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PLANNING LEVEL EVALUATION OF DENSITIES AND SOURCES OF INDICATOR BACTERIA IN A MIXED LAND USE WATERSHED

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ABSTRACT

The lower Buffalo River, NY, is environmentally impaired and the 38 combined sewer outfalls within this reach historically were believed to be the primary source of bacterial contamination. A planning level evaluation of bacteria contamination was done through sample testing and compilation of existing source data, in part, with the aid of GIS technology. The intent of such evaluation is to provide an overview of the magnitude and sources of the water quality problem without extensive resource commitments, as a first step in developing remediation strategies. Testing for fecal coliform and fecal streptococci was done at 12 sites within the watershed for one year, 1992-93. Indicator bacteria densities at all sites generally were high and the state guideline for primary contact (200 fecal coliform 100 ml^{-1}) was exceeded in 69% of 277 samples. Bacteria densities were greatest during storm events, suggesting runoff as an important source pathway. Mean fecal coliform densities significantly increased downstream, with higher levels of urbanization. Fecal coliform: fecal streptococci ratios, combined with the source inventory data, successfully were used to identify areas of human sewage inputs. Although combined sewer overflows in the lower Buffalo River have an impact on bacteria levels, upstream sources also degrade water quality. The costly elimination of combined sewer overflows in the lower river will not entirely alleviate problems with high bacteria levels. Water quality in the lower river will improve only through a basin-wide, co-ordinated reduction of bacteria inputs from multiple sources.

Keywords: Indicator bacteria; bacteria sources; fecal coliform; fecal streptococci ratio; runoff pollution; Buffalo River, N.Y.

INTRODUCTION

The poor water and sediment quality in the Buffalo River, New York, is well-documented (1, 2) and the lower 9.6 km of the river has been designated an Area of Concern (AOC) by the International Joint Commission (IJC) due to various environmental impairments (Figure 1). Under the amendments to the Canada-U.S. Water Quality Agreement, a Remedial Action Plan (RAP) will be developed for each of the 43 areas of concern around the lakes. A RAP is intended to identify the environmental impairments, remediation measures to alleviate the impairments, agencies or organizations responsible for implementing remediation, and a timetable for implementing remedial measures (3). A level I RAP was developed for the Buffalo River and has been submitted to the IJC (2).

Several research projects recently have been conducted to collect and analyse baseline water and sediment quality data for the Buffalo River and provide estimates of pollutant dynamics within the AOC (e.g. 4, 5, 6). This type of information is essential to help guide the selection of appropriate remediation strategies. The focus of these studies has been conventional parameters, metals and organic compounds, but sampling has been conducted only within the AOC. Pollutant inputs from the upper watershed have been determined simply by sampling at the top of the AOC and are lumped as a single category called "upstream sources".

There is less information on bacteria levels and sources for the AOC, although it was reported that the mean fecal coliform level was 562 colony forming units (cfu) 100 ml^{-1} for 23 samples collected at one site between 1982 and 1986 (2). The state guideline for primary contact is 200 cfu 100 ml^{-1}. The waters of the AOC frequently are used for swimming, boating, water-skiing and fishing and the fecal coliform levels appear to indicate a health risk to these populations. Furthermore, the city of Buffalo has ambitious redevelopment plans for the waterfront and there is the possibility of increased recreational use of the river. The 38 combined sewer outfalls that potentially discharge to the AOC often have been considered the primary source of bacterial contamination. Preliminary investigations (7) suggested that combined sewer overflows (CSOs) contributed to bacterial contamination of water and sediment, but high levels of indicator bacteria also reached the AOC from unidentified, upstream sources.

The primary objective of our paper is to illustrate methodologies for a planning level evaluation of bacterial contamination in a watershed. These methodologies include sampling, testing and interpretation of the spatial and temporal characteristics of fecal coliform and fecal streptococci densities in river water, as well as development of a potential source inventory using existing data. The intent of such evaluation is to provide an overview of the magnitude and sources of the water quality problems without excessive resource commitments.

BUFFALO RIVER WATERSHED

The Buffalo River drains an area of 1,155 km^2 and is fed by three major tributaries, Cayuga, Buffalo and Cazenovia Creeks (Figure 1). The watershed is within two physiographic regions. The northern and western portion of the watershed is within the Erie-Ontario Lake Plain Province, while the southern part of the watershed is within the Allegheny Plateau Province. The Erie-Ontario Province formerly was a glacial lake bed and therefore has limited relief. Accordingly, the Buffalo River within the AOC has a shallow bed slope, averaging 0.0002. The watershed consists primarily of 21 different soil series, but the majority of soils are a silt loam, that also may be shaly or channery in nature (8). The slopes of these soil units range between nearly level and 0.50, while the drainage classification ranges from very poorly drained to excessively drained (8).

Land use within the watershed varies. Much of the upper portion of the watershed is characterized by woods and farmland, but prior to joining the Buffalo River the creeks also pass through several small communities and receive industrial, commercial, residential and municipal discharges. Historically, the AOC was heavily industrialized, although activity has declined along the river in the last decade (9, 10). The south Buffalo urban area that drains toward the Buffalo River is serviced by a combined sewer system and, as noted above, a total of 38 combined sewer outfalls potentially discharge to the AOC.

Much of the AOC is designated a navigable channel and is maintained at a minimum depth of 7m by the Buffalo District Army Corps of Engineers. This dredged reach is wider and deeper than the tributaries, but the bed slope is shallower. As a result of the changes in hydraulic geometry, flow velocities within most of the AOC typically are less than those of the tributaries.

METHODS

Field methods

Sampling for bacteria and conventional parameters was done at 12 sites (Figure 1) on a weekly basis during the summer of 1992, twice per month during the fall of 1992 and spring of 1993 and once per month during the winter of 1992-93 . The number of samples at each site therefore was 24,

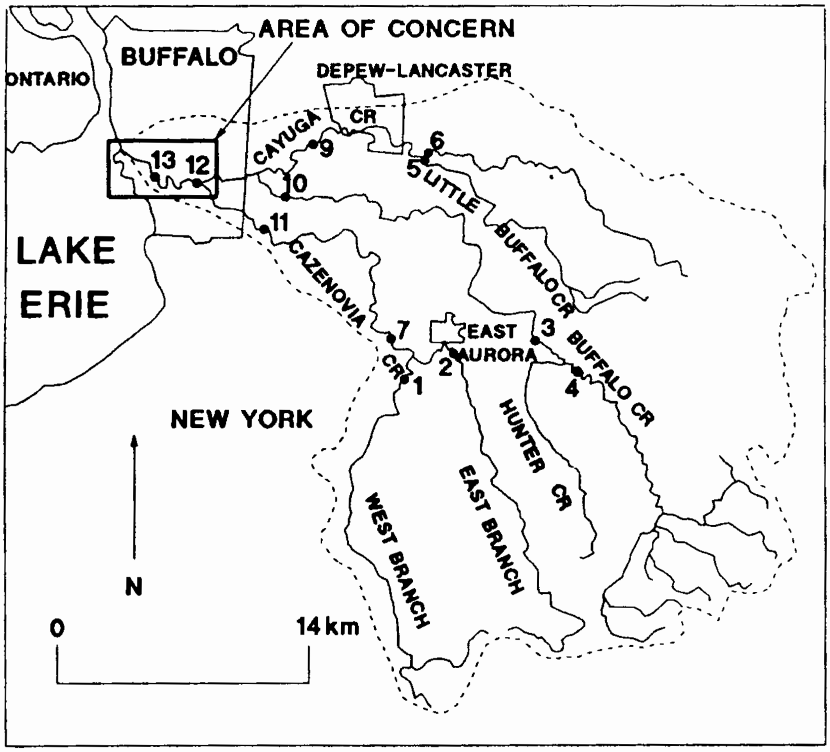

Figure 1. The Buffalo River watershed and sample sites (●)

unless ice cover or other field problems occured. The minimum number of samples was 21 at site 2. Sample site locations were selected to provide a geographical coverage of the major tributaries in the watershed, to represent areas up and downstream of major potential bacteria sources and for ease of access to the water. Sites 10, 11, 5 and 6 also were selected because of proximity to recording U.S. Geological Survey (USGS) gauge stations.

On each sample day, 500 ml water samples were collected from the "upstream sites" (i.e. those above the AOC) for bacteria analysis. These samples were collected at a single vertical (generally mid-channel) in the river cross-section using a Wheaton manual sampler fitted with sterile clear-glass bottles. Samples at all upstream sites were collected at 0.6 of the total river depth below the surface when possible. In some cases during low flow conditions, water depth was too shallow for sample collection at the 0.6 depth. At these times the sample bottle simply was rested on the bed of the river. The water samples collected for bacteria were kept on ice until analysis in the laboratory. Additional samples were collected at each site (2,000 ml during low flow conditions; 1,000 ml during event conditions) in clear-glass bottles for the analysis of suspended and dissolved sediment. The sample methodology for sediment analysis was the same as that for bacteria analysis. On each sample date, one upstream site was randomly selected for collection of duplicate bacteria and sediment samples. The levels of dissolved oxygen (DO) and water temperature were measured at each of the upstream sites in the same sample vertical and depth as that of the bacteria and sediment samples. The DO and temperature measurements were taken using a YSI model 50B meter. The meter was calibrated for DO at each site, prior to measurement, using the 100% air saturation method.

Water samples at sites 12 and 13 (Figure 1) for bacteria and sediment analyses were collected using similar methods and materials as samples collected at the upstream sites. However, from 6/15-8/24/92 the samples were taken at a depth of 1 m below the surface, from a Boston Whaler anchored at mid-channel. Subsequent to 8/24/92 the boat was not available and samples were taken approximately 6 m from the shoreline using an extended-handle Wheaton sampler. Sample depth was maintained at 1 m below the surface, but the samples were collected approximately 28 m closer to the shore than the summer samples. Because only one DO meter was available, DO was not measured at sites 12 and 13. A mercury thermometer was used at these sites to measure water temperature. Duplicate water samples normally were taken at site 13 for quality assurance/quality control measures.

Laboratory methods

Analysis of bacteria -fecal coliform:

Analyses of water samples for fecal coliform (FC) were done by membrane filtration following Standard Method 9222 D (11). Water samples were filtered, in triplicate, through Gelman GN6 membrane filters (diameter, 47mm; pore size, 0.45 µm) and rinsed three times with sterile 0.1% peptone water. Filters were than placed on the surface of mFC agar plates containing 1.0% rosalic acid. Plates were wrapped in water-tight plastic bags and incubated for 22-26 h submerged in a circulating waterbath (Blue M, General Signal, IL) held at 44.5 °C. After incubation, plates were removed and blue colonies were counted under 10-15 magnification as fecal coliform. Selected bacteria were verified as fecal coliform if they produced gas in both lauryl tryptose broth within 48 h at 35 °C and EC broth within 24 h at 44 °C.

Fecal streptococci:

Analyses of water samples for fecal streptococci (FS) were done by membrane filtration following Standard Method 9230 C (11). Triplicate subsamples of each water sample were filtered and rinsed as for fecal coliform. Filters were placed on the surface of mEnterococcus agar plates and incubated at 35 °C for 48 h ±3 h. After incubation, red to pink colonies were counted under 10-15 magnification as fecal streptococci. Selected bacteria were verified as fecal streptococci if they were catalase negative after incubation for 24 h at 35 °C on Brain Heart Infusion agar, and they could grow in Brain Heart Infusion broth during 24 h incubation at 44 ° C.

Determination of suspended and dissolved sediment concentration

Each sample collected for suspended sediment analysis was passed through a 0.45 µm Millipore filter. Material retained by the filter was considered suspended sediment while material passing through the filter was deemed the dissolved sediment. The general filtration procedure followed that described under Standard Method 2540 D (11). Thirty ml of each sample filtrate was collected in an aluminum evaporation tin and evaporated at 180 °C to determine the dissolved sediment concentration. The general dissolved sediment determination followed that described under Standard Method 2540 C (11).

Inventory of potential bacteria sources:

Potential bacteria sources were identified and inventoried using information available from the New York State Department of Environmental Conservation (NYSDEC); Erie County Department of Environment and Planning; Buffalo Sewer Authority; and the Erie County Field Office of the U.S. Department of Agriculture, Soil Conservation Service (SCS). The potential sources of bacteria included: runoff from forested, agricultural, urban and suburban land; discharge from commercial, institutional and industrial facilities having on-site sanitary treatment; discharge from failing septic systems or, in limited cases, direct sanitary input from rural residences; discharges from municipal sewage treatment plants; and combined sewer overflows (CSOs).

Design and operation characteristics of the municipal sewage treatment plants that discharge to the watershed were determined from (12) and a review of current State Pollutant Discharge Elimination System (SPDES) permits, cataloged at the Buffalo Office of the NYSDEC. The location and characteristics of major sanitary discharge points from commercial, industrial and institutional facilities were determined from the Private, Commercial, Institutional (PCI) SPDES permits. Private, single family dwellings on septic systems are not required to obtain discharge permits. Official evidence of failing septic systems would be on record only after inspection of a house due to property transfer. The combined sewer outfall locations within the AOC were determined in a previous study (5), through an examination of city sewer maps. The SPDES permits were used to identify combined sewer outfall locations for areas upstream of the AOC.

As a first approximation, all farm tracts having an edge within 305m (1,000 ft) of the Buffalo River and tributaries were considered possible contributors. The centroids of these tracts were indentified on aerial photographs (scale, 1:7,920) housed at the SCS offices serving Erie County. The tract centroids subsequently were plotted on USGS topographic maps (scale, 1:24,000) and the locations were digitized using GRASS 4.0 (Geographic Resources Analysis Support System), a personal computer GIS maintained at the SCS.

The SCS also maintains an extensive database on the physical and operational characteristics of most farm tracts. The data are maintained on a Unix version of CAMPS (Computer Aided Management and Planning System) and include: field acreage; soil type; crop type and management practices; special management practices (e.g. manure handling); Universal Soil Loss Equation parameters; and presence and size of grass buffer zones. All information associated with the identified farm tracts was stored as a separate file in CAMPS and was linked to the GRASS GIS. Census data on the number of domestic animals within Erie County also are collected by the New York Department of Agriculture and Markets, Division of Statistics and were obtained from the SCS.

RESULTS

Hydrology and conventional parameters

Hydrographs of the daily mean discharge through the sample period for Buffalo Cr. (site 10), Cayuga Cr. (sites 5 and 6) and Cazenovia Cr. (site 11) are presented in Figure 2. Flow duration curves for 1938-85 (13) indicate discharges associated with the larger sampled storm events during our study on Buffalo, Cayuga and Cazenovia Creeks are exceeded approximately 0.8, 0.9 and 2.0 percent of the time, respectively. The sample data therefore represent baseflow through moderate-sized storm event conditions. The mean and range of sampled values for total suspended sediment (TSS), dissolved sediment (DS) and DO at each site are summarized in Table 1. Water temperature at the sites varied, with a maximum range between 0 °C in the winter and 23.9 °C in the summer.

Enumeration of bacteria

The geometric mean and the range of counts for fecal coliform, fecal streptococci and the resulting FC:FS ratios are summarized in Table 2. The geometric mean fecal coliform densities exceeded the state guidelines of 2 cfu ml^{-1} (200 cfu 100 ml^{-1}) at 11 of the 12 sites. The largest proportions of exceedances occurred in response to runoff events generated either by rainfall or snowmelt. The numerous peaks in fecal coliform densities (Figure 3) indicate the response of the watershed to runoff events. Population dynamics of indicator bacteria in the water column were similar throughout the year, with a strong correlation between fecal coliform and fecal streptococci at the sites above the AOC (r=0.92), and within the AOC (site 12, r=0.65; site 13, r=0.86).

Table 1. Summary of conventional parameter results

Site	TSS (mg l^{-1})		DS (mg l^{-1})		DO (mg l^{-1})	
	Mean	Range	Mean	Range	Mean	Range
1	16	0.20-194	163	17-337	11.70	8.92-16.71
2	14.3	0.20-119	153	27.0-370	11.22	8.60-16.49
3	35.9	0.50-414	180	7.0-370	11.47	8.50-17.37
4	28.6	1.70-238	207	27.0-363	11.33	8.14-18.58
5	19.3	0.40-186	314	20.0-2463	11.20	8.5-17.1
6	15.4	0.21-222	191	47.0-363	11.70	8.42-17.6
7	18.8	0.30-212	167	53.0-310	12.29	8.74-15.45
9	18.7	1.15-215	201	33-317	10.2	6.8-15.6
10	35.8	0.42-453	207	40-400	11.6	8.22-15.96
11	42.6	0.50-408	179	27-373	11.0	5.94-19.58
12	56.7	0.60-674	191	20-323	-	-
13	61.8	3.35-659	195	67-353	-	-

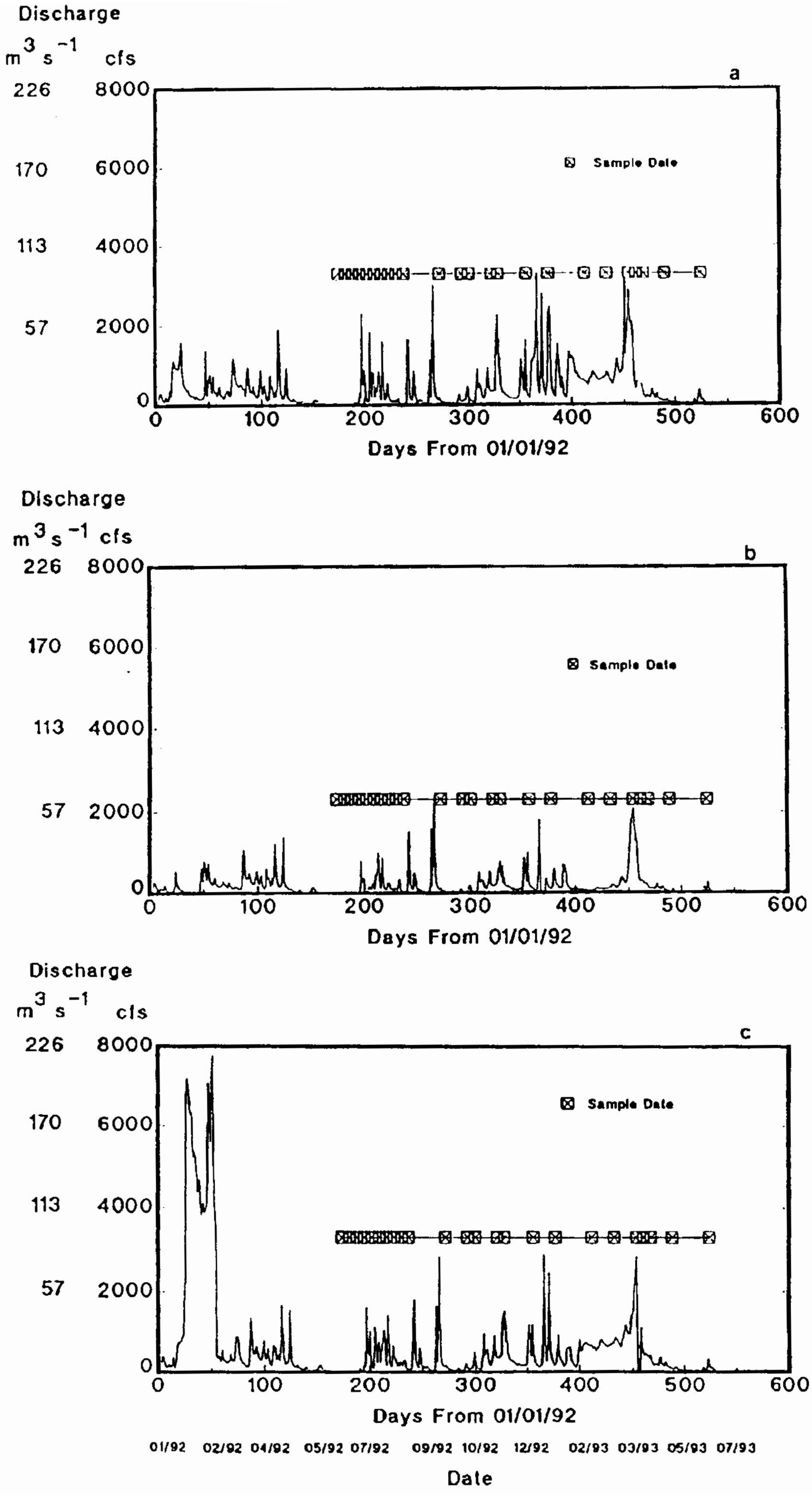

Figure 2. Daily mean discharge and sample dates for: (a) Cazenovia Creek; (b) Cayuga Creek; and (c) Buffalo Creek. The dates are represented using a month/year convention.

Table 2. Summary of bacteria data, all samples.

Site	FC (ml^{-1})		FS (ml^{-1})		FC:FS ratio	
	Mean*	Range	Mean*	Range	Mean	Range
1	1.9	0.1-160	1.2	0.1-154	1.99	0.6-6.3
2	2.8	0.6-165	1.9	0.2-156	2.04	0.35-5.2
3	4.6	0.1-770	2.9	0.06-690	2.04	0.6-8.9
4	6.6	0.3-960	3.2	0.1-750	2.5	0.5-8.2
5	4.2	0.7-85	2.3	0.1-100	2.5	0.45-10.6
6	3.3	0.5-120	1.5	0.1-98	3.0	0.37-10.0
7	4.2	0.4-116	1.5	0.2-210	3.17	0.56-13.1
9	12	0.7-280	2.8	0.1-307	10.7	0.71-114
10	6.7	0.5-140	3.4	0.2-140	2.58	0.21-8.0
11	6.7	1.5-180	2.7	0.3-126	3.35	0.36-9.9
12	34	1.3-970	7.0	0.1-333	7.07	0.72-43.9
13	11	0.7-180	6.3	0.3-300	2.53	0.3-7.62

*Geometric mean

Using the probability plot correlation coefficient test (14), it was determined that the fecal coliform densities at all sites could be considered log-normally distributed (α=0.05; except site 1 where α=0.01 and site 2 where α=0.005). Accordingly, a student's t-test was used to evaluate spatial differences in mean fecal coliform densities, since the log-transformed data have a "mound" shape (15). Fecal coliform densities generally increase in the downstream direction. For example, the mean of the log-transformed fecal coliform densities at site 12 (Figure 1) was significantly greater than the means at sites 9, 10 and 11 (α =0.05). The mean of the log-transformed fecal coliform densities at site 9 (Figure 1) was greater than those of sites 5 and 6 (α=0.05), and the mean at site 11 was greater than those of sites 1 and 2 (α=0.05). However, the mean of the log-transformed fecal coliform densities at site 10 was not significantly different (α=0.05) from the mean of sites 3 and 4.

The fecal coliform levels in the Buffalo River AOC tended to reflect upstream levels, particularly in the absence of CSOs. Figure 4 shows the levels of fecal coliform at sites above (site 10) and within the AOC (site 13). Densities of fecal coliform typically are of the same magnitude at both sites throught the year. Parallel increases in fecal coliform densities at the two sites are associated with rainfall or snowmelt events. However, a major CSO event occured within the AOC on 7/19/92, the day prior to the 7/20/92 sample date. The effect of the overflow event is reflected by higher fecal coliform counts at sites 13 (and 12), while all upstream sites showed a decrease in levels from the previous week (Figure 3 and 4).

Mean fecal coliform levels were relatively constant throughout the year. The data were divided into summer

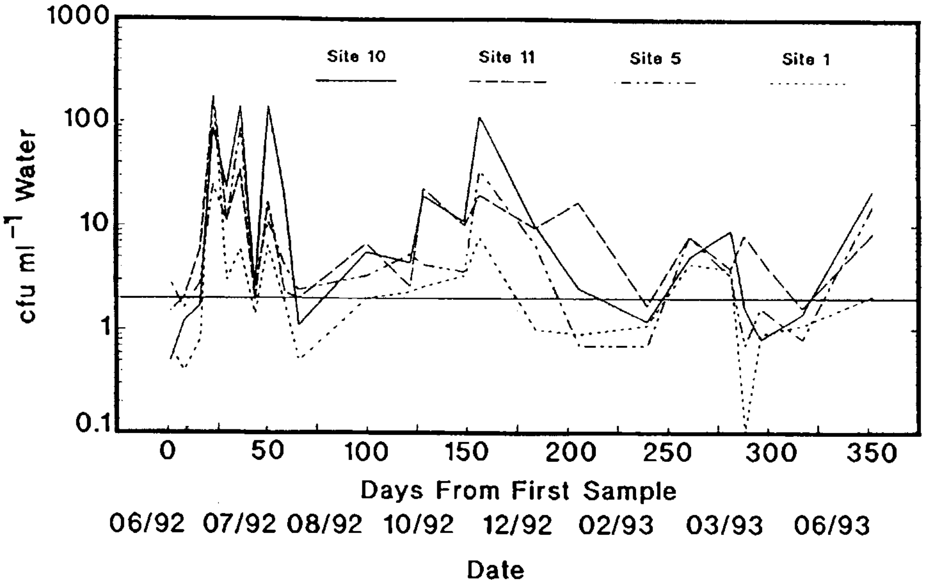

Figure 3. Densities of fecal coliform in water at selected sites above the AOC. The solid horizontal line at 2 cfu ml^{-1} represents the state guideline for primary contact. The dates are represented using a month/year convention.

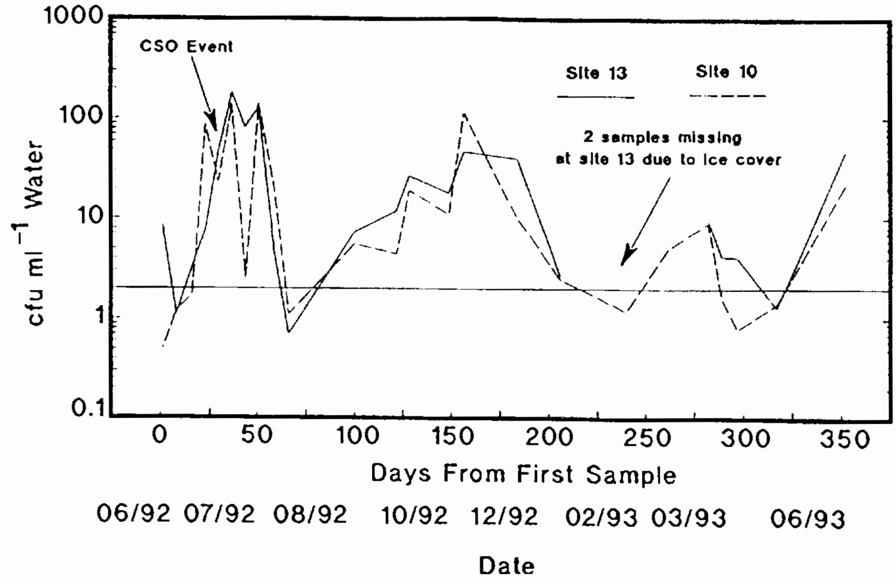

Figure 4. Densities of fecal coliform in water at sites above (site 10) and within (site 13) the AOC. The solid horizontal line at 2 cfu ml^{-1} represents the state guideline for primary contact. The dates are represented using a month/year convention.

(6/22/92-9/28/92; 5/3/93-6/7/93) and winter (10/19/92-4/12/93) samples and student's t-tests indicated no difference in the means of the seasonal, log-transformed data (α=0.05; except site 4 where α=0.01).

Bacteria source inventory

A total of 10 municipal treatment plants routinely discharge to the Buffalo River and its tributaries and one additional plant is maintained, but used infrequently. This information is summarized in Table 3. All facilities chlorinate, at least on a seasonal basis, but the general level of treatment ranged from primary to secondary, with activated sludge.

A total of 38 combined sewer outfalls discharge to the AOC and a detailed evaluation of sewer system characteristics (including frequency and volume of overflow occurrences) for south Buffalo has been done (5). The location of each outfall has been mapped (5) and a summary of the number of outfalls relative to site 12 and 13 is provided in Table 3. Combined sewer discharges to the Buffalo River tributaries also occur in several of the smaller towns located within the watershed. A search of SPDES permits indicated that 26-27 outfalls exist above the AOC (Table 3).

Information about major sanitary discharge points, obtained from the PCI SPDES permits also is summarized in Table 3. The type of treatment varied from septic systems with sand filters to aerated lagoons. Many permit holders chlorinate effluent, at least on a seasonal basis. However, because of the receiving water body stream class, some permit holders are not required to chlorinate.

A total of 477 farm tracts in Erie County have field edges within 305m of the waterways and the locations are shown in Figure 5. Clearly, most farming occurs in the upper part of the watershed. It was noted (16) that 51 of the 477 tracts have poor grass buffers (<6m) between field edges and waterways, while 426 of the 477 tracts have medium to very good grass buffers (6-30m). In addition, 105 of the 477 tracts (approximately 2,121 ha) are classified as being highly erodible, under the SCS classification system (16). This erodibility classification considers slope steepness, slope length, soil type and crop type, in an approach similar to that of the Universal Soil Loss Equation. The Buffalo Creek watershed (upstream of site 10) has the largest proportion of highly erodible land (59%), followed by the Cazenovia Creek watershed (upstream of site 11) with 31% and the Cayuga Creek watershed (upstream of site 5 and 6) with 10%.

The New York Department of Agriculture and Markets 1991 census of cattle indicate 32,000 head in the entire county while a 1988 census showed 8,000 horses were stabled. It was not possible to subdivide these census data by watershed, but as a first approximation 1/3 of the total cattle and horses in the county were assumed present in the Buffalo River watershed. This estimate is based on the area of the Buffalo River watershed and the assumption that the animals have an even spatial distribution throughout the entire county. Most farm tracts in the watershed are upsteam of site 10,11,5/6, (Figure 5). Therefore, the estimated number of cattle and horses within the watershed, divided by the area above the USGS gauge sites (10, 11, 5/6), can be used to represent the domestic animal density index. Using this approach it is estimated that the domestic animal density for the watershed is 0.14 animals ha^{-1}.

Table 3. Summary of potential bacteria sources to the Buffalo River watershed.

Location	Treatment plants		PCI permits		No. of CSOs
	Number	Design flow ($m^3 d^{-1}$)	Number of outfalls	Total permitted volume ($m^3 d^{-1}$)	
Above S1	2	367.18	12	124.9	-
Above S2	1	1,400.6	57	193.0	-
Above S4	1	98.42	4	15.90	-
Above S5	-	-	1	2.65	-
Above S6	1	83.28	4	37.85	-
Between S1/S2 and S7	1	5,678.2	3	495.9	-
Between S7 and S11	-	-	12	147.6	1
Between S5/S6 and S9	-	-	-	-	8-9
Between S9 and S12	-	-	1	13.25	12
Between S4 and S3	-	-	12	45.42	-
Between S3 and S10	4	370.98	11	166.6	-
Between S10 and S12	-	-	-	-	2** 9†
Between S11 and S12	-	-	-	-	3** 16†
Between S12 and S13	-	-	1	9.84	5
Total above AOC	10	7,998.66	117*	1,243	26-27

*total does not include two small volume outfalls that could not be located due to limited address information. The permitted discharge from the two outfalls represnts 0.2 % of the total permitted discharge.

**total above AOC

†total within AOC

DISCUSSION

Conventional parameters

A strong positive correlation exists between TSS and discharge at the USGS gauge sites, the correlation coefficients (r) being 0.934, 0.740, 0.904 and 0.987 for sites 10, 11, and 6, respectively. These results are consistent with data reported by many researchers (e.g. 17, 18, 19). Although the correlations are strongly positive, scatter in the data may be related to factors including antecedent conditions and reflex time, storm event hysteresis, seasonality and variable storm conditions (e.g. 19, 20). The relationship between TSS and discharge at the three USGS gauge sites has been examined more thoroughly using regression analysis (16). The mean TSS concentrations at the sites within the AOC are greater than those at sites above the AOC (Table 1). Historically, higher TSS concentrations in the AOC were related to industrial discharge and urban runoff (e.g. 1,9). Industrial inputs have declined over the past 25 years, as have the TSS concentrations within the AOC (9). However, urban and suburban land uses below the USGS gauges and within the AOC still maintain higher TSS inputs than the lands upstream of the gauges.

The dissolved oxygen (DO) levels at the upstream sites consistently were high (Table 1), and even at the low end of the range do not appear particularly limiting for aquatic biota. For example, the low end of the DO value range exceeds the NYSDEC class 4 stream criterion of 4 mg l^{-1}. Dissolved oxygen levels of 8.2 mg l^{-1}, 8.8 mg l^{-1} and 2.4. mg l^{-1} were reported two decades ago (1) for Buffalo, Cazenovia and Cayuga Creeks, respectively. The lower DO levels for Cayuga Creek were attributed to discharge from the primary sewage treatment plants in the villages of Depew and Lancaster and in the town of Lancaster. Sewage from the Depew-Lancaster area now is treated by the city of Buffalo and this appears to have contributed to the improvement in the DO levels of Cayuga Creek. The Depew-Lancaster area still has several combined sewer outfall points that can introduce bacteria to the creek (Table 3).

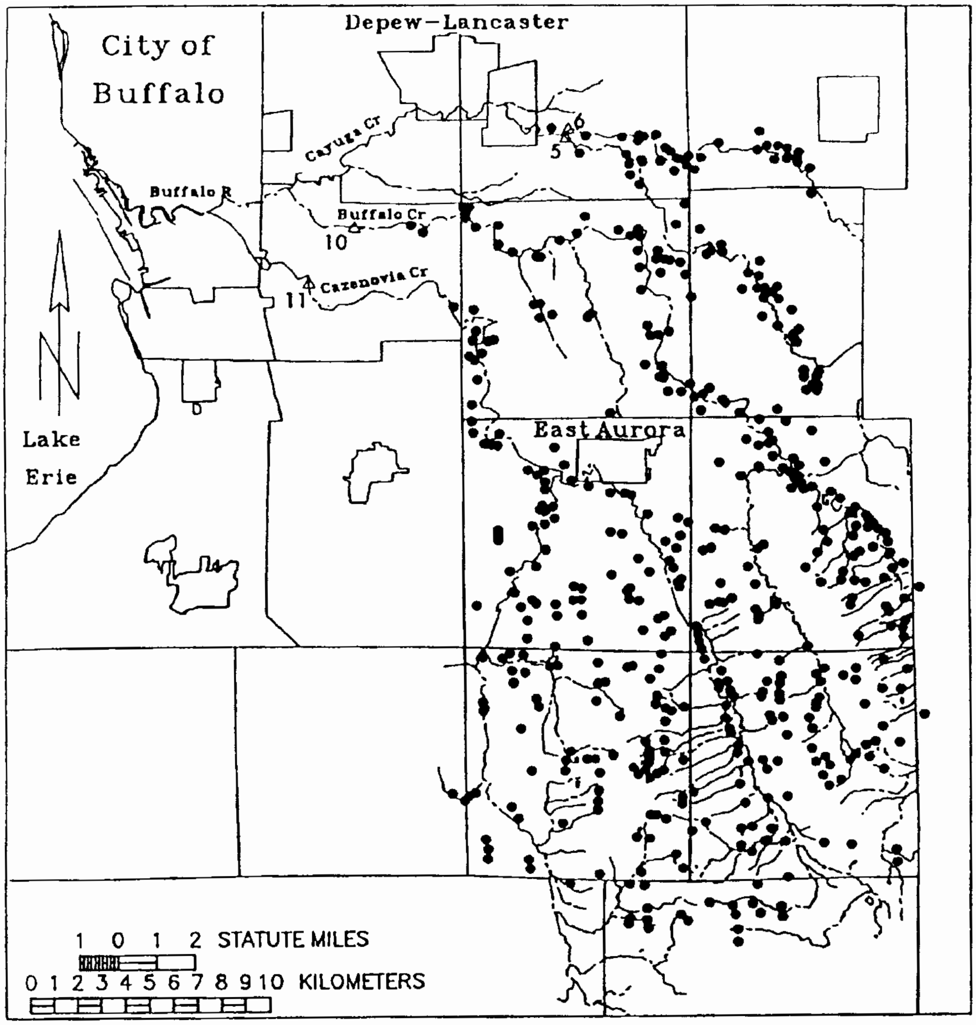

Figure 5. Location of farm tract centroids (●) in Erie County having a field edge within 305 m (1, 000 ft) of a waterway and sample sites (Δ) near USGS gauging stations.

Fecal coliform levels in water

The sanitary quality of water routinely is monitored by testing for the presence of indicator bacteria, especially fecal coliform. Since enteric pathogens may be present in waters containing high levels of fecal coliform, governments have adopted minimum standards for water usage based on fecal coliform densities (21, 22). Pathogenic bacteria, however, have been isolated from water containing low levels of fecal coliform (23). Furthermore, the coliform population in a water body may consist of strains of *Klebsiella pneumoniae* that are non-fecal in origin (11). Despite the obvious limitations to using coliform as indicators of fecal pollution they are still regarded as useful, particularly in waters that have been polluted as a result of sewage discharge.

A total of 277 samples were analysed for fecal coliform, considering all sites, but excluding duplicate samples. The state guideline for primary contact of 200 cfu 100 ml^{-1} (or 2 cfu ml^{-1}, as indicated by the horizontal line in Figure 3 and 4) was exceeded in 191 (69%) of the samples. In comparison, 65% of the samples collected at all sites above the AOC exceeded state guidelines, while 89% of the samples collected at the two sites within the AOC exceeded the guidelines. Geometric mean fecal coliform levels during the summer exceeded the state guidelines for primary contact at all 12 sites. Geometric mean fecal coliform densities exceeded state guidelines at nine of the 12 sites during winter months. It can be argued, strictly speaking, that fecal coliform levels in the tributaries should not be compared with the state guidelines since these were developed for designated bathing beaches. However, public swimming and bathing frequently were observed in both the AOC and the tributary areas and high bacteria levels present a health risk to this population.

Many of the observed exceedances appear related to storm events, suggesting that greater densities of fecal coliform enter the waterway due to runoff processes. These processes may include CSOs, general runoff from urban, agricultural and forested land and septic system discharges due to elevated groundwater levels. Accordingly, data collected during summer steady-state conditions were examined separately from data collected during summer storm events. The summer period (6/22/92-9/28/92; 5/3/93/-6/7/93) was examined because this is a time of potentially greater water activity and human exposure. For purposes of separation, steady-state, inter-event sample periods were identified using the daily mean discharge hydrographs for the three USGS gauge stations (Figure 2.) Samples from a particular tributary were considered to represent inter-event periods if the hydrograph was relatively flat for several days prior to sample collection.

Five summer inter-event dates were identified and a total of 58 samples were collected at all sites on these dates. The state guideline for primary contact was exceeded in 16 of the 58 (28%) samples. A large proportion of these exceedances (6 of 16) was observed at sites 12 and 13. Proportionally, there were fewer exceedances of state guideline for primary contact during summer inter-event periods. The exceedance proportionality supports the hypothesis that higher bacteria densities were associated with some type of runoff. Several others also have observed increases in fecal and thermotolerant coliforms in water bodies receiving runoff from different land uses, including feedlots, agricultural, pristine and urban land (12, 22, 24, 25, 26, 27). Furthermore, if continous point sources (e.g. wastewater treatment plants smaller commercial, industrial and institutional interests) had a major impact on basin water quality, it might be expected that this would become apparent during low flow periods when there is less dilution.

Sites closer to the AOC tended to have higher mean coliform densities throughout the year, which could reflect the increased urbanization of the area nearer to Buffalo. The two sites within the AOC also had yearly mean fecal coliform counts that greatly exceeded state water quality guidelines. Site 12 had a higher mean than site 13 during the study period, which may reflect: i) its position near several combined sewer outfalls both within and above the AOC (Table 3); and ii) the depositional nature of the AOC between sites 12 and 13 due to changes in hydraulic geometry (e.g. 28).

FC:FS Ratios

The mean FC:FS ratios showed a general increase at sites nearer the AOC which could indicate increased input from anthropogenic sources. An FC:FS ratio of 4 or greater generally indicates that bacteria in the water predominantly are from human sources (22). Ratios of 0.6 or less suggest warm blooded animals other than humans are the predominant source of bacteria. A range of 0.1 to 0.6 is typical of domestic animals and values <0.1 are typical of wildlife. The FC:FS ratio has been used successfully to differentiate contributions from livestock and wildlife (27,29). The FC:FS ratio in a water body gradually will shift as organisms age because of differences in die-off rates, although this effect should be minimized if samples are collected less than 24 hours of stream travel from the pollution source. It has been suggested that FC:FS ratios of 0.7 to 3 characterize this "aging" of fecal pollution in a stream (22). The use of the ratio therefore is not recommended by some to differentiate human from non-human sources of pollution (11). However, it has been argued by others (30) that judicious use of the FC:FS ratio is warranted in the absence of any better indicator system. For example, samples collected immediately downstream of a primary sewage treatment plant at Hereford, Texas, had FC:FS ratios ranging from 6.7 to 15.3 (25). Samples collected upstream and 1.1 km downstream of the treatment plant had lower FC:FS ratios of 0.1-1.6, which primarily reflected the inputs from cattle feedlots.

We felt that calculations of the FC:FS ratio might allow us to make some relative assessments as to source or type of fecal pollution at the study sites. The majority of the yearly mean FC:FS ratios fell between approximately 0.7 and 3 which is a range that does not allow us to discriminate between human and non-human sources. However, higher ratios were seen consistently at site 7, 9, 11 and 12 (Table 2). As noted previously, these sites are in the vicinity of municipalities and the increase in the ratio probably reflects the input of domestic sewage into the waterways near these sites (Table 3).

Fecal coliform levels in river water that exceed the 200 cfu 100 ml^{-1} level have been observed in natural and agricultural watersheds (22, 26, 27,29, 31). Although some of these monitored watersheds did not have bacterial contributions from domestic animals, fecal coliform levels in receiving water bodies generally are observed to increase with greater livestock contact (22). It has been noted (26) that fecal coliform discharge could be substantial from a watershed with a domestic animal density of 0.6 animals ha^{-1}. The domestic animal density for the upper watershed in our study was 0.14 animals ha^{-1} and therefore it might be expected that there would be a relatively smaller impact as compared to that reported in (26).

CONCLUSION

Our data show that the mean level of indicator bacteria in the water column at all sample sites generally was high during the study period and the state guideline for primary contact (200 cfu of fecal coliform 100 ml^{-1}) was exceeded in 69% of 277 samples. A larger proportion of guideline exceedances was observed for storm events as compared to inter-event periods, suggesting that greater densities of fecal coliform enter the waterways due to runoff processes. Sites closer to the AOC tended to have higher mean fecal coliform densities, which could reflect the increased urbanization of the area nearer Buffalo. These sources include CSOs, municipal treatment plant discharges, permitted discharges from commercial, industrial and institutional facilities, septic discharges and runoff from urban land. Resuspension of inoculated bed sediment due to storm or lake-going ship passages also may affect water quality in the AOC (28).

The spatial extent of the Buffalo River AOC as defined in the RAP (2) includes only the lower 9.2 km of the river. Our source inventory and sample results show that high indicator bacteria levels clearly is a watershed-wide management problem. In particular, while the 38 combined sewer outfalls within the AOC are a source of indicator bacteria, high fecal coliform levels also are translated from upstream areas and have a negative impact on water quality in the absence of CSOs. Even a costly total elimination of CSOs will not entirely alleviate problems with high bacteria levels. Water quality within the AOC will improve only through co-ordinated reduction of bacteria inputs from the various upstream sources. Finally, GIS technology can be an effective tool in the inventory and evaluation of bacteria sources for management decisions.

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