each of the five beach sites was considered to be good for recreational purposes. Water properties, such as temperature, alkalinity, and SO_4^{2-}, were slightly higher in the swimming season, while DO and TSS were slightly higher in the non-swimming season. Constituents, such as pH, conductivity, Cl^-, and nutrients, showed no difference between the swimming and non-swimming seasons. Results from using the regression equation by Dufour (1984), show a very low probability that someone would become sick from swimming at any of the five beaches during the swimming season (April 1 through September 30). All beaches were reported as having probabilities <1 for a swimmer becoming sick based on the *E. coli* samples included in this study. None of the *E. coli* geometric means exceeded the criterion of 126 MPN/100 mL, deeming the water safe for contact recreation. The maximum *E. coli* observation at B4 was 9.70 MPN/100 mL, which is well below the criterion of 235 MPN/100 mL for a single sample set forth by the U.S. EPA. Results from the Wilcoxon Rank-Sum comparative test suggest that total coliform concentrations in the swimming season were significantly higher than were concentrations in the non-swimming season. Evidence did not suggest any significant differences in *E. coli* concentrations between the swimming and non-swimming seasons.

NOTICE

The U. S. Environmental Protection Agency through its Office of Research and Development funded and managed the research described here through in-house efforts. It has not been subjected to agency review and, therefore, does not necessarily reflect the views of the agency, and no official endorsement should be inferred.

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