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FECAL-INDICATOR BACTERIA IN STREAMS ALONG A GRADIENT OF RESIDENTIAL DEVELOPMENT[1]

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ABSTRACT: Fecal-indicator bacteria were sampled at 14 stream sites in Anchorage, Alaska, USA, as part of a study to determine the effects of urbanization on water quality. Population density in the subbasins sampled ranged from zero to 1,750 persons per square kilometer. Higher concentrations of fecal-coliform, *E. coli*, and enterococci bacteria were measured at the most urbanized sites. Although fecal-indicator bacteria concentrations were higher in summer than in winter, seasonal differences in bacteria concentrations generally were not significant. Areas served by sewer systems had significantly higher fecal-indicator bacteria concentrations than did areas served by septic systems. The areas served by sewer systems also had storm drains that discharged directly to the streams, whereas storm sewers were not present in the areas served by septic systems. Fecal-indicator bacteria concentrations were highly variable over a two-day period of stable streamflow, which may have implications for testing of compliance to water-quality standards.
(KEY TERMS: fecal-indicator bacteria; *E. coli*; enterococci; water quality; population density; residential; Anchorage.)

INTRODUCTION

Background

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) has as its goals to describe the current status and long-term trends in water quality and to better understand the influence of natural and human factors on water quality (Hirsch *et al.,* 1988). A NAWQA study of the Cook Inlet Basin, Alaska, was begun in 1997, and one of the issues identified as important to water quality in that area was the effect of residential development (Frenzel, 1997).

Bacterial and other microbiological assessments often are important parts of state and local monitoring programs, yet they have received little attention in national scale studies (Francy *et al.,* 2000). Water-quality standards for fecal-indicator bacteria depend on the intended use of the water, and standards vary greatly among states. In Anchorage, several streams and lakes are listed by the State as water-quality impaired (for recreational use) due to elevated concentrations of fecal-coliform bacteria. The fecal-coliform bacteria standard in Alaska for water-contact recreation is 100 colonies per 100 milliliters of water (100 col/100 mL) using the geometric mean of samples collected during a 30-day period (Alaska Department of Environmental Conservation, 1999). Additionally, no more than 10 percent of the samples (if more than 10 samples are collected) may exceed 200 col/100 mL. Although some of Anchorage's drinking water is supplied from a reservoir in the upper Ship Creek basin, drinking-water standards are not applicable to the sites sampled in the lower part of the basin during our study.

Alaska, as well as many other states, does not currently have a water-quality standard for concentrations of *Escherichia coli* (*E. coli*) or enterococci. The U.S. Environmental Protection Agency (USEPA) has recommended that states adopt standards for those indicator bacteria, particularly for recreational waters, because of potential nonfecal sources of fecal-coliform and fecal-streptococci bacteria (U.S. Environmental Protection Agency, 1986; 1999). Alternatively, *E. coli*, a member of the fecal-coliform group, which inhabits only the gastrointestinal tract of warm-blooded animals, provides specific evidence of

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contamination from a fecal source. Enterococci are a subgroup of the fecal-streptococci bacteria, but are a more specific indicator of fecal contamination in water than fecal-streptococci bacteria (Francy *et al.,* 2000). The recommendation of *E. coli* and enterococci bacteria for standards in recreational-use water was based on studies that showed statistically significant relations between concentrations of those bacteria and gastrointestinal illness in swimmers (U.S. Environmental Protection Agency, 1986). Conversely, no relation was observed between fecal-coliform bacteria concentrations and gastrointestinal illness.

Water quality degradation in response to residential development, or urbanization, has been documented by numerous researchers (e.g., Klein, 1979; Whiting and Clifford, 1983; Garie and McIntosh, 1986; Booth, 1991; May *et al.,* 1997; Winter and Duthie,1998; Milner and Oswood, 2000; Wang *et al.,* 2000). However, few studies describe fecal-indicator bacteria in relation to residential development. Mallin *et al.* (2000) found that in five watersheds, fecal-indicator bacteria concentrations were significantly correlated with watershed population, percentage of developed land, and impervious area. Embrey (2001) also observed that fecal-indicator bacteria concentrations closely corresponded to the level of human population density in urban/suburban watersheds.

Purpose and Scope

To address the issue of residential development in the Cook Inlet Basin, a sampling network of 14 sites in five stream basins in Anchorage was established. Preliminary information was obtained at those sites in 1999, and more thorough sampling was done in 2000. One aspect of that study is an examination of fecal-coliform, *E. coli,* and enterococci-bacteria concentrations under a variety of hydrologic conditions and a gradient of residential development. This paper describes the results of that aspect of the larger study.

Description of Study Area and Site Classification

The Municipality of Anchorage is located in south central Alaska and is bordered by the Chugach Mountains on the east and the Knik and Turnagain arms of Cook Inlet to the north, west, and south (Figure 1). Detailed descriptions of the streams sampled for this study may be found at http://ak.water.usgs.gov/Projects/Nawqa, and some characteristics are shown in Table 1. Streams originate in the mountains and flow through undeveloped lands before entering a residential area of about 260,000 people. Ship Creek, which flows through military lands, has little residential development. Chester Creek has the highest population density of the stream basins sampled. Campbell Creek drains large areas of park land, but has relatively high population density in the lower parts of the basin. Chester and Campbell Creeks flow into Westchester Lagoon and Campbell Lake, respectively; both are popular recreation areas. Little Rabbit and Rabbit Creeks are located in south Anchorage and drain a low-density residential area known as the "Hillside." Ice covers the streams in Anchorage on average from late November to the beginning of April, depending on elevation. Areas of the Chester Creek basin remain ice-free during the winter, providing areas where waterfowl congregate. Streamflow minima usually occur just prior to the break-up of ice cover. Snowmelt runoff may begin at lower elevations in Anchorage in early April, but peak flows typically result from runoff of higher elevation snowpacks in late May to June. Streamflow generally recedes until runoff from summer rains in late July through September increases streamflow.

Sampling sites were selected to represent a gradient of residential development in Anchorage. We grouped sites into three categories-low, medium, and high population density-according to their subbasin population density (Table 1). The break between low and medium population density was made at 39 persons per square kilometers (km^2) or 100 persons per square mile (mi^2), and between medium and high population density at 390 persons/km^2 or 1,000 persons/mi^2. Using these criteria, five sites are low-density, six are medium-density, and three are high-density. Population data were for 1998 (Municipality of Anchorage, unpublished data), and locations of residences for 1999 (Municipality of Anchorage, 1999). A distinction is made between rural and urban areas at 1,000 persons/mi^2 by the U.S. Census Bureau (1990). Using that distinction, only 3 of the 14 subbasins (C3, CH2, and CH3) sampled would be considered urban. Two sites on Rabbit Creek (R2 and R3) are approaching an urban population density (Table 1).

Populations in the Campbell and Chester Creek basins are largely served by a sanitary-sewer system (hereinafter "sewer"), whereas in the Little Rabbit and Rabbit Creek basins wastewater is treated by household septic systems ("septic"). However, to compare areas served by sewer systems to areas served by septic systems, sites in basins with very few residents – the low-population-density sites – were not included. Therefore, sites considered to represent areas served by sewer systems were two Campbell Creek sites (C2 and C3) and two sites in the Chester Creek basin (CH2 and CH3). Sites considered to represent areas served by septic systems were on Rabbit

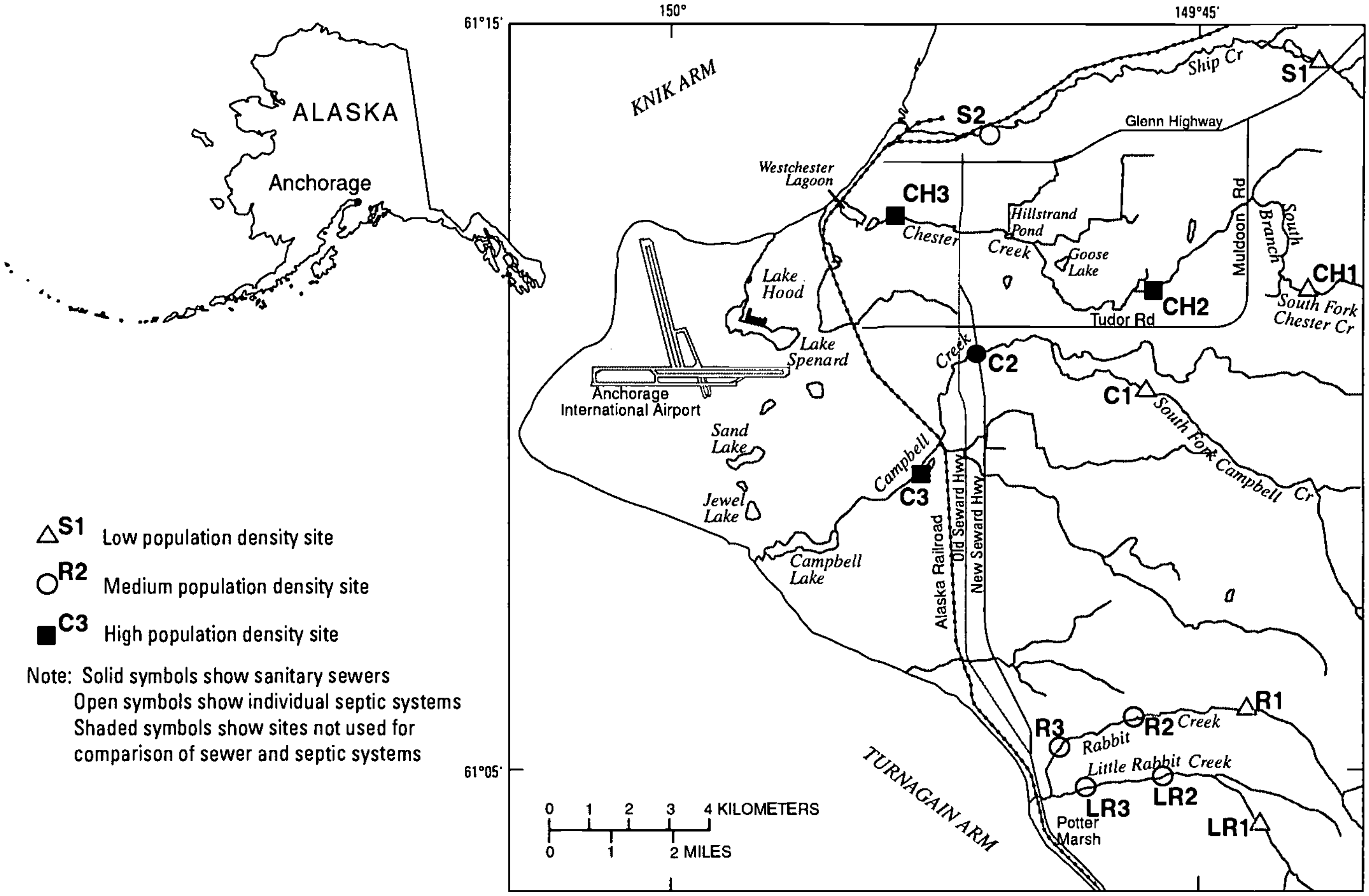

Figure 1. Location of Sampling Sites in the Anchorage Area.

Creek (R2 and R3) and Little Rabbit Creek (LR2 and LR3) (Table 1).

Storm-water sewers, or storm drains, in Anchorage are used to collect surface runoff. The network of storm drains closely follows sanitary-sewer lines where the latter exist. However, geographical information system data show that storm drains have outlets to streams, whereas sanitary-sewer lines do not. Storm-drain density is used in this paper to describe the degree of hydrologic alteration in a given subbasin.

METHODS

Sample Collection and Processing

All bacteria samples were collected from streams using either depth- and width-integrating methods described by Edwards and Glysson (1999), or the hand-dip method described by Myers and Sylvester (1997). Sampling equipment was purchased presterilized or was autoclaved before use. After collection, samples were transported on ice to the USGS Alaska District Field Office in Anchorage for processing within six hours. The samples were processed using the membrane filtration method and incubated as described by Myers and Sylvester (1997). Equipment blanks using sterile, buffered water were processed to check for equipment sterilization before each sample was filtered, and procedure blanks were processed after sample filtration to check that adequate rinsing techniques were used. Typically, three to four different volumes of sample water were processed for each sample collected. Bacteria colonies were enumerated for each volume of water filtered, resulting in counts within a statistically ideal range (ideal count), outside of the ideal range (nonideal count), or too numerous to count (TNTC; Myers and Sylvester, 1997). A single concentration for each fecal-indicator bacteria was reported for each sample, although as many as seven volumes of water, including replicates, may have been processed for that environmental sample.

TABLE 1. Description of Sampling Sites in Anchorage, Alaska; Listed in Downstream Order (see Figure 1 for site locations).

Map ID	Site Name	Subbasin Drainage Area (km^2)	Stream Gradient (percent)	Subbasin Population Density (No./km^2)*	Subbasin Population Density Category	Subbasin Wastewater System Designation	Subbasin Storm Drain Density (km storm (drains/km^2)
R1	Rabbit Creek at Hillside Drive	25.5	3.10	12	Low	–	0
R2	Rabbit Creek at E. 140th Street	3.8	3.96	323	Medium	Septic	0
R3	Rabbit Creek at Porcupine Trail	5.2	2.80	376	Medium	Septic	0
LR1	Little Rabbit Creek at Nickleen Street	6.7	5.81	23	Low	–	0
LR2	Little Rabbit Creek at Goldenview Drive	7.7	4.92	70	Medium	Septic	0
LR3	Little Rabbit Creek Near Anchorage	2.1	4.96	222	Medium	Septic	0.74
C1	S. Fork Campbell Creek Near Anchorage	75.5	0.95	4	Low	–	0
C2	Campbell Creek at New Seward Hwy.	43	0.40	180	Medium	Sewer	0.77
C3	Campbell Creek at C Street	51	0.26	691	High	Sewer	3.27
CH1	S. Branch of S. Fork Chester Creek at Tank Trail	11.1	2.86	0	Low	–	0
CH2	S. Branch of S. Fork Chester Creek at Boniface Parkway	27.2	0.72	664	High	Sewer	2.82
CH3	Chester Creek at Arctic Blvd.	32.4	0.40	1750	High	Sewer	9.43
S1	Ship Creek at Glenn Hwy.	268	0.79	0	Low	–	0
S2	Ship Creek Below Powerplant at Elmendorf Air Force Base	26	0.48	122	Medium	–	0.54

*Based on 1998 population data (Municipality of Anchorage, unpublished data).

Quality Control

In addition to the total of 370 filter and procedure blanks, 17 sets of field blanks were processed. Fecal indicator bacteria were detected seven times in filter, procedure, and field blanks. On four occasions, 1 col/100 mL was observed and there was one observation each at 2, 3, and 5 col/100 mL. A total of 79 replicate volumes of sample water were filtered, including triplicate volumes for some samples. The median difference between replicates was 25 percent and the median concentration for the samples that were replicated was 27 col/100 mL.

Data Analysis

The statistical distribution of fecal-indicator bacteria concentrations was examined by using box plots and by comparing the data to a normal distribution. All data collected from March 2000 through November 2000 at all 14 sites were included in the plots. These plots show that the data do not appear to be normally distributed. Data transformations did not consistently produce normally distributed data; therefore, a nonparametric approach was used to test hypotheses. Only samples for fecal-indicator bacteria collected from March through September 30, 2000, were included in the hypotheses testing. Additional samples were collected at sites C1 and CH3 during the course of routine sampling for the NAWQA program and were used to describe the statistical distribution of fecal-indicator-bacteria data.

Fecal-indicator-bacteria concentrations were compared among: (1) population-density categories, (2) sewer and septic areas, and (3) seasons. To compare two sets of samples a Wilcoxon-rank-sum test (Wilcoxon, 1945), the nonparametric equivalent of a t-test, was performed using the S-PLUS 2000 software (MathSoft, Inc., 1999). Because these hypotheses dealt with specific sets of sites or dates, not all data were included in each statistical test. Comparisons between population density groups were made using all data collected from March through September 2000. Comparison of sewer and septic areas was done using data from sites C2, C3, CH2, CH3 and R2, R3, LR2, LR3, respectively. Seasonal comparisons were made using data from all sites. Samples collected from March to early April were designated "winter samples;" "snowmelt" samples were collected at high streamflows from late April to mid-July; and "summer" samples were collected at lower streamflows from late July through September (Figure 2).

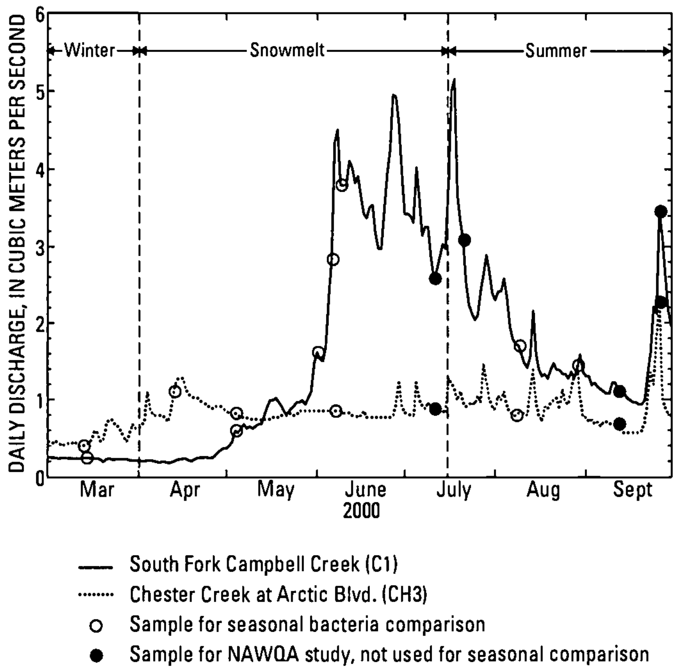

Figure 2. Hydrographs and Sample Collection Dates for South Fork Campbell Creek (C1) and Chester Creek at Arctic Boulevard (CH3).

RESULTS AND DISCUSSION

Fecal-indicator bacteria counts from the 14 sites in Anchorage ranged from less than 1 col/100 mL (*E. coli* and enterococci) to an estimated 3,400 col/100mL (enterococci). On several occasions, an ideal count could not be obtained from the volumes of water filtered. Ranges and geometric means of each bacteria group for each site are shown in Table 2. Samples collected at all 14 sites during winter, snowmelt, and summer were supplemented by additional sampling for the NAWQA program at two sites, South Fork Campbell Creek (C1; Figure 2) and Chester Creek at Arctic Blvd (CH3). Including all data collected during 2000, fecal-indicator bacteria concentrations for groups of sites used in hypothesis testing are shown in Figure 3.

Quality-assurance samples showed that field and laboratory techniques were generally effective in preventing sample contamination and results were repeatable. Samples collected to describe short-term variability also verified the repeatability of the bacteria measurements, but demonstrated the extreme variability in samples collected hours apart and with little change in streamflow (Table 3).

All bacteria groups measured showed a tendency to have many samples with relatively low concentrations and a few relatively high concentrations. The highest

TABLE 2. Range and Geometric Mean Concentrations of Fecal-Indicator Bacteria From Samples Collected in 2000 (see Figure 1 for site locations).

	E. coli		Fecal Coliforms		Enterococci	
Map ID	**Range**	**Geometric Mean (number of samples)**	**Range**	**Geometric Mean (number of samples)**	**Range**	**Geometric Mean (number of samples)**
R1	1-6	3 (3)	1-4	2 (3)	1-13	5 (3)
R2	2-81	17 (3)	4-120	24 (3)	1-4	2 (2)
R3	3-9	5 (3)	6-12	8 (3)	1-5	3 (3)
LR1	1-55	4 (3)	2-45	6 (3)	4-50	20 (3)
LR2	1-90	7 (3)	1-97	10 (3)	6-34	14 (3)
LR3	11-32	21 (3)	3-42	17 (3)	24-32	28 (3)
C1	1-29	5 (10)	2-110	9 (10)	< 1-25	3 (10)
C2	1-26	3 (3)	5-35	12 (3)	6-49	22 (3)
C3	8-55	24 (4)	11-76	37 (4)	20-87	32 (4)
CH1	1-5	2 (3)	1-7	2 (3)	1-30	5 (3)
CH2	67-700	270 (3)	90-2500	660 (4)	87-2400	450 (3)
CH3	21-1500	160 (7)	58-1500	360 (9)	1-3400	120 (10)
S1	< 1-2	1 (3)	1-10	3 (3)	1-3	2 (3)
S2	3-24	10 (3)	9-31	17 (3)	17	17 (1)

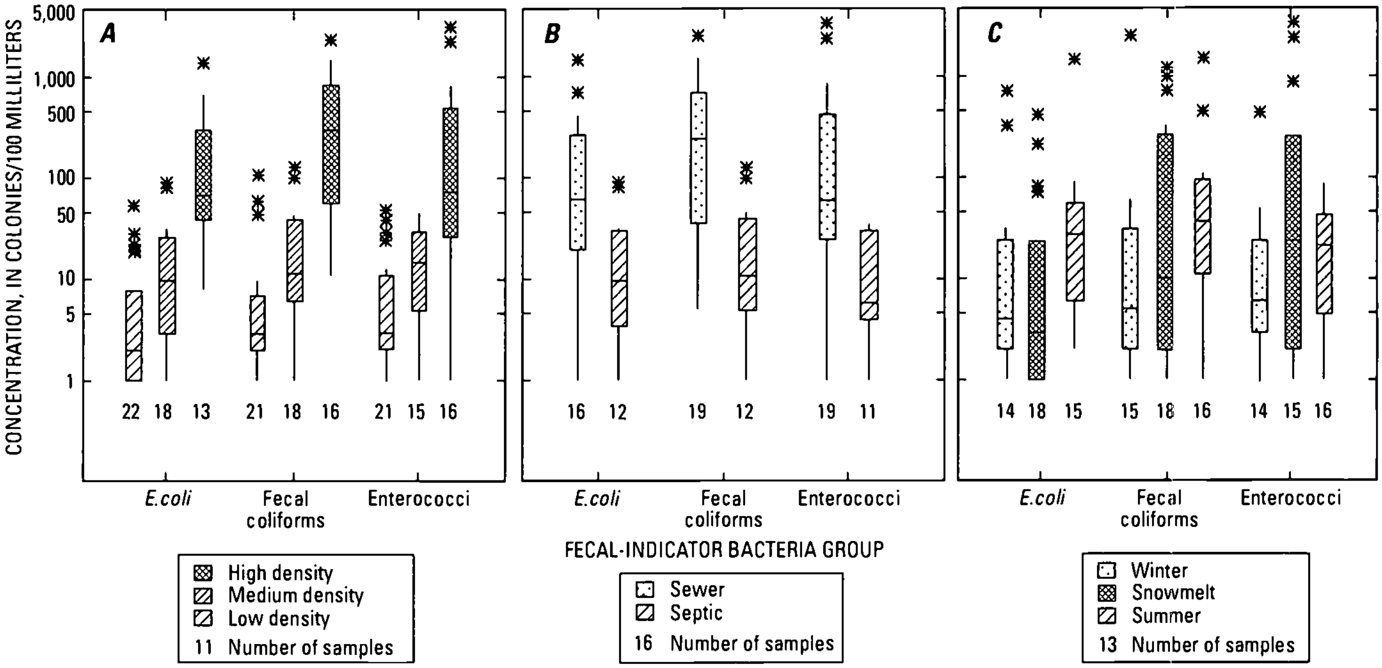

Figure 3. Fecal-Indicator Bacteria Concentrations (a) at Sites in Three Population Density Groups, (b) at Sites in Areas Served by Central Sewer or Individual Septic Systems, and (c) During Different Seasons.

TABLE 3. Short-Term Variability of Fecal-Indicator Bacteria Concentrations at Chester Creek at Arctic Boulevard (CH3), Triplicate (TNTC, too numerous to count).

Date	Time	Stream Discharge (m^3/s)	*E. coli*			Fecal Coliforms			Enterococci		
November 16, 2000	1300	0.52	1700	1800	1700	3500	3400	TNTC	990	1300	1600
November 16, 2000	1700	0.52	80	93	67	60	60	130	640	600	430
November 17, 2000	1130	0.52	73	87	73	70	87	110	350	850	850
November 17, 2000	1440	0.57	2500	2570	2910	4000	4000	3900	200	260	190

concentrations for each bacteria group measured were from samples collected at either South Branch South Fork Chester Creek at Boniface Parkway (CH2) or at Chester Creek at Arctic Blvd (CH3; Table 2).

Statistically different fecal-indicator bacteria concentrations were noted in eight of the nine possible comparisons of the population density groups (Table 4). Only for the comparison of enterococci between low and medium density sites were the results inconclusive. Sites in the high population density groups had significantly higher concentrations of all bacteria groups tested than did sites in the low and medium density groups. A comparison of sites on streams draining areas served by a central sewer system and areas served by individual septic systems showed a significant difference for fecal-coliform bacteria and enterococci concentrations. Comparisons among seasons showed only one statistically significant difference, winter versus summer samples for fecal coliforms (Table 4).

Although samples of fecal-indicator bacteria were not collected for the purposes of determining potential violations of water-quality standards, it may be useful to compare observed concentrations to suggested and existing standards. Alaska currently (2001) has contact-recreation standards only for fecal coliforms (100 col/100 mL geometric mean or 200 col/100 mL for no more than 10 percent of samples), which were exceeded in several samples. The U.S. Environmental Protection Agency (1986) suggested a geometric mean concentration of 126 col/100 mL for *E. coli* bacteria as a standard for primary-contact recreational (swimming) waters. Additionally, it was recommended that no more than 10 percent of the samples within a

TABLE 4. Results of Statistical Comparisons of Fecal-Indicator Bacteria Concentrations Between Groups of Sites (differences significant at α = 0.05 shown in bold).

		p-Values From Wilcoxon Rank-Sum Test (number of samples in comparison groups)		
Comparison	**Null Hypothesis**	***E. coli***	**Fecal Coliforms**	**Enterococci**
Low Versus Medium Population Density	Low = Medium	**0.0370** (22:18)	**0.0072** 21:18)	0.0643 (21:15)
Low Versus High Population Density	Low = High	**< .0001** (22:13)	**< .0001** (21:16)	**< .0001** (21:16)
Medium Versus High Population Density	Medium = High	**.0010** (18:13)	**< .0001** (18:16)	**.0014** (15:16)
Sewer Versus Septic Systems	Sewer = Septic	.0599 (16:12)	**.0014** (19:12)	**.0014** (19:11)
Winter Versus Snowmelt Season	Winter = Snowmelt	.5626 (14:18)	.2767 (15:18)	.3933 (14:15)
Winter Versus Summer Season	Winter = Summer	.0517 (14:15)	**.0241** (15:16)	.2612 (14:16)
Snowmelt Versus Summer Season	Snowmelt = Summer	.0519 (18:15)	.5456 (18:16)	.7817 (15:16)

30-day period exceed 235 col/100 mL (single-sample standard). Only at the two sites in the urbanized parts of the Chester Creek Basin were *E. coli* concentrations from any samples greater than 235 col/100 mL (Table 2). Higher concentrations of fecal-coliform bacteria than of *E. coli* (Table 2) suggests that the flushing of sediment particles into the stream increased the concentrations of fecal-coliforms not associated with warm-blooded animals. The use of *E. coli* as a means of monitoring reduces the chance of falsely attributing fecal coliform bacteria concentrations to contamination from warm-blooded animals.

Water-quality standards for enterococci bacteria have been established for very few states. The USEPA's recommended standard for primary-contact recreation is a geometric mean of 33 enterococci bacteria col/100 mL (U.S. Environmental Protection Agency, 1986). In contrast with *E. coli*, several sites in our study had single-sample concentrations well above the 33 col/100 mL level (Table 2). For example, site CH3 on Chester Creek just upstream from Westchester Lagoon, had enterococci-bacteria concentrations ranging from 1 to 3,400 col/100 mL, or nearly 100 times the guideline for primary-contact recreation. Although enterococci-bacteria concentrations from sites CH2 and CH3 were at least an order of magnitude higher than at other sites, a total of six sites had at least one sample in which enterococci-bacteria concentrations exceeded 33 col/100 mL. The high degree of short-term variability may also have implications in terms of testing for compliance with water-quality standards.

There was a large amount of overlap in comparisons of high and medium population density sites and comparison of areas served by central sewer systems and by individual septic systems. Site C2 was the only site served by a sewer system that was not in the high population density group. Therefore, results of comparisons between sewer and septic areas may not provide additional information that is not described by population density. An additional factor that distinguishes sites with sewer from those with septic is the presence of storm drains (Table 1). Storm drains are extensively developed only in the Chester Creek basin (and to a lesser degree in the lower Campbell Creek basin) and route surface runoff directly into the stream. Upstream from the site at Boniface Parkway (CH2), 18 storm drains discharge into the creek. Between CH2 and CH3, an additional 37 storm drains discharge into the creek. The presence of the storm drains, therefore, may affect transport of fecal-indicator bacteria from the land surface to the streams for those two sites in the urbanized area of Chester Creek basin.

Fecal-indicator bacteria need not be introduced into the streams immediately prior to sample collection in order to be detected. Survival times for fecal-indicator bacteria are variable, as long as a month or more, and are affected by water temperature and fine-grained sediment concentrations (Sherer *et al.,* 1992;

Howell *et al.,* 1996). Bacterial survival times, expressed as a half-life, decreased from 15.6 and 35.9 days for fecal coliform and fecal streptococci in 4°C water to 13.9 and 6.4 days in 25°C water (Howell *et al.,* 1996). Bacteria that settle to streambeds with clay-rich sediments may survive several months and may be redistributed when the bed material is disturbed (Sherer *et al.,* 1992). Sites in the more urbanized areas of Anchorage (C2, C3, CH2, and CH3) tended to have finer-grained sediments in the streambed, thereby providing a more favorable habitat for bacteria than at the less urbanized sites.

Comparisons of seasonal samples revealed one significant difference-fecal coliform concentrations were significantly higher during the summer than winter. Perhaps more notable was the much larger range of concentrations observeed for fecal coliforms and enterococci during snowmelt than during other seasons (Figure 3). The long duration of snowmelt in Anchorage and the timing of peak flows at the various sites probably contribute to the variability in fecal-indicator bacteria concentrations among the sites.

Indications of the need for a large number of samples may be evident in the extreme variability in fecal-indicator bacteria concentrations measured over the course of two days at Chester Creek at Arctic Blvd (CH3; Table 3). A similar, although not as extreme, range of variability in E. coli was observed in samples collected from morning to evening at two sites in the Yakima River basin, Washington (Embrey, 1992). The data from our study show that with little or no change in stream discharge, concentrations in samples taken hours apart may vary by more than an order of magnitude. Quality control samples (triplicates) indicate that the data are repeatable. Therefore, some processes unrelated to stream discharge affected fecal-indicator bacteria concentrations. *E. coli* and the more broadly encompassing group of fecal-coliform bacteria varied in similar patterns, whereas enterococci concentrations varied somewhat differently (Table 3). One possible explanation for the variability, high concentrations, and differences between coliform bacteria and enterococci bacteria may be the waterfowl that are concentrated in areas of open water in the Chester Creek basin during the winter months. A significant positive correlation between gull densities and fecal-coliform-bacteria concentrations at a swimming beach in Quebec was observed by Levesque *et al.* (1993).

CONCLUSIONS

Sites or groups of sites that represent areas of little or no human population had fecal-indicator bacteria concentrations significantly lower than sites in areas with relatively high population densities. Fecal-indicator bacteria concentrations showed consistently high levels at two sites in the Chester Creek basin (CH2 and CH3). These sites have some of the highest population densities and storm-drain densities of the sites sampled. The sources of fecal-indicator bacteria to the stream cannot be determined from these data. The lower stream gradient and greater proportion of fine-grained sediments in the streambed of the Chester Creek basin may yield an environment more conducive to bacterial deposition and survival than exists at other sites. Additionally, areas of the Chester basin tend to remain ice-free during the winter, providing areas where waterfowl concentrate. The sites in areas having the highest population density generally are served by a central sewer system, whereas sites in areas with lower population density are served by individual septic systems. Storm sewers in the Chester Creek basin that route surface runoff directly to the stream may affect the transport of fecal-indicator bacteria in that basin. The CH3 site is just upstream from Westchester Lagoon, a popular recreational area. Enterococci-bacteria concentrations at CH3 can be as much as 100 times a recommended guideline for primary-contact recreation.

Fecal-indicator bacteria concentrations were highly variable over a two-day period of stable streamflow at two sites in the Chester Creek basin. This variability may have implications in terms of testing for compliance with water-quality standards. Enterococci-bacteria concentrations showed a different pattern of variability from *E. coli* and fecal-coliform-bacteria concentrations during that period.

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