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Fecal Coliform Bacteria Loading from the Polecat Creek Watershed in Virginia, USA

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Polecat Creek 유역의 분변성 대장균 배출 부하 특성. 임상준* · Saied Mostaghimi[1] (한국건설기술연구원 수자원연구부, [1]버지니아 주립 공과대학 생물시스템공학과)

분변성 대장균(Fecal coliform bacteria)은 미국 버지니아주의 수체에 있어서 주요 오염원 중의 하나이다. 1995년부터 2000년까지의 Polecat Creek 유역의 4개 측정지점에 대하여 하천수의 분변성 대장균 농도를 조사하였다. 조사기간 동안에 측정된 분변성 대장균 농도의 중앙값은 80 cfu/100 mL부터 170 cfu/100 mL까지 변화하였으며, 기하평균은 81 cfu/100 mL부터 141 cfu/100 mL의 범위를 보였다. Caroline호의 수체에 의한 희석과 침전 등의 영향으로 측정지점 QPB의 분변성 대장균 농도가 주변의 측정지점인 QPD보다 낮게 나타났다. 계절별로는 여름철(6～8월)에 비교적 높은 농도를 보인 반면에 겨울철(12～2월)에는 상대적으로 분변성 대장균의 농도가 낮게 조사되었다. 이는 여름철 기간동안에 가축과 야생동물들이 하천에서 보내는 시간이 많기 때문에 이들 동물의 분비물이 직접 하천으로 유입되며, 낮은 온도보다는 높은 온도에서 대장균의 생장과 번식이 활발하기 때문이다. 본 연구의 결과로부터 분변성 대장균과 같은 미생물의 조사는 조사목적에 따라 측정시기를 결정하는 것이 측정에 의한 오차를 배제할 수 있을 것으로 판단되었다.

Key words : fecal coliform, bacteria contamination, geometric mean, seasonal variability

INTRODUCTION

Bacteria contamination of surface water is the most widespread problem in the mid-Atlantic region of the United States. Of more than 50,415 miles of rivers and streams in Virginia, over 300 miles of reaches are impaired due to high fecal coliform (FC) bacteria concentration (VaDEQ, 2002). FC bacteria are not necessarily dangerous to human, but their presence in streams or rivers indicates contamination by fecal materials from warm-blooded animals, such as human, domestic livestock, pets, and wildlife (Baxter-Potter and Gilliland, 1988; Niemi and Niemi, 1991). This contamination poses human health risk and threatens recreational uses of many lakes and streams. Water quality standards for FC bacteria depend on the intended use of the water, and vary greatly among states in the United States. Virginia established two water quality standards for FC bacteria in non-shell fish waters (SWCB, 2003). The maximum allowable level of FC shall not exceed a geometric mean of 200 colony forming units (cfu)/100 mL for any calendar month, nor shall more than ten percent of the samples examined during any month exceed a 400 cfu/100 mL.

Monitoring of in-stream concentration is one of the most commonly used methods to identify sources and determine the magnitude of bacteria contamination (Valiela *et al*., 1991). In-stream

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concentration of FC bacteria can be affected by variables such as land use, soil, runoff, and sampling timing (Edwards *et al*., 1997). Thus, it is needed to qualify the effects of these variables with a scientific sense.

As part of water quality monitoring program in Virginia, Virginia Tech has monitored FC bacteria at four monitoring stations within the Polecat Creek watershed in Virginia since 1995. The primary objective of this paper was to examine the occurrence of FC in streams in the watershed for the period of 1995 to 2000. Seasonal variation of FC concentration was also investigated.

STUDY AREA AND MONITORING NETWORK

The Polecat Creek watershed, as shown in Figure 1, is located in Caroline County in the northeastern Virginia. The total drainage area of the watershed is 12,048 ha and drains the Mattaponi River, one of main tributaries of the York River. The Polecat Creek watershed is located topographically within the Coastal and Piedmont Plains. The majority of the watershed lies in the Coastal Plain, while the upper area of the watershed is located in the Piedmont Plain. According to the 2000 U.S. Census (U.S. Census Bureau, 2000), approximately 6,400 people live in the Polecat Creek watershed, and most watershed residents are served by septic systems.

In 1995, a comprehensive monitoring project was initiated in the Polecat Creek. Surface water quantity and quality has been monitored at four stations on major rivers and their tributaries of the Polecat Creek. The locations of the monitoring stations are also shown in Figure 1. Site QPB received the outflow of the Lake Caroline, and installed to measure FC loading from a 2,658 ha subwatershed, which included the town of Ladysmith. Monitoring site QPC was located in the northwestern part of the Polecat Creek watershed and drained a subwatershed of 888 ha. Site QPD has a drainage area of 2,604 ha and contained entirely outflows from sites QPC. Site QPE was located at the outlet of the Polecat Creek watershed and represented the overall response of the watershed. Land use characteristics are summarized in Table 1.

Stream flow is measured using a continuous stage recorder at each site. Grab samples are collected monthly from the each site and analyzed for FC concentration under varying hydrologic condition (Mostaghimi *et al*., 2001).

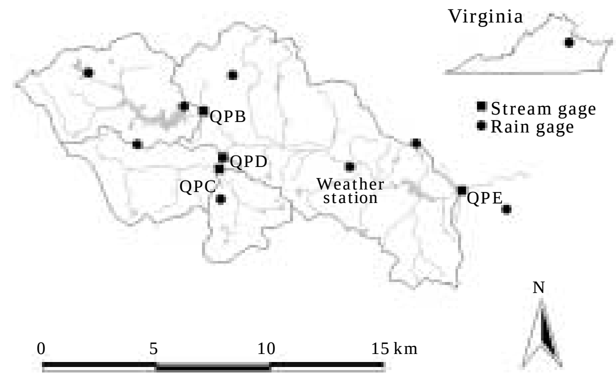

Fig. 1. Surface water monitoring sites in the Polecat Creek watershed.

Table 1. Land use data for selected sub-watersheds in the Polecat Creek watershed.

Land use	QPB	QPC	QPD	QPE
Area (ha)	2,658	888	2,605	12,048
Forest (%)	56.5	71.8	77.9	74.4
Cropland (%)	11.6	11.9	13.0	12.8
Pasture (%)	0.3	3.8	1.4	1.5
Commercial (%)	1.0	7.3	3.3	2.4
Residential (%)	25.4	5.2	4.4	7.8
Water (%)	5.2	0.0	0.0	1.1

One-way analysis of variance (ANOVA) was accomplished using natural logarithm of FC concentration to evaluate the effect of sampling time of year. The seasons were grouped as winter (December, January–February), spring (March–May), summer (June–August), and fall (September–November).

RESULT AND DISCUSSION

Data analysis included the estimation of univariate statistical parameters, such as arithmetic mean, geometric mean, median, minimum and maximum values. Summary statistics of FC concentrations collected at four monitoring sites in the Polecat Creek watershed are presented in Table 2. A total of 76 bacteria samples were collected from 1995 to 2000 at the watershed outlet (QPE), and 76 and 72 samples were available at two subwatersheds outlets, QPB and QPD, respectively.

The highest median concentration for all sites was 170 cfu/100 mL at site QPE. On the Polecat Creek watershed, the median FC concentration was lower at the upstream site (QPB and QPC) than at the downstream sites (QPD and QPE). Geometric means were also calculated to represent FC concentrations over the monitoring period. The geometric mean is the best estimate of central tendency for microbiological data to minimize the effect of outliers (APHA *et al.*, 1998). Geometric mean concentrations in water samples ranged from 81 cfu/100 mL at site QPB to 141 cfu /100 mL at site QPD.

Table 2. Summary statistics of FC concentrations at monitoring sites on the Polecat Creek watershed

Subwatersheds	QPB	QPC	QPD	QPE
No. of samples	76	66	72	76
Minimum (cfu/100 mL)	20[a]	20[a]	20[a]	20[a]
Maximum (cfu/100 mL)	9000[a]	9000[a]	9000[a]	5000
Arithmetic mean (cfu/100 mL)	455	1045	727	487
Median (cfu/100 mL)	80	95	150	170
Geometric mean (cfu/100 mL)	81	134	141	139
% exceedance of 400 cfu/100 mL (%)[b]	13.4	27.3	29.2	26.3

[a] 20 and 9000 are the minimum and maximum detection limits, respectively

[b] % exceedence is the percent of samples at that stations exceeding 400 cfu/100 mL

Bacteria concentrations in sampled data were also compared to the instantaneous maximum standard of 400 cfu/100 mL for recreational uses. The percent exceedance was calculated by dividing the number of exceedance by the total number of samples and does not represent the amount of time that the water quality is in violation. The water quality standard of 400 cfu/100 mL for non −shellfish waters in Virginia (SWCB, 2003) was exceeded by 14 samples (18.4%) collected at QPB, 18 samples (27.3%) at QPC, and 21 samples (29.2 %) at QPD. Of the 76 water quality samples collected from 1995 through 2000 at the outlet of the watershed (QPE), 26.3% of the samples exceeded the instantaneous standard of 400 cfu/100 mL. A review of the available monitoring data for the watershed indicates that there is a violation of the instantaneous standard for all monitoring sites.

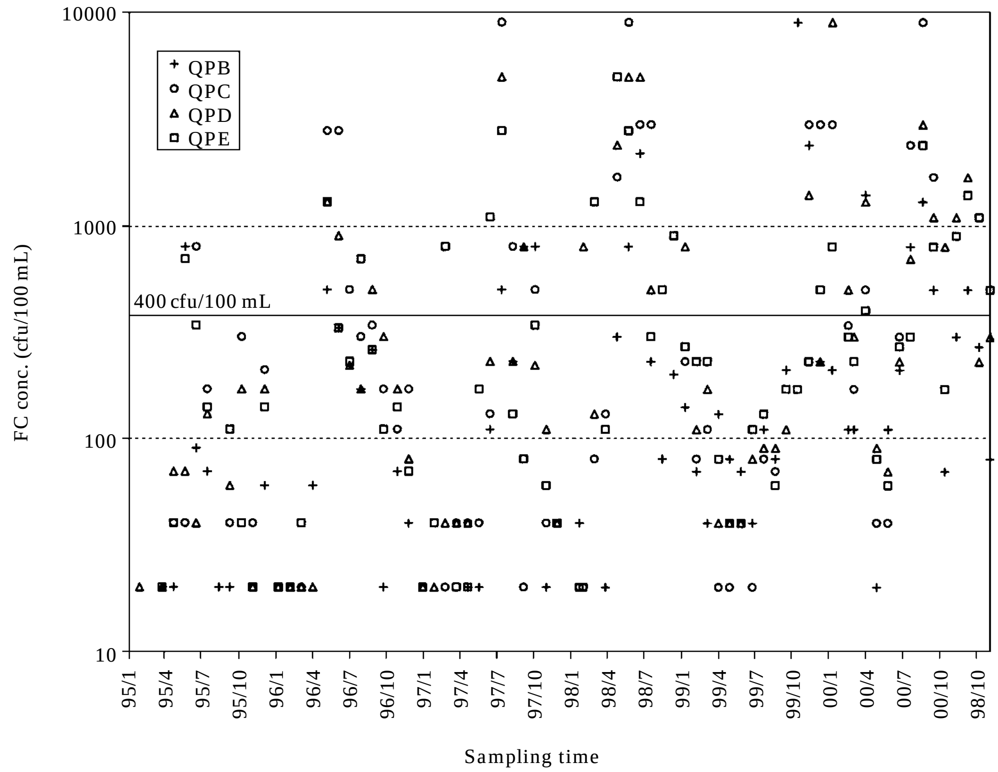

Fig. 2. The concentrations of FC bacteria collected at the Polecat Creek watershed.

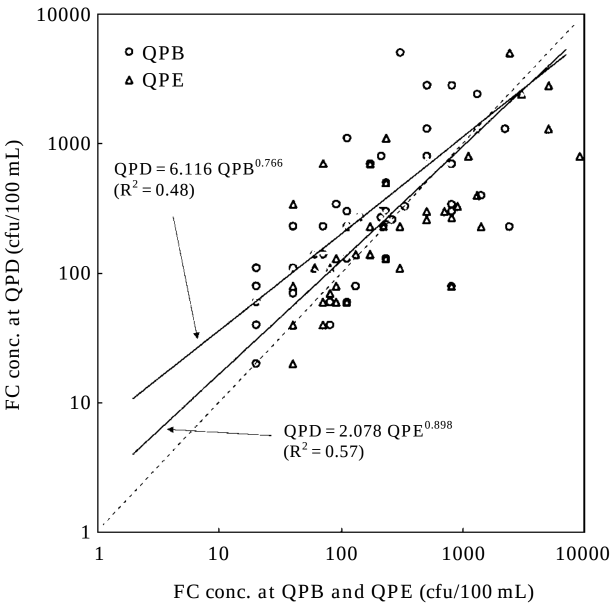

Fig. 3. A comparison of FC concentrations collected at different monitoring sites.

Time series of graph of the data collected at the monitoring sites from 1995 to 2000 is presented as Figure 2. The horizontal line indicating the 400 cfu/100 mL represents the instantaneous FC water quality standard for non−shell fish waters in Virginia.

By comparing FC concentrations collected at two watersheds, QPB and QPD, having almost the same drainage area (Table 1), it will be expected to evaluate the effects of different land uses and reservoir. Figure 3 indicates that the relatively lower concentration of FC bacteria at site QPB were found, as compared FC concentration collected at QPD. This is due to the effect of reservoir, Lake Caroline. The volume of water flowing into the reservoir is very small compared to the volume of water already residing in the reservoir, and the residence time of water in a reservoir is long. It causes to increase in natural die−off of bacteria by Lake Caroline (Socolofsky, 1997). However, no sample was collected at sites above and below the reservoir, it was impossible to quantitatively investigate the effect of reservoir in FC concentration. A comparison of in−stream FC concentrations collected at QPD and QPE is also presented in Figure 3. Although a great difference existed in size of the watershed between QPD and QPE, no significant difference in FC concentrations was observed in Figure 3.

Table 3. Geometric mean of FC concentration during the season in the Polecat Creek watershed

Monitoring	Season			
Sites	Winter	Spring	Summer	Fall
QPB	30a[1)]	52a	277b	100a
QPC	36a	82ab	785c	180b
QPD	59a	81a	449b	297b
QPE	47a	126ab	344c	229b

[1)]means with the same letter within a row are not significantly ($p > 0.05$) different.

To evaluate seasonal variability, all data was subject to ANOVA procedures and significant means were identified. The effect of the time of sample collection on geometric mean concentration is demonstrated in Table 3. Geometric mean concentrations of FC bacteria for the summer period ranged from 277 cfu/100 mL at monitoring site QPB to 785 cfu/100 mL at QPC over the period of 1995 to 2000, while geometric mean values for the winter period ranged from 30 cfu/100 mL at site QPB to 59 cfu/100 mL at QPD. Significant difference ($p < 0.05$) in geometric mean concentration of FC bacteria among the seasons were observed in Table 3. Table 3 also indicated that higher in−stream FC concentrations occurred during the summer and fall seasons for all monitoring sites. This is due to more cattle in streams and more animal waste land−applied during the fall. Greater survival and sometimes regrowth under warmer condition can be result in higher concentration during the summer (Howell *et al.*, 1995). Lower concentrations occurred during the winter and spring, and there were usually no significant differences in geometric means between those two seasons (Table 3). These findings are generally consistent with the results of Edwards *et al.* (1997), and Howell *et al.* (1995). They reported that the FC concentrations are generally higher in the warmer months than in the cooler months.

Seasonal variation of FC concentration in the streams was also evaluated by the whiskey box-plotting, as shown in Figure 4. Whiskey boxplot is a useful tool to show the variation in FC concentrations over the monitoring period. Figure 4 indicated seasonal variability with higher in−stream FC concentrations occurring during the summer period and lower concentrations typically occurring during the winter period.

FC bacteria contamination has a significant

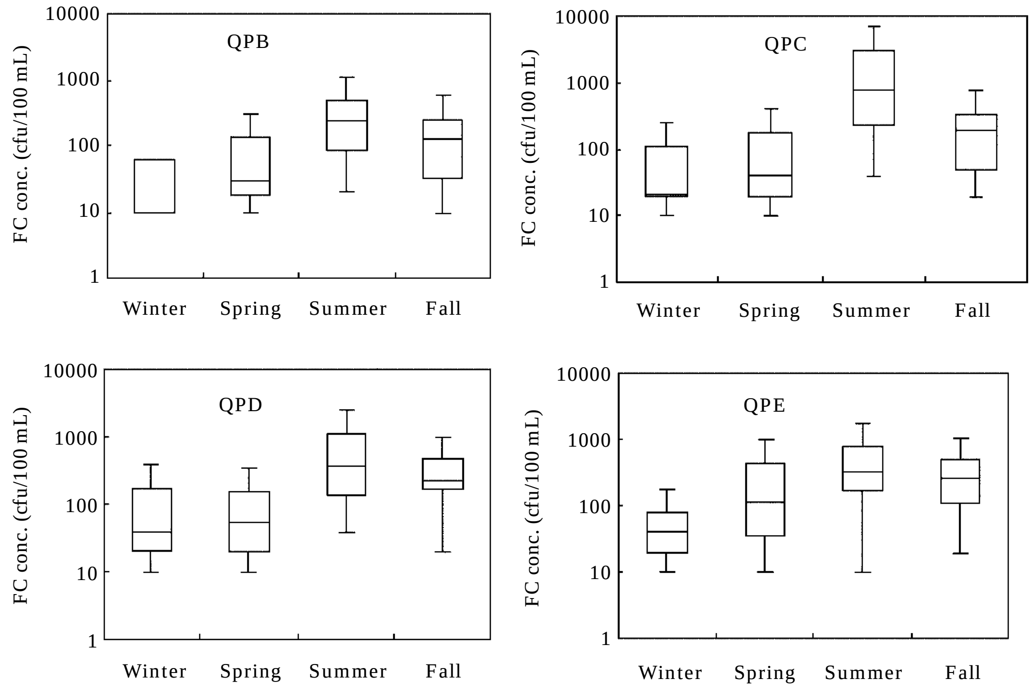

Fig. 4. Seasonal variations of FC concentrations.

role in terms of microbiological quality of surface waters. In−stream concentration of FC bacteria may be influenced simply by the season of sample collection. Therefore, the findings of this study can be helpful in planning the water quality monitoring program in Korea, as well as in USA. If, for example, water sampling is conducted during warmer months, the results can over−estimate the concentration of FC bacteria, because FC concentration is higher during warmer months than during cooler months. The inaccurate assessment of FC concentration due to the timing of sample collection can be avoided by sampling during the time of year under which the intended use is practical.

CONCLUSION

The surface water has been collected for analysis of FC bacteria at monitoring sites as a part of comprehensive monitoring program on the Polecat Creek watershed. A total of 290 bacteria samples were collected from 1995 through 2000 at four monitoring sites in the watershed.

The highest median concentration for all sites was 170 cfu/100 mL at site QPE, while the lowest concentration was 80 cfu/100 mL at site QPB. Geometric mean concentrations in water samples ranged from 81 cfu/100 mL at site QPB to 141 cfu/100 mL at site QPD. Site QPB has the relatively lower concentration of FC bacteria, due mainly to the dilution and deposition by Lake Caroline.

Geometric mean concentrations of FC bacteria for the summer period ranged from 277 cfu/100 mL at monitoring site QPB to 785 cfu/100 mL at QPC over the period of 1995 to 2000, while mean values for the winter period ranged from 30 cfu/100 mL at site QPB to 59 cfu/100 mL at QPD. FC concentration was significantly ($p < 0.05$) affected by the season of sample collection. FC concentration was generally higher in the warmer months than in the cooler months. This finding can be helpful in planning the water quality monitoring program to avoid the inaccurate assessment of water quality due to the timing of sample collection.

ABSTRACT

Fecal coliform bacteria is one of the most common cause of water quality impairments in Virginia, USA. Instream concentrations of fecal col-

iform (FC) bacteria were routinely monitored to assess surface water quality of the Polecat Creek watershed. Median concentration in water samples collected from 1995 to 2000 ranged from 80 cfu/100 mL to 170 cfu/100 mL, while geometric mean concentrations ranged from 81 cfu/100 mL to 141 cfu/100 mL. The dilution and deposition by Lake Caroline may cause to lower FC concentration at monitoring site QPB, as compared FC concentration at QPD. Higher in−stream FC concentration occurred during the summer period (June−August), and lower concentration typically occurred during the winter period (December−February). This is due to more cattle in streams, and greater survival and regrowth of FC bacteria under warmer condition. The findings of this study can be helpful in planning the water quality monitoring program to avoid the inaccurate assessment of water quality due to the timing of sample collection.

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