Distribution of *Escherichia coli* and Enterococci in Water, Sediments, and Bank Soils Along North Shore Channel Between Bridge Street and Wilson Avenue, Metropolitan Water Reclamation District of Greater Chicago

Submitted by
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SUMMARY

The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) wished to know the distribution and potential sources of fecal indicator bacteria, *E. coli* and enterococci, in water, sediments, and upland soils along an upstream and downstream portion of the North Shore Channel (NSC) that is the receiving stream for the District's North Side Water Reclamation Plant (NSWRP) outfall. Biweekly water and sediment samples were collected between August and October 2008 and included the following locations upstream of the outfall: Bridge Street (UPS-1), Oakton Street (UPS-2), the NSWRP outfall (OF), and downstream: Foster Avenue (DNS-1), and Wilson Avenue (DNS-2). *E. coli* and enterococci were consistently found in water and sediments at all sampling locations, with bacterial densities in water increasing below the NSWRP outfall; bacterial densities in sediment were more variable. On a relative measurement basis (i.e., 100 ml=100 g), both *E. coli* and enterococci densities were significantly higher in sediments than water. *E. coli* and enterococci were consistently recovered from bank soil along wooded, grassy, erosional, and depositional areas at two recreational parks, as well as other riparian areas along the river. Thus, soils along the river basin are likely sources of these bacteria to the NSC channel, introduced through runoff or other physical processes. Tributaries, such as the North Branch of the Chicago River (NBCR) that flow into NSC near Albany Ave, may provide a constant source of *E. coli* and enterococci to the NSC. Additionally, storm sewer outfalls may increase *E. coli* loadings to NSC during wet weather conditions. Our findings suggest that the abundance of nonpoint sources contributing to the overall fecal indicator bacteria (FIB) load in the NSC channel may complicate bacteria source determination and remediation efforts to protect the stream water quality.

INTRODUCTION

Fecal indicator bacteria (FIB), especially *Escherichia coli* and enterococci, have historically been used as markers of human pollution and then to develop water quality standards in the United States (USEPA 1986). While the primary source of FIB is the GI tract of humans and warm-blooded animals, there is growing evidence that populations of *E. coli* and enterococci do occur, survive, and may even grow in natural environments, such as soils and sediments (Hardina and Fujioka 1991, Solo-Gabriele et al. 2000, Byappanahalli et al. 2003, Byappanahalli et al. 2006b, Ishii et al. 2006), beach sand and water (Alm et al. 2003, Whitman and Nevers 2003, WHO 2003, Byappanahalli et al. 2006a, Ishii et al. 2007, Yamahara et al. 2008), and even in plant fluid of presumably pristine areas (Carrillo et al. 1985, Bermudez and Hazen 1988, Whitman et al. 2005). Consequently, identifying FIB sources in natural waters (e.g., lakes, ponds, streams) has not only proven to be a challenging task, but also requires considerable financial and technical resources. Such problems are amplified in large water bodies, such as the Chicago Area Waterway System (CAWS) that receive microbial pollutants from multiple sources.

The CAWS consists of 78 miles of man-made canals and modified river channels that support commercial navigation. Over 70% of the river volume originates from the discharge of treated municipal wastewater effluent (i.e., point source) from four Water Reclamation Plants (MWRDGC 2008). Additionally, it receives storm water, tributary streams, and runoff from urban and rural areas. It also supports recreational activities (e.g., boating, fishing, streamside recreation) and provides habitats for wildlife (MWRDGC 2008). The NSC carries two use designations: the waterway reach above the NSWRP is designated as general use, whereas, the section of the NSC downstream of the NSWRP is designated as secondary contact and indigenous aquatic life.

Previous research has shown that high levels of fecal coliform (FC) bacteria above the proposed limitation in effluent discharge (>400 colony-forming units, CFU/100 ml) (http://www.ipcb.state.il.us/documents/dsweb/Get/Document-59147) are common in the North Shore Channel (NSC) (MWRDGC 2007). For example, at Oakton Street, which is upstream of NSWRP outfall, FC densities (colony-forming units, CFU/100 ml) were as high as 9,800, 42,000, and 47,000 during dry weather, light rain, and heavy rain conditions, respectively (MWRDGC 2007).

In addition, NCBR tributary seems to adversely affect the microbiological quality of NSC. Under dry weather conditions, FC densities in NCBR that empties into the NSC near Albany Avenue (downstream of the outfall) increased by 100-fold after heavy rains: 3,500 CFU/100 ml during dry weather to 360,000 CFU/100 after heavy rains, respectively (MWRDGC 2007). It should be noted that most of the bacteriological studies in NSC and other connecting water bodies have focused on water, and to our knowledge, no systematic studies have been undertaken to identify and quantify bacterial contributions from environmental sources, including river sediments and bank soils.

The current study was focused on a segment of the NSC and NBCR from Bridge Street (Evanston, IL) to Wilson Avenue (Chicago, IL). The area surrounding this channel segment is a combination of urban, commercial, industrial, residential, and park land/open space. The overall goal of this study was to investigate the occurrence, distribution, and possible non-point sources of FIB in and along a portion of the NSC. Specific objectives were (a) to characterize the distribution of *E. coli* and enterococci in surface water and sediments above and below the

NSWRP outfall along a segment of the NSC/NCBR and (b) to determine the potential contributions of *E. coli* and enterococci from nonpoint sources, such as stream bank soils and river outfalls, to the channel basin.

MATERIALS AND METHODS

General Site Description

Most of the studies took place in and along the NSC, including the upper north branch of the NBCR. In brief, the NSC is man-made, begins at the North Branch Dam in West River Park, extends north for 12.3 km (7.7 miles), and receives sixteen CSO outfalls. The NSC consists of earthen side slopes, with an average width and depth of 27-m and 1.5 to 3.0 m, respectively. The NSC has a narrow riparian corridor that is bordered mostly by park land owned by the MWRDGC and managed in some locations by Evanston, Skokie, and Wilmette. The channel's riparian land use includes recreational parks and a few commercial lots (MWRDGC 2008).

Sampling Sites

The study area included a 10.7-km (6.7 miles) stretch (86%) of the NSC/NBCR, beginning 4.1 km (2.5 miles) above the NSWRP outfall and continuing downstream to 6.6 km (4.1 miles) below the plant outfall. There were a total of six main sampling sites, two upstream: UPS-1 at Bridge Street (42.056168°, -87.700571°) and UPS-2 at Oakton Street (42.026811°, -87.710081°); two downstream: DNS-1 at Foster Avenue (41.975897°, -87.704796°) and DNS-2 at Wilson Avenue (41.964910°, -87.697396°); the NSWRP outfall (OF) near Howard Street (42.021981°, -87.710173°); and the North Branch of Chicago River near Albany Avenue (AL)

(41.974066°, -87.705667°), (Figure 1). Storm-sewer samples were collected from two outfalls: at Cleveland Avenue-Pitner Avenue (Evanston; Storm Sewer-1) and at Lincoln Avenue-McCormick Blvd. (Lincolnwood; Storm Sewer-2). Additionally, soil/sediment samples were collected at two recreational parks: Channelside Park Canoe Launch (CP; above outfall) near UPS-2 and West River Park (RP; below outfall) near AL. In all, there were 10 sampling locations, including storm-sewer outfalls and the two recreational parks.

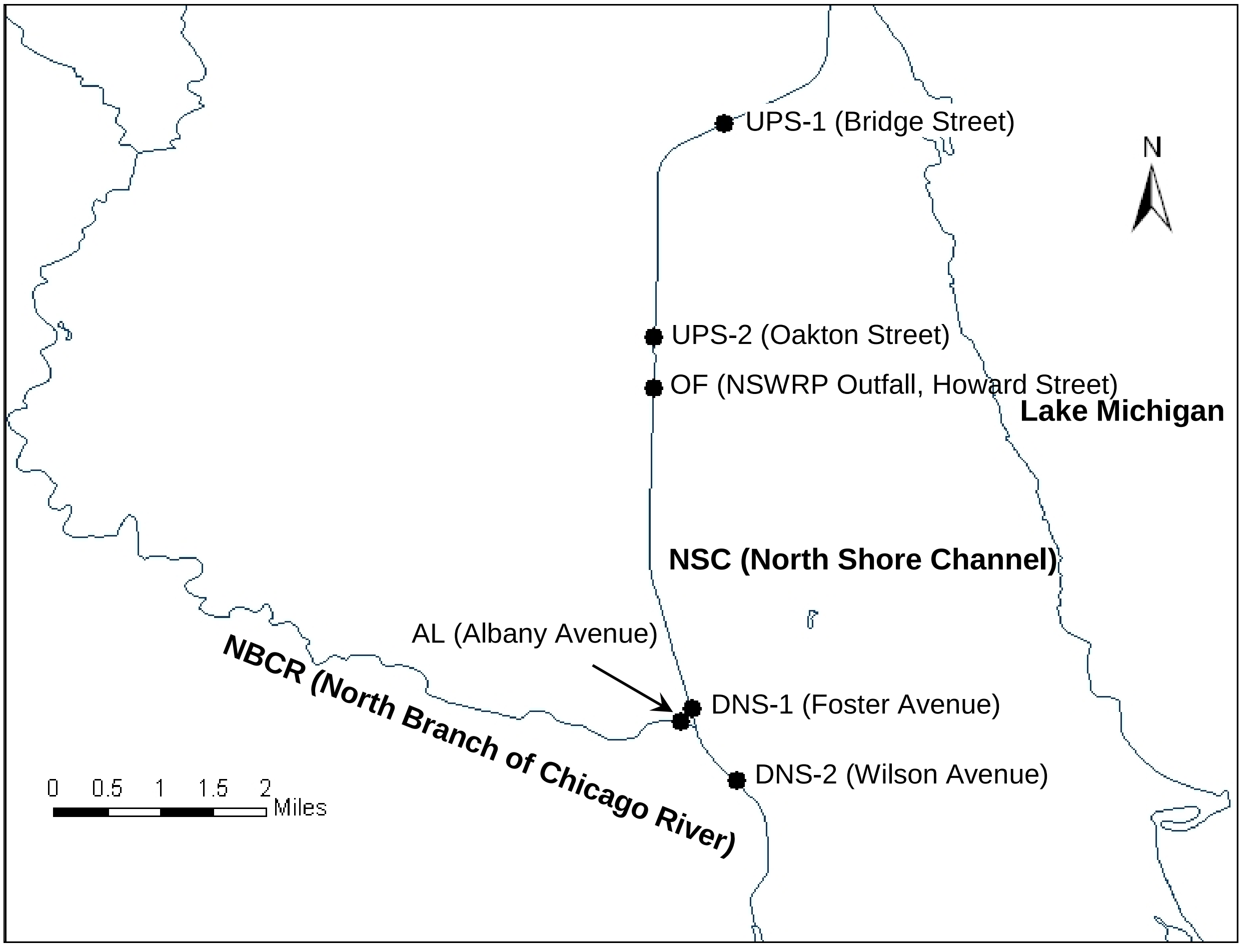

Figure 1. Sampling locations along the North Shore Channel and North Branch of Chicago River.

Sample Collection

Biweekly water and submerged sediment samples were collected on five occasions between August 26 and October 31, 2008 at UPS-1, UPS-2, DNS-1, DNS-2, and AL; only water was collected at OF. All locations, except for UPS-1 and AL, were reached by boat. All samples were collected using well established protocols, including sterile/sanitized containers and sampling equipments (APHA 2005). Triplicate samples of water were collected with a 500-mL bottle attached to a sampling pole and transferred into 18-oz (532 ml) Whirl-Pak bags (UPS-1 and AL) or with a bucket and transferred into 27-oz (798 ml) Whirl-Pak bags (boat sampling; DNS-2, DNS-1, OF, and UPS-2). Immediately following water sample collections, triplicate sediment samples (each approximately 500 g fresh weight) were collected at the same locations using a Petite Ponar or an Ekman sampler; samples were aseptically transferred into 24-oz (710 ml) Whirl-Pak bags. Triplicate water samples were collected from Storm Sewer-1 and Storm Sewer-2 locations on four occasions between September 4, 2008 and October 20, 2008.

Soil samples were collected on three occasions between September 23, 2008 and October 31, 2008 from two recreational parks along the NSC: Channelside Park Canoe Launch (CP; above outfall) near UPS-2 and West River Park (RP; below outfall) near AL. At both parks, samples from five randomly chosen areas (each approximately 2- to 5-m [length] × 1-m [width]) were collected from each of wooded, grassy, stream bank, and depositional areas. Within each of the five areas, five individual sub-samples, which were pooled immediately, were collected to a depth of approximately 10 cm with a sterile, liquid-medicine dispenser (as a sampling device) and placed into 7-oz (207 ml) Whirl-Pak bags. This sampling design resulted in a total of 20 soil samples, five each for wooded, grassy, stream bank, and depositional areas, per event. A different sterile liquid-medicine dispenser was used for each area to prevent cross-contamination between samples. Samples were placed on ice in a cooler during collection and transportation and analyzed for *E. coli* and enterococci within 24 hr of collection. General stream conditions, water and air temperature, and relevant weather conditions were recorded at each sampling location.

Terminology

We have used several terms, such as riparian, erosional, and depositional areas, where soil samples were collected over the course of this study and they are defined as follows. Riparian areas are those that are transitional zones between open water and dry land. Areas of the stream bank that are subject to erosion from physical processes (e.g., runoff) are defined as erosional areas. Areas adjacent to the waterline that are characterized by accumulating materials (soil, sediments) from upland and erosional areas are defined as depositional areas.

Microbiological Analysis

Water, sediment, and soil samples were analyzed for *E. coli* using the Colilert-18 method (Edberg et al. 1990, Edberg et al. 1991). Colilert results have been shown to correlate well with the results of traditional assays for *E. coli*—membrane filtration (MF) and multiple tube fermentation—in both fresh (Clark et al. 1991, Eckner 1998) and marine waters (Palmer et al. 1993). The Colilert-18 method has successfully been used to enumerate *E. coli* from a variety of environmental substrates other than water, including soil and sediment samples (Solo-Gabriele et al. 2000, Desmarais et al. 2002, Byappanahalli et al. 2003).

Sediment and soil samples in each Whirl-Pak bag were thoroughly homogenized with a sterile spatula for 2 min; a sub-sample (10 g fresh weight) was weighed into a 250-mL dilution bottle to which 90 mL phosphate-buffered diluent water (PBW; pH 7.0) (APHA 2005) was later added. Bacteria were elutriated by vigorously shaking the sediment-PBW mixture for 2 min; after standing for 2 min, the supernatant was used as is or serially diluted and then analyzed for *E. coli* as previously described (Byappanahalli et al. 2003). Enterococci were analyzed on pooled water or sediment/ soil supernatants using the membrane filtration (MF) technique with mEI agar (USEPA 2000). Bacterial densities in water are reported as most probable number (MPN)/100 ml (*E. coli*) and as colony-forming units (CFU)/100 ml (enterococci); for sediment and soil, densities are reported as most probable number (MPN)/g dry weight (*E. coli*) and as colony-forming units (CFU)/g dry weight (enterococci). Storm sewer samples were analyzed for *E. coli* by the District's Illinois Department of Public Health (IDPH)-certified Analytical Microbiology Laboratory using the Colilert-18 method. All bacterial numbers (raw data) are provided in Appendix A.

Bacterial densities in substrates, such as soil, sediments, and sand, are usually expressed in MPN or CFU/g dry weight; however, corresponding numbers in other per unit mass (e.g., MPN or CFU/100 g) is common in scientific literature. The dynamic nature of FIB in aquatic environments has been greatly explored over the years, with an emphasis on the interactions between water and sediments. In this study, we used the assumption that 100 ml = 100 g to compare bacterial densities in water and sediments; accordingly, all sediment bacterial densities were converted to MPN (*E. coli*) and CFU (enterococci)/100 g dry weight.

About 10% of the presumptive *E. coli* (from Colilert-18) and enterococci (from mEI) were confirmed by additional tests described elsewhere (APHA 2005). In brief, liquid/broth from fluorescing wells (i.e., presumptive *E. coli* positive) of randomly chosen Quanti-Trays were streaked onto nutrient agar with MUG and tested in EC+MUG broth; fluorescing colonies (nutrient agar with MUG) and turbid growth plus fluorescence (EC+MUG broth) were considered as positive tests for *E. coli*. Presumptive enterococci colonies (colonies with blue halos) were confirmed for enterococci by growth in brain heart infusion broth (45°C) and brain heart infusion broth containing 6.5% NaCl (35°C), as well as esculin hydrolysis using bile esculin agar (APHA 2005). *E. coli* and enterococci analyses included suitable positive and negative controls (*E. coli* ATCC 25922 and *E. faecalis* 29212, and PBW, respectively).

Chemical and Physical Analysis

Turbidity (2100N Laboratory Turbidimeter, Hach Company) and conductivity (EC500, Extech Instruments) were measured on all water samples. Textural composition and organic carbon contents of sediment and soil samples were determined on composited samples (A&L Great Lakes Laboratories, Inc., Fort Wayne, Indiana). Detailed characteristics of the sediment and soil samples are included in Appendix B.

Statistical Analysis

Statistical analyses and graphical presentations of all soil and bacterial count data were performed using SPSS, Version 12.0 (SPSS, Chicago, IL) (SPSS. 2003). Non-parametric tests (e.g. K-S test) were used to test normality of bacterial densities; subsequently, densities were $\log_{10}$-transformed to meet parametric assumptions of equality of variances and normal distribution. All statistical analyses were performed on these $\log_{10}$-transformed. In addition, data were aggregated (replicates for water and sediment samples for each sampling event were averaged) prior to analyses. ANOVA was used to compare means and Pearson correlation analysis was used to explore relationships. A paired sample t-test was performed to determine the difference in FIB densities between the site immediately above the NSWRP and the site immediately below the outfall. Unless otherwise stated, statistical significance was set at $\alpha = 0.05$.

RESULTS

Water

Escherichia coli: Mean log *E. coli* densities (MPN/100 ml) in water at the study sites ranged from 2.46 (UPS-2) to 3.97 (DNS-1) (Figure 2). ANOVA revealed that *E. coli* densities at DNS-1 and DNS-2 were significantly higher than densities at both of the upstream sites ($F_{5, 24} = 6.985$, $P < 0.0001$), but not significantly different from AL and OF; DNS-1 and DNS-2 were also highly correlated ($R = 0.926$, $P = 0.025$, $N = 5$). A paired-samples t-test comparing UPS-2 (immediately upstream of NSWRP) to DNS-1 (immediately downstream of NSWRP) revealed that *E. coli* densities at DNS-1 were significantly higher than densities at UPS-2 ($t = 7.15$, $P = 0.002$, $df = 4$).

Enterococci: Mean log enterococci densities (CFU/100 ml) in water at the study sites ranged from 1.53 at UPS-2 to 2.96 DNS-2 (Figure 2). According to ANOVA, enterococci densities at UPS2 were significantly lower than those at DNS-1, AL, and DNS-2, but not significantly different from UPS1 or OF ($F_{5, 24} = 5.422$, $P = 0.002$). Similar to *E. coli* results for UPS-2 and DNS-1 locations, a paired t-test comparing UPS-2 enterococci densities to DNS-1 densities revealed that densities at DNS-1 were significantly higher than UPS-2 ($t = 11.37$, $P < 0.0001$, $df = 4$).

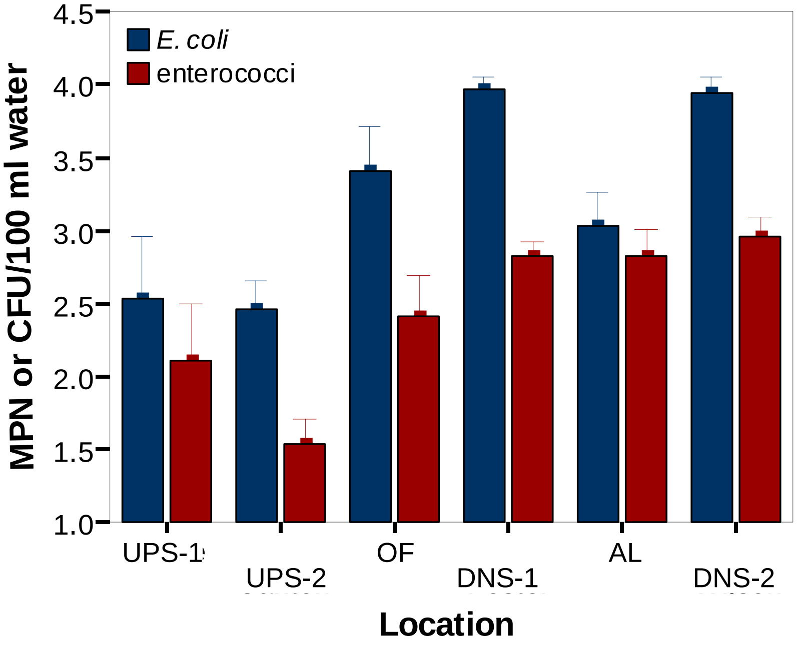

Figure 2. Mean $\log_{10}$ *E. coli* and enterococci densities in water at the study sites: UPS-1 (Bridge Street); UPS-2 (Oakton Street); OF (Outfall); DNS-1 (Foster Avenue); AL (Albany outfall); and DNS-2 (Wilson Avenue); error bars represent ± 1 SE.

Sediment

Escherichia coli: Mean log *E. coli* densities (MPN/g dry sediment) in bottom sediment collected at the study sites ranged from 2.27 at AL to 3.60 at DNS-1 (Fig. 3). There were no significant differences in *E. coli* densities between sites ($F_{4, 20} = 2.416$, $P = 0.083$), and densities at the study sites were not correlated. A paired-samples t-test comparing UPS-2 (immediately upstream of NSWRP) to DNS-1 (immediately downstream of NSWRP) revealed that *E. coli* densities at DNS-1 were significantly higher than densities at UPS-2 ($t = 7.15$, $P = 0.002$, $df = 4$).

Enterococci: Mean log enterococci densities at the study sites (CFU/g dry sediment) ranged from 1.31 at UPS-2 to 2.82 at DNS-1 (Fig. 3). Similar to *E. coli*, enterococci densities at the study sites were not significantly different ($F_{4, 20} = 2.047$, $P = 0.126$) or correlated. Similar to *E. coli* results for UPS-2 and DNS-1 locations, a paired t-test comparing UPS-2 enterococci densities to DNS-1 densities revealed that densities at DNS-1 were not significantly higher than UPS-2 (t = 2.46, P = 0.070, df = 4).

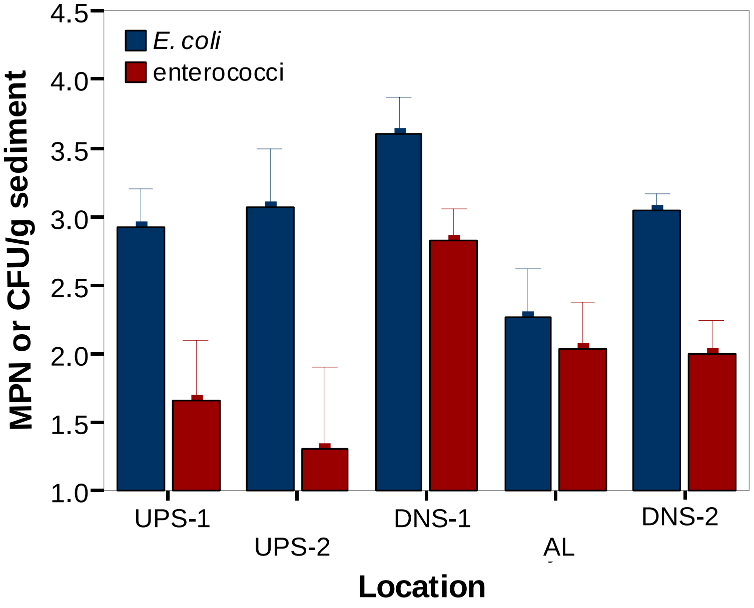

Figure 3. Mean $\log_{10}$ *E. coli* and enterococci densities in sediment at the study sites. Error bars represent ± 1 SE.

Comparison between water and sediment

When bacterial densities in 100 ml (water) and 100 g dry weight (sediment) were assumed to be comparable, overall mean *E. coli* and enterococci densities in sediment were significantly higher than in water. When looking at relationships between water and sediment at individual sites, *E. coli* densities in sediment at all locations were significantly higher than densities in water; for enterococci, densities in sediment at AL, DNS-1, and DNS-2 were significantly higher than densities in water. Although enterococci densities in sediment at the upstream sites (i.e., UPS-1 and UPS-2) were higher than the corresponding densities in water, the difference was not significant. For *E. coli*, densities in water and sediment at AL were significantly correlated (R =

0.996, $P < 0.0001$, $N = 5$); water and sediment enterococci densities were not correlated at any of the sampling sites.

Escherichia coli and enterococci in soils

At two recreational areas (West River Park, RP and Channelside Park Canoe Launch , CP), soils from wooded, grassy, stream bank, and depositional areas were examined to determine potential sources of *E. coli* and enterococci to the channel. At RP, which is downstream of NSWRP, there was an obvious gradient in *E. coli* but not enterococci distribution, with densities increasing toward the depositional area. Mean log *E. coli* densities (MPN/g dry soil ± SE) in wooded, grassy, stream bank, and depositional areas were as follows: 1.84 ± 0.21, 1.94 ± 0.27, 3.24 ± 0.33, and 3.49 ± 0.07, respectively (Table 1A, Fig. 4). The corresponding enterococci densities (mean log CFU/g dry soil ± SE) at these sites were 1.74 ± 0.05, 1.72 ± 0.86, 4.13 ± 0.95, and 3.22 ± 0.49, respectively (Table 1B, Fig. 4).

Table 1. Mean $\log_{10}$ *E. coli* (A) and enterococci (B) densities in soil at RP.

(A)

Area	*E. coli* (log MPN/g dry soil)			
	Mean	Minimum	Maximum	SE
Wooded	1.84	1.51	2.23	0.21
Grassy	1.94	1.41	2.26	0.27
Stream bank	3.24	2.60	3.69	0.33
Depositional	3.49	3.39	3.62	0.07

(B)

Area	enterococci (log CFU/g dry soil)			
	Mean	Minimum	Maximum	SE
Wooded	1.74	1.69	1.84	0.05
Grassy	1.72	0.00	2.66	0.86
Stream bank	4.13	2.69	5.94	0.95
Depositional	3.22	2.26	3.86	0.49

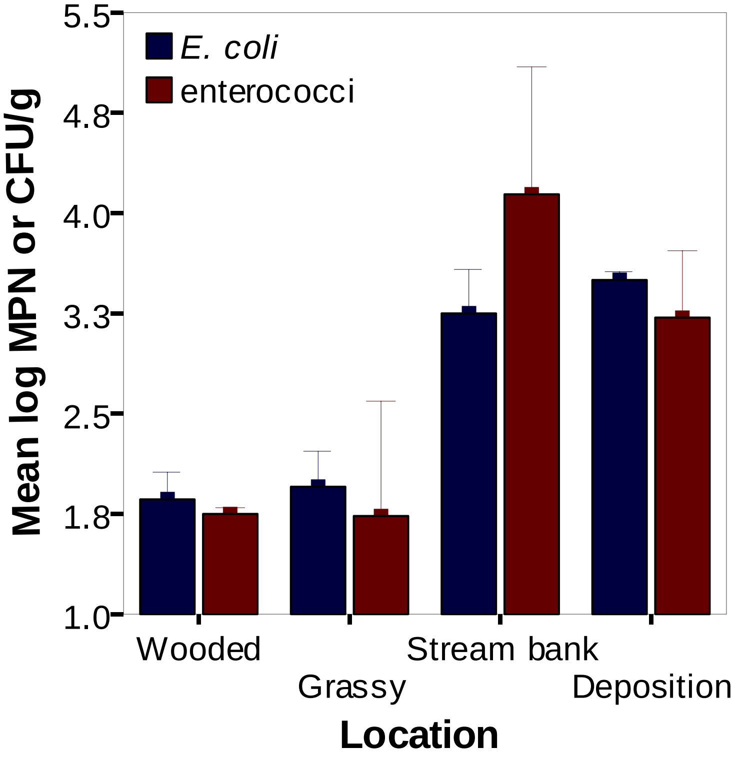

Figure 4. Mean $\log_{10}$ *E. coli* and enterococci densities in soil at RP. Error bars represent ± 1 SE.

E. coli densities of the stream bank and depositional areas were significantly higher than densities of the wooded and grassy areas ($F_{3,8} = 12.907$, $P < 0.0002$), but not significantly different than one another. There were no significant differences in enterococci densities between area samples at RP.

For the CP soils (upstream of NSWRP), *E. coli* and enterococci densities were highly variable, with no apparent gradient in bacterial distribution. Mean log *E. coli* densities in upstream wooded, grassy, stream bank, and depositional areas were 2.62 ± 0.09, 2.46 ± 0.75, 3.07 ± 0.15, and 2.58 ± 0.49, respectively (Table 2A, Figure 5). Patterns of enterococci densities at these corresponding locations generally mirrored those of *E. coli*: 2.79 ± 0.38, 2.25 ± 0.14, 2.91 ± 0.18 and 2.21 ± 0.45, respectively (see Table 2B, Figure 5). There were no significant differences in *E. coli* and enterococci densities between areas sampled at CP.

Table 2. Mean $\log_{10}$ *E. coli* (A) and enterococci (B) densities in soil at CP.

(A)

Area	*E. coli* (log MPN/g dry soil)			
	Mean	Minimum	Maximum	SE
Wooded	2.62	2.45	2.76	0.09
Grassy	2.46	1.04	3.58	0.75
Stream bank	3.07	2.87	3.37	0.15
Depositional	2.58	1.62	3.18	0.49

(B)

Area	enterococci (log CFU/g dry soil)			
	Mean	Minimum	Maximum	SE
Wooded	2.79	2.04	3.31	0.38
Grassy	2.25	2.03	2.52	0.14
Stream bank	2.91	2.61	3.24	0.18
Depositional	2.21	1.36	2.88	0.45

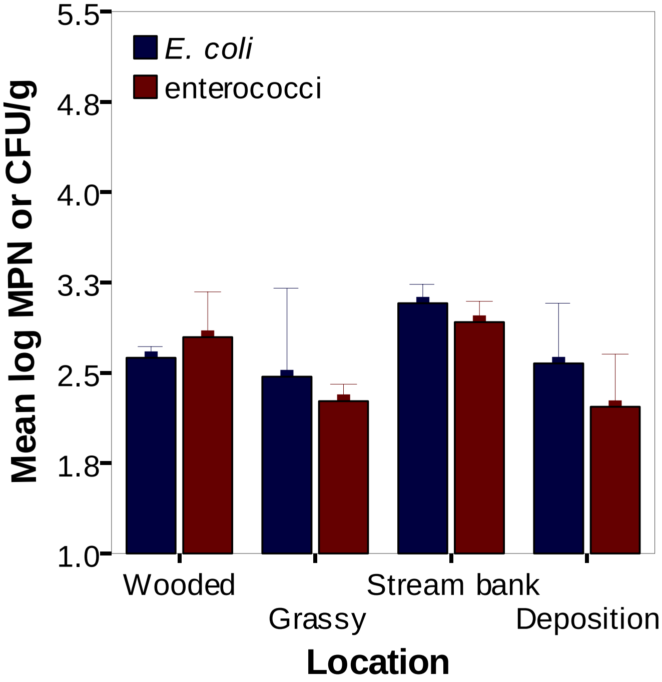

Figure 5. Mean $\log_{10}$ *E. coli* and enterococci densities in soil at CP. Error bars represent ± 1 SE.

Table 3 shows *E. coli* densities from twenty soil samples collected approximately 10-20 m from the water edge along the channel. Log *E. coli* densities (MPN/g dry soil) were highly variable among the twenty samples, with overall mean log densities ranging from 0.61 to 1.89. Mean log *E. coli* densities in soils sampled along the NSC near Howard/Touhy, Bridge St., and Albany locations were 0.83 to 1.28 units higher compared to that of Foster.

Table 3. *E. coli* densities from twenty soil samples collected along the NSC channel banks within the study area.

Location	Site	Sample #	*E. coli* (log MPN/g dry soil)
Downstream NSWRP	Albany (tributary river)	F1	1.20
		F2	1.46
		F3	0.70
		F4	1.66
		F5	2.16
		Mean	**1.44**
Downstream NSWRP	Foster (NSC)	F6	0.78
		F7	0.48
		F8	0.00
		F9	0.32
		F10	1.48
		Mean	**0.61**
Outfall NSWRP	Howard and Touhy	F11	1.41
		F12	2.25
		F13	2.04
		F14	2.58
		F15	1.08
		Mean	**1.87**
Upstream NSWRP	Bridge St. (NSC)	F16	1.72
		F17	2.24
		F18	0.95
		F19	1.34
		F20	3.23
		Mean	**1.89**

Storm water

Water was collected from Storm Sewer-1 (Evanston) and Storm Sewer-2 (Lincolnwood) during rain storm events to determine the relative *E. coli* contribution from storm water to the NSC. Mean log *E. coli* densities (MPN/100 ml ± SE) were 4.25±0.24 and 4.83±0.27 at Evanston and Lincolnwood stations, respectively (Table 4). Overall, *E. coli* densities were higher at Lincolnwood station than Evanston station, but not significantly.

Table 4. Mean log $_{10}$ *E. coli* densities in storm water collected at Evanston (Storm Sewer-1) and Lincolnwood (Storm Sewer-2) stations. Numbers in gray represent overall means. Footnotes represent rain gauge data associated with sample collection.

Date	Storm Sewer *E. coli* (Log MPN/100 ml)	
	Evanston	Lincolnwood
9/4/2008[1]	4.86	4.77
9/29/2008[2]	4.37	5.90
10/8/2008[3]	4.72	3.45
10/20/2008[4]	3.05	5.21
Mean	4.25	4.83

[1] 9/3-4/08 ranged from 0.14-2.55 inches

[2] 9/28-29/08 ranged from 0.00-0.60 inches

[3] 10/7-8/08 ranged from 0.20-1.00 inches

[4] 10/19-20/08 ranged from 0.00-0.22 inches

Chemical analyses

Water

Mean turbidity and conductivity results for water samples collected at the study sites are summarized in Table 5. Mean turbidity at individual study sites ranged from 10.38 to 25.77 NTU, with highest values at UPS-2 and lowest at UPS-1. Mean conductivity at individual study sites ranged from 292.97 to 929.37 µS/cm, with highest values at AL and lowest at UPS-1. *E. coli* densities in water collected at the WRP outfall and UPS-2 were negatively correlated with turbidity (R = -0.909, P = 0.032, N = 5); densities at the WRP outfall were positively correlated with conductivity (R = 0.913, P = 0.030, N = 5). Enterococci densities at the WRP outfall were correlated with conductivity (R = 0.910, P = 0.032, N = 5).

Table 5. Mean turbidity (NTU) and conductivity (µS/cm) readings of water samples collected at the study sites.

Location	Site	statistic	Turbidity	Conductivity
upstream	UPS-1	Mean	10.38	292.97
		Minimum	6.66	268.50
		Maximum	15.77	306.00
	UPS-2	Mean	25.77	293.47
		Minimum	12.53	279.00
		Maximum	51.13	308.33
		Mean	18.08	293.22
Outfall	Outfall	Mean	12.14	538.73
		Minimum	4.69	305.33
		Maximum	23.67	816.67
		Mean	12.14	538.73
downstream	DNS-1	Mean	10.47	640.87
		Minimum	6.93	525.00
		Maximum	15.37	896.67
	AL	Mean	19.35	929.37
		Minimum	7.24	558.67
		Maximum	52.53	1173.50
	DNS-2	Mean	14.08	679.67
		Minimum	6.85	534.67
		Maximum	28.43	863.00
		Mean	14.63	749.97

Soil and sediment

Physical characteristics of the sediment and soil samples at the study sites are shown in Table 6. The sediments were mainly sandy loam, and the soils were mainly clay loam. At UPS-2, silt makes up the majority of the sediment composition. Organic matter content ranged from 2.33 to 18%, with the highest in soil collected at the West River Park forest area and the lowest in sediment collected at DNS-2. Overall, the soils contained a higher percentage of organic matter than sediments. The soils of the wooded and grassy areas of both parks contained the highest percentage of organic matter. The sediments of the upstream sites, especially UPS-2, contained the highest (17%) percentage of organic matter. Particle size analysis revealed that overall the sediment contained a higher percentage of sand, which was highest in sediment collected at the downstream sites. Compared to stream sediment, soils had higher silt content than sand and clay.

Table 6. Textural composition and classification of soils and sediments collected at the study sites.

				Particle size analysis (%)			
Site	Substrate	Location	Organic matter (%)	Sand	Silt	Clay	Textural classification
UPS-1	sediment	upstream	6	50	26	24	Sandy Clay Loam
UPS-2	sediment	upstream	17	23	58	19	Silt Loam
DNS-1	sediment	downstream	4	72	24	4	Sandy Loam
DNS-2	sediment	downstream	2	84	14	2	Loamy Sand
AL	sediment	downstream	4	65	21	14	Sandy Loam
Mean	sediment		7	59	29	13	
Wooded	soil	downstream	18	24	48	28	Clay Loam
Grassy	soil	downstream	13	29	45	26	Loam
Stream bank	soil	downstream	9	30	36	34	Clay Loam
Deposition	soil	downstream	6	52	28	20	Sandy Clay Loam
Wooded	soil	upstream	14	36	38	26	Loam
Grassy	soil	upstream	14	23	47	30	Clay Loam
Stream bank	soil	upstream	9	30	42	28	Clay Loam
Deposition	soil	upstream	4	49	27	24	Sandy Clay Loam
Mean	soil		11	34	39	27	

DISCUSSION

The source of microorganisms, especially fecal indicator bacteria (FIB), in large streams or rivers is difficult to identify and partition because these microorganisms likely originate from multiple sources, including final effluents from wastewater plants. Over the years, investigations have typically focused on a particular environment, geographic location, or contamination source and have aimed to link effluent discharges and stream water quality. Recent research by

Whitman et al (2006) (Whitman et al. 2006) suggests that in order to explain these relationships, it is important to integrate both contaminant source and flux of FIB; however, integrative studies are limited. Efforts to identify sources of microbial contaminants are often limited to human and animal waste inputs (Stoeckel et al. 2004). Natural or ambient FIB contributions, such as soil and sediments (Hardina and Fujioka 1991, Fujioka et al. 1999, Byappanahalli 2000, Solo-Gabriele et al. 2000, Byappanahalli et al. 2003), and FIB survival and regrowth in the environment (Solo-Gabriele et al. 2000, Byappanahalli and Fujioka 2004, Ishii et al. 2006, Whitman et al. 2006, Byappanahalli et al. 2007) have not been thoroughly addressed.

The primary focus of the current investigation was to determine the occurrence, distribution, and some of the nonpoint potential sources of *E. coli* and enterococci along the North Channel, encompassing a 10.7-km stretch of the NSC from Bridge St. to Wilson Ave. Generally, *E. coli* and enterococci densities in water and sediment were higher downstream of the NSWRP than upstream, which may be attributed to bacterial loadings from the WRP outfall and the NCBR tributary. While the North Channel segment, including many of the sampling locations here, has been extensively studied by the MWRDGC for its microbiological water quality (MWRDGC 2008), the current study is perhaps the first to document *E. coli* and enterococci densities in the NSC sediment and river bank soil. When 100 milliliters of water and 100 grams dry weight of sediment are assumed to be equal (Whitman and Nevers 2003), results confirmed that *E. coli* densities in these sediment were significantly higher than corresponding densities in water at all sampled locations. For enterococci, bacterial densities in sediment were significantly higher than in water at downstream sites (AL, DNS-1 and DNS-2), but not at upstream sites. Although there were no clear correlations in bacterial densities between water and sediments, the consistently higher *E. coli* and enterococci densities in sediments relative to water could have an influence on densities in the water column. High stream flow events (CSOs, dams, stream confluence, storm drains) and related hydrological effects could release or resuspend the sediment-borne bacteria to the overlying water. Such processes, apparently affecting water quality, have been well documented in streams, rivers, and at bathing beaches (Solo-Gabriele et al. 2000, An et al. 2002, Steets and Holden 2003, Craig et al. 2004).

Many studies have concluded that FIB are ubiquitous in watersheds and riparian areas of Lake Michigan and Lake Superior (Byappanahalli et al. 2003, Ishii et al. 2006, Whitman et al. 2006); the results of this study revealed similar conclusions. Two riparian recreational parks (CP upstream and RP downstream from NSWRP) were examined to determine potential *E. coli* and enterococci inputs to the adjacent NSC. Results revealed that *E. coli* and enterococci were always recovered (100%) from samples collected from grassy, wooded, stream bank and depositional areas, with bacterial densities often in excess of 100 MPN/g soil. While *E. coli* and enterococci densities were ubiquitous in both parks, a bacterial gradient was evident in samples from RP, with higher mean densities in the stream bank and depositional areas than in upland areas (see Figure 4). A similar pattern, however, was not apparent in soil samples collected at CP. On one sampling event, twenty soil samples were randomly collected within the study area; *E. coli* was highly variable (<1 to 3.23 MPN/g dry weight), but was recovered in 95% (19/20) of the samples, indicating its widespread occurrence in the soil along the NSC; no enterococci were analyzed in these samples. Although no concurrent water and soil samples were collected during rain or high flow conditions, the near ubiquity of *E. coli* and enterococci across the riparian gradient suggests that these areas could be a significant non-point source of *E. coli* and enterococci to the adjacent NSC during high flow/run-off events.

The source and growth potential of *E. coli* and enterococci in riparian soils were beyond the scope of this study. Nonetheless, analyses of representative soil and sediment samples collected over the course of this study showed that the riparian soils and stream sediments contain nutrients (i.e., organic matter; see Table 6) that can promote *E. coli* growth under certain environmental conditions. Recent studies show that *E. coli* can potentially grow in riparian soils of Lake Michigan (Byappanahalli et al. 2006b, Whitman et al. 2006) and Lake Superior (Ishii et al. 2006) watersheds.

There are several storm sewer outfalls to the NSC and to the tributaries of the NSC (MWRD 2008). In this study, storm sewer outfalls, one upstream (Storm Sewer-1) and one downstream (Storm Sewer-2) the NSWRP were examined during four different rainfall events to determine potential *E. coli* inputs. *E. coli* densities in Storm Sewer-2 samples were higher than those in Storm Sewer-1 samples but not significantly different. However, the relative impacts of storm sewer outfalls on *E. coli* and enterococci densities in NSC are difficult to speculate since no concurrent water samples were collected (from NSC) during the storm events.

Besides the wastewater effluent, riparian soils along the NSC, channel sediments, and storm sewer outfalls may contribute to the overall FIB load in the NSC. Additionally, it could be argued that the FIB contribution may increase downstream as the non-point source contributions from the watershed accumulate. In this study, limited non-point sources were examined; nonetheless, many watershed studies have explored non-point FIB sources (see Winfield and Groisman 2003) (Winfield and Groisman 2003) and found that microbial loads increase downstream from increased non-point sources and dynamic interactions between input sources. The complexity of a given watershed (e.g., CAWS) also affects microbial loadings since there are contributing tributary flow and multiple CSO outfalls (MWRDGC 2003). During storm events, rainfall acts to magnify non-point source *E. coli* loadings to streams through run-off from riparian areas and presumably by increased resuspension.

In conclusion, FIB (*E. coli* and enterococci) were consistently found in water (range of 2.46 - 3.97 log MPN/100 ml, *E. coli*; 1.53-2.96 log CFU/100 ml, enterococci) and sediments (range of 2.27-3.60 log MPN/g, *E. coli*; 1.31-2.82 log CFU/g, enterococci) at all sampling locations along NSC, with higher densities downstream of the NSWRP outfall (OF), including the tributary river feeding into the NSC. *E. coli* and enterococci densities were significantly higher in sediments than water.

Both *E. coli* and enterococci were consistently recovered from soil along the wooded through depositional areas at the two recreational parks during all sampling occasions, as well as other recreational areas along the NSC, suggesting that these bacteria were common in this environment. Thus, soils along the river basin may be a source of these bacteria to the river, potentially with higher inputs during wet weather events. Higher *E. coli* and enterococci densities were found in sediments and soils of the bank areas, relative to the wooded and grassy areas. While the bacteria may be common in these environments, the gradient suggests that the sediment and bank areas may both be a source and sink of FIB, with bacterial contributions coming from the river itself. River outfalls, such as the NCBR that flow into NSC near Albany Ave, also provide a constant source of *E. coli* and enterococci to the river. Additionally, storm sewer outfalls during rain events contribute high levels of *E. coli* to the NSC.

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Appendix A

E. coli and enterococci data from water, sediment, and soils collected at the study locations. Enterococci analysis was performed on composite samples. No sediment samples were collected at the NSWRP outfall.

Date	Location	Replicate	Water *E. coli* (MPN/100 ml)	Sediment *E. coli* (MPN/g)
8/26/08	UPS-1	1	41	83
8/26/08	UPS-1	2	41	186
8/26/08	UPS-1	3	No sample	221
8/26/08	UPS-2	1	98	375
8/26/08	UPS-2	2	51	57
8/26/08	UPS-2	3	72	218
8/26/08	DNS-1	1	14136	4580
8/26/08	DNS-1	2	15531	131
8/26/08	DNS-1	3	12997	214
8/26/08	DNS-2	1	12997	728
8/26/08	DNS-2	2	14136	1893
8/26/08	DNS-2	3	14136	4361
8/26/08	AL	1	763	60
8/26/08	AL	2	882	396
8/26/08	AL	3	No sample	115
8/26/08	OF	1	14136	
8/26/08	OF	2	19863	
8/26/08	OF	3	17329	
8/26/08	NSWRP effluent	1	15531	
9/9/08	UPS-1	1	7270	7443
9/9/08	UPS-1	2	7270	9092
9/9/08	UPS-1	3	6867	507
9/9/08	UPS-2	1	677	38385
9/9/08	UPS-2	2	733	14241
9/9/08	UPS-2	3	708	2719
9/9/08	DNS-1	1	15531	5321
9/9/08	DNS-1	2	9804	19878
9/9/08	DNS-1	3	15531	6904
9/9/08	DNS-2	1	9804	1595
9/9/08	DNS-2	2	19863	1976
9/9/08	DNS-2	3	12033	2879
9/9/08	AL	1	9208	6141
9/9/08	AL	2	8664	826
9/9/08	AL	3	7701	13059
9/9/08	OF	1	2755	
9/9/08	OF	2	4884	
9/9/08	OF	3	3609	
9/9/08	NSWRP effluent	1	14136	
9/9/08	NSWRP effluent	2	17329	
9/9/08	NSWRP effluent	3	11199	

9/23/08	UPS-1	1	259	799
9/23/08	UPS-1	2	199	1128
9/23/08	UPS-1	3	173	334
9/23/08	UPS-2	1	727	1212
9/23/08	UPS-2	2	733	6301
9/23/08	UPS-2	3	703	38397
9/23/08	DNS-1	1	8664	31617
9/23/08	DNS-1	2	7270	13966
9/23/08	DNS-1	3	8164	16204
9/23/08	DNS-2	1	4352	276
9/23/08	DNS-2	2	5172	675
9/23/08	DNS-2	3	7270	383
9/23/08	AL	1	457	18
9/23/08	AL	2	313	7
9/23/08	AL	3	272	481
9/23/08	OF	1	613	
9/23/08	OF	2	601	
9/23/08	OF	3	669	
9/23/08	NSWRP effluent	1	3448	
9/23/08	NSWRP effluent	2	5794	
9/23/08	NSWRP effluent	3	3784	
10/7/08	UPS-1	1	52	5076
10/7/08	UPS-1	2	41	3449
10/7/08	UPS-1	3	74	3604
10/7/08	UPS-2	1	189	8718
10/7/08	UPS-2	2	171	1329
10/7/08	UPS-2	3	160	822
10/7/08	DNS-1	1	4884	3760
10/7/08	DNS-1	2	4352	5290
10/7/08	DNS-1	3	4884	1397
10/7/08	DNS-2	1	3873	1058
10/7/08	DNS-2	2	4884	1033
10/7/08	DNS-2	3	5172	1090
10/7/08	AL	1	733	194
10/7/08	AL	2	907	85
10/7/08	AL	3	1081	129
10/7/08	OF	1	7701	
10/7/08	OF	2	5172	
10/7/08	OF	3	6488	
10/7/08	NSWRP effluent	1	9804	
10/7/08	NSWRP effluent	2	8164	
10/7/08	NSWRP effluent	3	9804	
10/21/08	UPS-1	1	1301	321
10/21/08	UPS-1	2	1467	454
10/21/08	UPS-1	3	1281	251
10/21/08	UPS-2	1	528	110
10/21/08	UPS-2	2	226	30
10/21/08	UPS-2	3	259	145
10/21/08	DNS-1	1	9208	6749
10/21/08	DNS-1	2	10462	2128

10/21/08	DNS-1	3	10462	3947
10/21/08	DNS-2	1	12033	655
10/21/08	DNS-2	2	12033	1405
10/21/08	DNS-2	3	12033	1039
10/21/08	AL	1	780	73
10/21/08	AL	2	546	79
10/21/08	AL	3	697	67
10/21/08	OF	1	441	
10/21/08	OF	2	450	
10/21/08	OF	3	441	
10/21/08	NSWRP effluent	1	5794	
10/21/08	NSWRP effluent	2	5794	
10/21/08	NSWRP effluent	3	6867	

Date	**Location**	**Water enterococci (MPN/100 ml)**	**Sediment enterococci (MPN/g)**
8/26/08	AL	540	91
8/26/08	DNS-1	620	97
8/26/08	DNS-2	900	29
8/26/08	NSWRP effluent	1520	
8/26/08	OF	1560	
8/26/08	UPS-1	21	113
8/26/08	UPS-2	15	0
9/9/08	AL	2880	2130
9/9/08	DNS-1	780	887
9/9/08	DNS-2	2100	437
9/9/08	NSWRP effluent	210	
9/9/08	OF	220	
9/9/08	UPS-1	500	383
9/9/08	UPS-2	25	1024
9/23/08	AL	220	63
9/23/08	DNS-1	560	2864
9/23/08	DNS-2	340	27
9/23/08	NSWRP effluent	460	
9/23/08	OF	41	
9/23/08	UPS-1	37	47
9/23/08	UPS-2	33	146
10/7/08	AL	800	24
10/7/08	DNS-1	380	487

10/7/08	DNS-2	640	137
10/7/08	NSWRP effluent	960	
10/7/08	OF	780	
10/7/08	UPS-1	32	91
10/7/08	UPS-2	20	22
10/21/08	AL	460	50
10/21/08	DNS-1	1340	1033
10/21/08	DNS-2	1500	208
10/21/08	NSWRP effluent	1080	
10/21/08	OF	101	
10/21/08	UPS-1	2400	0
10/21/08	UPS-2	156	0

Date	Location	Plot	Soil E. coli (MPN/g)	Soil enterococci (CFU/g)
9/23/08	Upstream wooded	1	29	2053
9/23/08	Upstream wooded	2	35	
9/23/08	Upstream wooded	3	13375	
9/23/08	Upstream wooded	4	857	
9/23/08	Upstream wooded	5	150	
9/23/08	Upstream grassy	1	84	107
9/23/08	Upstream grassy	2	89	
9/23/08	Upstream grassy	3	2	
9/23/08	Upstream grassy	4	1	
9/23/08	Upstream grassy	5	11	
9/23/08	Upstream river bank	1	245	1738
9/23/08	Upstream river bank	2	2714	
9/23/08	Upstream river bank	3	2648	
9/23/08	Upstream river bank	4	11676	
9/23/08	Upstream river bank	5	3261	
9/23/08	Upstream depositional	1	2	22
9/23/08	Upstream depositional	2	58	
9/23/08	Upstream depositional	3	83	
9/23/08	Upstream depositional	4	27	
9/23/08	Upstream depositional	5	474	
9/23/08	Downstream wooded	1	48	48

9/23/08	Downstream wooded	2	773	
9/23/08	Downstream wooded	3	394	
9/23/08	Downstream wooded	4	103	
9/23/08	Downstream wooded	5	93	
9/23/08	Downstream grassy	1	385	313
9/23/08	Downstream grassy	2	214	
9/23/08	Downstream grassy	3	83	
9/23/08	Downstream grassy	4	127	
9/23/08	Downstream grassy	5	69	
9/23/08	Downstream river bank	1	341	5895
9/23/08	Downstream river bank	2	7954	
9/23/08	Downstream river bank	3	135264	
9/23/08	Downstream river bank	4	1557	
9/23/08	Downstream river bank	5	5075	
9/23/08	Downstream depositional	1	944	3464
9/23/08	Downstream depositional	2	724	
9/23/08	Downstream depositional	3	46895	
9/23/08	Downstream depositional	4	22797	
9/23/08	Downstream depositional	5	302	
10/21/08	Upstream wooded	1	637	1022
10/21/08	Upstream wooded	2	1703	
10/21/08	Upstream wooded	3	196	
10/21/08	Upstream wooded	4	98	
10/21/08	Upstream wooded	5	1030	
10/21/08	Upstream grassy	1	581	330
10/21/08	Upstream grassy	2	1591	
10/21/08	Upstream grassy	3	897	
10/21/08	Upstream grassy	4	544	
10/21/08	Upstream grassy	5	125	
10/21/08	Upstream river bank	1	411	734
10/21/08	Upstream river bank	2	621	
10/21/08	Upstream river bank	3	979	
10/21/08	Upstream river bank	4	903	
10/21/08	Upstream river bank	5	3741	
10/21/08	Upstream depositional	1	2372	762
10/21/08	Upstream depositional	2	5979	

10/21/08	Upstream depositional	3	427	
10/21/08	Upstream depositional	4	1555	
10/21/08	Upstream depositional	5	867	
10/21/08	Downstream wooded	1	1624	68
10/21/08	Downstream wooded	2	34	
10/21/08	Downstream wooded	3	12	
10/21/08	Downstream wooded	4	25	
10/21/08	Downstream wooded	5	57	
10/21/08	Downstream grassy	1	213	460
10/21/08	Downstream grassy	2	238	
10/21/08	Downstream grassy	3	55	
10/21/08	Downstream grassy	4	189	
10/21/08	Downstream grassy	5	383	
10/21/08	Downstream river bank	1	80	869616
10/21/08	Downstream river bank	2	986	
10/21/08	Downstream river bank	3	670425	
10/21/08	Downstream river bank	4	2374	
10/21/08	Downstream river bank	5	1212	
10/21/08	Downstream depositional	1	3410	180
10/21/08	Downstream depositional	2	2369	
10/21/08	Downstream depositional	3	748	
10/21/08	Downstream depositional	4	5537	
10/21/08	Downstream depositional	5	2679	
10/31/08	Upstream wooded	1	1004	109
10/31/08	Upstream wooded	2	256	
10/31/08	Upstream wooded	3	212	
10/31/08	Upstream wooded	4	480	
10/31/08	Upstream wooded	5	2358	
10/31/08	Upstream grassy	1	40	159
10/31/08	Upstream grassy	2	1541	
10/31/08	Upstream grassy	3	5743	
10/31/08	Upstream grassy	4	34208	
10/31/08	Upstream grassy	5	63138	
10/31/08	Upstream river bank	1	67	411
10/31/08	Upstream river bank	2	2199	
10/31/08	Upstream river bank	3	1889	

10/31/08	Upstream river bank	4	572	
10/31/08	Upstream river bank	5	1341	
10/31/08	Upstream depositional	1	388	234
10/31/08	Upstream depositional	2	1157	
10/31/08	Upstream depositional	3	633	
10/31/08	Upstream depositional	4	7094	
10/31/08	Upstream depositional	5	231	
10/31/08	Downstream wooded	1	47	49
10/31/08	Downstream wooded	2	90	
10/31/08	Downstream wooded	3	11	
10/31/08	Downstream wooded	4	33	
10/31/08	Downstream wooded	5	23	
10/31/08	Downstream grassy	1	55	0
10/31/08	Downstream grassy	2	19	
10/31/08	Downstream grassy	3	127	
10/31/08	Downstream grassy	4	2	
10/31/08	Downstream grassy	5	40	
10/31/08	Downstream river bank	1	117	491
10/31/08	Downstream river bank	2	3123	
10/31/08	Downstream river bank	3	2219	
10/31/08	Downstream river bank	4	127	
10/31/08	Downstream river bank	5	102	
10/31/08	Downstream depositional	1	737	7254
10/31/08	Downstream depositional	2	1813	
10/31/08	Downstream depositional	3	227984	
10/31/08	Downstream depositional	4	800	
10/31/08	Downstream depositional	5	5267	

Appendix B

Textural composition and organic carbon contents of sediment and soil samples collected at the study locations. Analysis was performed on composited samples

Sample ID	Analysis	Result	Unit	Method
UPS-1	Organic Matter (LOI @ 550C)	6.06		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	3.92	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	6.30	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	12.88	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	19.16	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	7.24	%	MSA Part 1 (1986) p 401
	Total Sand	49.50	%	MSA Part 1 (1986) p 401
	Sand	50	%	Bouyoucos 1962
	Silt	26	%	Bouyoucos 1962
	Clay	24	%	Bouyoucos 1962
	Soil Textural Class	Sandy Clay Loam		Bouyoucos 1962
UPS-2	Organic Matter (LOI @ 550C)	17.47		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	1.52	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	3.68	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	4.48	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	6.52	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	6.98	%	MSA Part 1 (1986) p 401
	Total Sand	23.18	%	MSA Part 1 (1986) p 401
	Sand	23	%	Bouyoucos 1962
	Silt	58	%	Bouyoucos 1962
	Clay	19	%	Bouyoucos 1962
	Soil Textural Class	Silt Loam		Bouyoucos 1962
DNS-1	Organic Matter (LOI @ 550C)	4.27		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	2.58	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	4.52	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	7.88	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	48.56	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	8.46	%	MSA Part 1 (1986) p 401
	Total Sand	72.00	%	MSA Part 1 (1986) p 401
	Sand	72	%	Bouyoucos 1962
	Silt	24	%	Bouyoucos 1962
	Clay	4	%	Bouyoucos 1962
	Soil Textural Class	Sandy Loam		Bouyoucos 1962
DNS-2	Organic Matter (LOI @ 550C)	2.33		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	3.18	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	8.74	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	35.54	%	MSA Part 1 (1986) p 401

	Fine Sand (0.10-0.25 mm)	35.06	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	1.86	%	MSA Part 1 (1986) p 401
	Total Sand	84.38	%	MSA Part 1 (1986) p 401
	Sand	84	%	Bouyoucos 1962
	Silt	14	%	Bouyoucos 1962
	Clay	2	%	Bouyoucos 1962
	Soil Textural Class	Loamy Sand		Bouyoucos 1962
AL	Organic Matter (LOI @ 550C)	4.48		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	17.26	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	20.60	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	15.40	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	10.54	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	1.08	%	MSA Part 1 (1986) p 401
	Total Sand	64.88	%	MSA Part 1 (1986) p 401
	Sand	65	%	Bouyoucos 1962
	Silt	21	%	Bouyoucos 1962
	Clay	14	%	Bouyoucos 1962
	Soil Textural Class	Sandy Loam		Bouyoucos 1962
Upstream wooded	Organic Matter (LOI @ 550C)	13.81		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	1.34	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	3.44	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	10.16	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	15.78	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	5.04	%	MSA Part 1 (1986) p 401
	Total Sand	35.76	%	MSA Part 1 (1986) p 401
	Sand	36	%	Bouyoucos 1962
	Silt	38	%	Bouyoucos 1962
	Clay	26	%	Bouyoucos 1962
	Soil Textural Class	Loam		Bouyoucos 1962
Upstream grassy	Organic Matter (LOI @ 550C)	14.00		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	1.50	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	3.20	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	6.86	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	9.02	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	1.94	%	MSA Part 1 (1986) p 401
	Total Sand	22.52	%	MSA Part 1 (1986) p 401
	Sand	23	%	Bouyoucos 1962
	Silt	47	%	Bouyoucos 1962
	Clay	30	%	Bouyoucos 1962
	Soil Textural Class	Clay Loam		Bouyoucos 1962
Upstream stream bank	Organic Matter (LOI @ 550C)	8.59		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	3.44	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	5.08	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	7.00	%	MSA Part 1 (1986) p 401

	Fine Sand (0.10-0.25 mm)	11.24	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	3.10	%	MSA Part 1 (1986) p 401
	Total Sand	29.86	%	MSA Part 1 (1986) p 401
	Sand	30	%	Bouyoucos 1962
	Silt	42	%	Bouyoucos 1962
	Clay	28	%	Bouyoucos 1962
	Soil Textural Class	Clay Loam		Bouyoucos 1962
Upstream depositional	Organic Matter (LOI @ 550C)	4.28		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	9.20	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	12.16	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	14.64	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	10.96	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	1.84	%	MSA Part 1 (1986) p 401
	Total Sand	48.80	%	MSA Part 1 (1986) p 401
	Sand	49	%	Bouyoucos 1962
	Silt	27	%	Bouyoucos 1962
	Clay	24	%	Bouyoucos 1962
	Soil Textural Class	Sandy Clay Loam		Bouyoucos 1962
Downstream wooded	Organic Matter (LOI @ 550C)	18.02		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	0.54	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	1.74	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	6.92	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	11.34	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	3.26	%	MSA Part 1 (1986) p 401
	Total Sand	23.80	%	MSA Part 1 (1986) p 401
	Sand	24	%	Bouyoucos 1962
	Silt	48	%	Bouyoucos 1962
	Clay	28	%	Bouyoucos 1962
	Soil Textural Class	Clay Loam		Bouyoucos 1962
Downstream grassy	Organic Matter (LOI @ 550C)	12.89		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	0.70	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	2.00	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	6.32	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	16.50	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	3.62	%	MSA Part 1 (1986) p 401
	Total Sand	29.14	%	MSA Part 1 (1986) p 401
	Sand	29	%	Bouyoucos 1962
	Silt	45	%	Bouyoucos 1962
	Clay	26	%	Bouyoucos 1962
	Soil Textural Class	Loam		Bouyoucos 1962
Downstream river bank	Organic Matter (LOI @ 550C)	8.63		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	2.10	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	4.62	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	7.86	%	MSA Part 1 (1986) p 401

	Fine Sand (0.10-0.25 mm)	10.12	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	5.06	%	MSA Part 1 (1986) p 401
	Total Sand	29.76	%	MSA Part 1 (1986) p 401
	Sand	30	%	Bouyoucos 1962
	Silt	36	%	Bouyoucos 1962
	Clay	34	%	Bouyoucos 1962
	Soil Textural Class	Clay Loam		Bouyoucos 1962
Downstream depositional	Organic Matter (LOI @ 550C)	5.92		TMECC 05.07-A
	Very Coarse Sand (2-1 mm)	4.38	%	MSA Part 1 (1986) p 401
	Coarse Sand (0.5-1 mm)	8.04	%	MSA Part 1 (1986) p 401
	Medium Sand (0.25-0.5mm)	11.82	%	MSA Part 1 (1986) p 401
	Fine Sand (0.10-0.25 mm)	23.02	%	MSA Part 1 (1986) p 401
	Very Fine Sand (0.05-0.10 mm)	5.16	%	MSA Part 1 (1986) p 401
	Total Sand	52.42	%	MSA Part 1 (1986) p 401
	Sand	52	%	Bouyoucos 1962
	Silt	28	%	Bouyoucos 1962
	Clay	20	%	Bouyoucos 1962
	Soil Textural Class	Sandy Clay Loam		Bouyoucos 1962