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E. COLI AND ENTEROCOCCI LEVELS IN URBAN STORMWATER, RIVER WATER AND CHLORINATED TREATMENT PLANT EFFLUENT

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Abstract—Stormwater from the Ann Arbor, Michigan area affects the bacterial indicator organism quality of the Huron River. Investigations during the 1985 summer period involved sampling during dry and wet periods with parallel determination on each sample for fecal coliforms, fecal streptococci, *E. coli* and enterococci. Wet weather bacterial indicator densities were statistically significantly higher than dry weather levels, and downstream densities were statistically significantly higher than upstream densities. The FC/FS (fecal coliforms/fecal streptococci) ratios for the storm drains were low and suggestive of more animal than human sources. The geometric mean EC/FC (*E. coli*/fecal coliforms) ratios were in the range of 0.82–1.34, well above the ratio of 0.63 calculated using the U.S. EPA recommended level for *E. coli* of 126/100 ml to the presently accepted level for fecal coliforms of 200/100 ml. If the intent is to maintain the currently accepted illness rate, additional results from other areas are necessary to refine the *E. coli* and enterococci levels for water quality standard development purposes. In general, physical-chemical observations reflected the source of the sample.

Key words—indicator bacteria, urban runoff, *E. coli*, enterococci, water quality, wastewater, stormwater

INTRODUCTION

Urban stormwater impacts the ambient bacteriological quality of the Huron River downstream from separate storm drains in the Ann Arbor, Michigan, area. Particular concern existed about the use of a downstream river impoundment for windsurfing. Existing sampling was conducted during the 1985 summer recreational season to evaluate the impact on the river water quality of discharges from these drains, during both dry weather and wet weather periods.

The U.S. EPA (1986a) concluded that the indicator organism group, the fetal coliforms, is inadequate, and recommended instead the use of either *E. coli* or enterococci as a bacterial indicator to evaluate ambient fresh water quality. They further recommended densities for *E. coli* not to exceed a geometric mean of 126/100 ml, or densities for enterococci not to exceed a geometric mean of 33/100 ml to provide for the protection of primary water contact recreation. The selection of these indicator organisms and the associated levels is based on the work of Dufour (1984) and Cabelli (1983) relating mean bacterial indicator densities to gastrointestinal illness rates in bathers. It is intended that the new organisms would replace the present fecal coliform standard of a geometric mean of 200/100 ml.

The present study involved parallel determinations on each sample for total coliforms, fecal coliforms, fecal streptococci, *E. coli* and enterococci. In addition, samples of the effluent from the Ann Arbor, Michigan tertiary wastewater treatment plant, which discharges chlorinated effluent downstream of the study area, were collected on a number of occasions that the storm drains and river were sampled. Thus, a comparison of indicator organism levels is possible for urban stormwater, subsequent downstream river conditions, and chlorinated wastewater treatment plant effluent.

Allen Drain, one of the main drains in the study area, has been reported on by several investigators including Burm and Vaughan (1966), Benzie and Courchaine (1966), Collins and Ridgeway (1980) and, more recently, by Schmidt and Spencer (1986) and Schillinger and Gannon (1985). Also, Geldreich *et al.* (1968) and Olivieri (1977) have presented material on the bacteriological aspects of stormwater pollution. Others have reported on recreational water quality including Henderson (1968), Foster *et al.* (1971), Vasconcelos and Anthony (1985) and Geldreich (1970).

STUDY AREA

Figure 1 shows the survey area involving the Huron River flowing through Ann Arbor, Michigan starting at Maple Road upstream of the City and extending to Geddes Dam downstream of the City. The main impact is Gallup Park located on Geddes Impoundment downstream of the Allen, Traver Creek, Fuller and North Campus storm drains. The Huron River is a tributary of Lake Erie, with a drainage area of 1888 km^2 (729 sq. miles) at the U.S. Geological stream gage on the river located below the Allen Drain discharge.

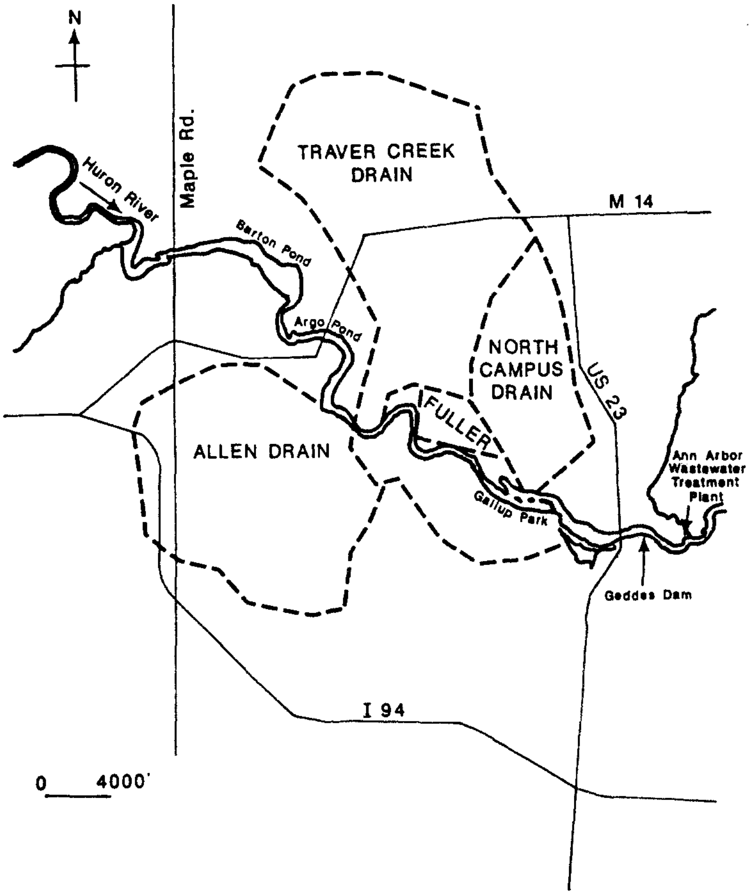

Fig. 1. Drainage areas of major storm drains in the Ann Arbor, Michigan area upstream of Gallup Park, the Huron River.

Allen Drain (Wastenaw County, Mich. 1981) is almost completely enclosed with the majority of its 15,378,220 m^2 (3800 acres) within the City of Ann Arbor. Land use in this area is 73% residential, 17% commercial and 10% undeveloped. Traver Creek watershed covers approx. 18,478,145 m^2 (4,566 acres) with 67% of the land undeveloped, 31% residential and 2% commercial. Fuller Drain covers a small part of the University of Michigan North Campus. The North Campus Drain has a watershed of 6,357,680 m^2 (1571 acres), with 62% of the land area undeveloped, 34% residential and 4% commercial. It discharges directly into the Gallup Park area.

Operation of the gates on the dams of two upstream river impoundments, Barton and Argo Ponds, significantly influenced the river flow into Gallup Park on an hourly basis during the 1985 summer period. As a result, meaningful mass balance calculations have not been possible.

PROCEDURES

The strategy of the field sampling was to sample during and following precipitation. In addition, the plan called for at least a once a week sampling interval, with a goal of at least one wet weather event per month. As it turned out, this goal was exceeded because of above average precipitation, particularly during July and August. The minimum weekly sampling interval also provided for dry weather observations. Increased attention was given to the Gallup Park area which involved additional sampling for 1 and 2 days following each wet weather effort. Thirteen sites were routinely sampled which included main river locations, the outlet from each of the major storm drains, and the effluent from the Ann Arbor, Michigan wastewater treatment plant.

Field processing included water temperature measurement and dissolved oxygen fixation, while laboratory analyses included: *E. coli* (membrane filter), fecal coliforms (membrane filter), total coliforms (membrane filter), fecal streptococci (membrane filter), enterococci (membrane filter), conductivity, pH, turbidity, total solids and suspended solids. Procedures recommended by *Standard Methods* (APHA, 1985) were employed in all cases, with the exception of *E. coli* (U.S. EPA, 1985; Dufour *et al.*, 1981) and enterococci (U.S. EPA, 1985; Levin *et al.*, 1975) procedures which were recommended by the U.S. EPA. Sodium thiosulfate was included in the containers used to sample the chlorinated effluent of the Ann Arbor wastewater plant to neutralize any chlorine present in the effluent. All bacteriological samples were placed immediately after collection in an insulated chest containing a coolant for transport to a nearby laboratory, where they were processed upon receipt, with no sample held longer than 6 h from the time of collection to the time of processing.

The MIDAS statistical program, available on the University of Michigan computing facility, was used for data summary and analysis. Specific procedures have been documented by Fox and Guire (1976), and the staff of the Statistical Research Laboratory, The University of Michigan (1976). Primary reliance has been on Student's t- and F-tests for comparing two sets of data. In a few instances where the F-test indicated the Student test to be inappropriate, the Mann–Whitney and the median tests were used. The lognormal distribution ($\log_{10}$ transformation) was found to best describe the variation of the bacterial indicator organisms, and it has been used in all summaries and tests for statistical significance. On the other hand, the normal distribution was found to best describe the variation of the physical-chemical data, and it has been used to summarize and test this data. Various statistical procedures were used to test the normality of these respective distributions. Primary reliance was on normal and lognormal probability plots generated using the MIDAS statistical program, with data plots approximating a straight line as the main criteria for accepting the normality of the distribution. Velz (1984) and Gannon (1959) have used similar procedures for data summary and normality testing.

RESULTS AND DISCUSSION

Sampling was conducted during the period 6 May 1985–10 September 1985. Indicator organism levels are summarized in Table 1 in terms of the Barton –Argo upstream area involving three river stations together, the mouth of each major storm drain including Allen, Traver, Fuller and North Campus, the Gallup Park downstream area involving three river stations together, and the Ann Arbor Wastewater Treatment Plant effluent. Also, the results are separated according to dry periods and wet periods, with the wet periods defined as times when the precipitation was greater than 0.25 cm/day (0.1 in./day). Nineteen separate rain events were sampled in 1985 at most stations, with the daily average precipitation ranging from 0.33 cm/day (0.13 in./

Table 1. Bacterial indicator densities 1985

	Mean (Geom.) No. 100 ml	Geometric S.D. ($\log_{10}$)	Maximum No. 100 ml	Minimum No. 100 ml	N
Barton–Argo (upstream)					
Fecal coliforms					
Dry	21	0.70	220	<1	21
Wet	55	0.66	800	<4	33
Significance—yes at $P = 0.05$					
E. coli					
Dry	24	0.76	240	1	21
Wet	74	0.68	1200	4	33
Significance—yes at $P = 0.05$					
Fecal streptococci					
Dry	28	0.59	490	<4	21
Wet	68	0.65	2000	<4	33
Significance—yes at $P = 0.05$					
Enterococci					
Dry	21	0.63	250	<4	21
Wet	65	0.69	1000	<4	33
Significance—yes at $P = 0.05$ level					
Allen Drain					
Fecal coliforms					
Dry	98	1.67	24,000	<1	7
Wet	3780	1.09	84,000	45	19
Significance—yes at $P = 0.01$ level					
E. coli					
Dry	120	1.68	22,000	<1	7
Wet	4000	1.06	130,000	<50	19
Significance—yes at $P = 0.05$ level					
Fecal streptococci					
Dry	260	1.50	25,000	3	7
Wet	9800	1.22	1,400,000	<50	19
Significance—yes at $P = 0.05$ level					
Enterococci					
Dry	120	1.73	27,000	<1	7
Wet	6400	1.16	340,000	<50	19
Significance—yes at $P = 0.01$ level					
Traver Drain					
Fecal coliforms					
Dry	520	0.48	4700	150	7
Wet	5800	0.68	190,000	550	10
Significance—yes at $P = 0.01$ level					
E. coli					
Dry	520	0.53	4900	130	7
Wet	4700	0.69	110,000	450	10
Significance—yes at $P = 0.01$ level					
Fecal streptococci					
Dry	1780	0.52	23,000	790	7
Wet	17,100	0.77	760,000	700	10
Significance—yes at $P = 0.01$ level					

continued overleaf

Table 1—*continued*

	Mean (Geom.) No. 100 ml	Geometric S.D. (log_{10})	Maximum No. 100 ml	Minimum No. 100 ml	N
Enterococci					
Dry	1550	0.45	13,000	700	7
Wet	10,800	0.75	80,000	150	10
Significance—yes at $P = 0.05$ level					
Fuller Drain					
Fecal coliforms					
Dry	3	0.43	10	<1	7
Wet	15	1.01	1600	<2	9
Significance—not significant ($P > 0.05$)					
E. coli					
Dry	4	0.45	10	<1	7
Wet	16	0.98	1100	<2	9
Significance—not significant ($P > 0.05$)					
Fecal streptococci					
Dry	6	0.42	20	1	7
Wet	29	1.18	8000	<2	9
Significance—not significant ($P > 0.05$)					
Enterococci					
Dry	4	0.39	10	1	7
Wet	23	1.11	6400	<2	9
Significance—not significant ($P > 0.05$)					
North Campus Drain					
Fecal coliformis					
Dry	520	0.17	1000	330	7
Wet	3900	0.36	11,000	800	15
Significance—yes at $P = 0.01$ level					
E. coli					
Dry	550	0.28	1400	220	7
Wet	3900	0.33	14,000	1100	15
Significance—yes at $P = 0.01$ level					
Fecal streptococci					
Dry	700	0.17	1000	390	7
Wet	11,900	0.50	6000	1600	15
Significance—yes at $P = 0.01$ level					
Enterococci					
Dry	790	0.45	7000	350	7
Wet	9100	0.45	34,000	1700	15
Significance—yes at $P = 0.01$ level					
Gallup Park (downstream)					
Fecal coliforms					
Dry	88	0.33	520	25	21
Wet	610	0.76	41,000	18	142
Significance—yes at $P = 0.01$ level					
E. coli					
Dry	80	0.34	470	15	21
Wet	540	0.71	34,000	20	142
Significance—yes at $P = 0.01$ level					
Fecal streptococci					
Dry	58	0.40	260	<10	21
Wet	380	0.90	52,000	4	142
Significance—yes at $P = 0.01$ level					
Enterococci					
Dry	42	0.49	260	<4	21
Wet	300	0.95	45,000	<2	142
Significance—yes at $P = 0.01$ level					
Ann Arbor wastewater effluent					
Fecal coliforms					
Dry	27	0.71	530	<4	7
Wet	74	0.75	440	<2	9
Significance—not significant ($P > 0.05$)					
E. coli					
Dry	25	0.66	280	4	7
Wet	75	0.65	360	4	4
Significance—not significant ($P > 0.05$)					
Fecal streptococci					
Dry	34	0.47	170	8	7
Wet	87	0.63	890	10	9
Significance—not significant ($P > 0.05$)					
Enterococci					
Dry	39	0.41	140	<10	7
Wet	57	0.60	310	8	9
Significance—not significant ($P > 0.05$)					

day) to 4.84 cm/day (1.59 in./day). Gannon (1988) reported on the development of a model relating precipitation rate to resulting fecal coliforms level in the Gallup Park area. This model is in use as a short-term management tool to alert the public to times when fecal coliforms are predicted to exceed current State of Michigan water quality standards.

The first column in Table 1 is the geometric mean value for the various bacterial indicator densities and is expressed in number of organisms per 100 ml. The second column is labeled as the geometric standard deviation and is expressed in $\log_{10}$ units.

Fuller Drain presented an unusual condition of very low indicator organism levels in comparison to the other drains. A special study was conducted on 24 October 1985 following 0.1 in. of precipitation, at which time a significant residual chlorine was measured at the mouth of the drain. The source of this chlorine is not known, but the Fuller Drain indicator bacteria levels must be viewed cautiously in the light of this observation.

Statistical significance conclusions between wet and dry bacterial indicator densities are presented in Table 1. Significance levels at $P = 0.01$ and $P = 0.05$ and a no significance level of $P > 0.05$ are indicated. It is apparent that the wet weather levels are statistically significantly higher than the dry weather levels at all river and storm drain outlets, except for Fuller Drain and the Ann Arbor wastewater treatment plant effluent.

The geometric mean level for all indicator organisms is higher at Gallup Park than at Barton–Argo reflecting discharges from the urban storm drains. A statistically significant difference was demonstrated at $P = 0.05$ and at a lower P during wet periods. Traver, North Campus and Allen Drains all have indicator bacteria levels above the nearby river stations, which in turn are higher than the Ann Arbor wastewater treatment plant effluent. Also, it is apparent this effluent is approximately the same level as the upstream Barton–Argo stations. No statistical significance ($P > 0.05$) in the levels at Barton–Argo and the Ann Arbor wastewater effluent was found.

The storm drains (except Fuller) have much higher bacterial levels and also a greater impact on the Gallup Park area during wet periods over dry periods. This results not only from higher bacterial levels in the storm drains, but also from much higher storm drain water discharges during wet periods. Fecal coliforms as high as 41,000/100 ml were measured on occasion in the Gallup Park area.

Indicator organism ratios including FC/FS (fecal coliforms/fecal streptococci), EC/FC (*E. coli*/fecal coliforms), and EN/FC (enterococci/fecal coliforms) are summarized in Tables 2 and 4. The column headings are the same as Table 1, with the log normal distribution used to summarize the variation of the bacterial indicator ratios. The FC/FS ratio has been recommended by Geldreich *et al.* (1969) and Geldreich (1970, 1972) and by *Standard Methods* (APHA, 1985) as an indication of origin of fecal contamination, with values greater than 4.0 suggesting human sources and a value less than 0.7 suggesting animal souces. The EC/FC ratio for the U.S. EPA recommended level of *E. coli* of 126 to the accepted fecal coliforms of 200 is 0.63, while the EN/FC ratio for the U.S. EPA recommended level of enterococci of 33 to the accepted fecal coliforms of 200 is 0.165. The results in Tables 2 and 4 should be viewed in relation to these levels.

No statistically significant difference ($P > 0.05$) was found between the ratios for the wet and dry

Table 2. Bacterial indicator ratios 1985

	Mean (Geom.)	Geometric S.D. ($\log_{10}$)	Maximum	Minimum	N
Barton–Argo (upstream)					
FC/FS					
Dry	0.76	0.43	4.33	0.11	21
Wet	0.81	0.52	6.00	0.05	33
Significance—not significant ($P > 0.05$)					
EC/FC					
Dry	1.13	0.26	5.17	0.33	21
Wet	1.34	0.40	10.00	0.20	33
Significance—not significant ($P > 0.05$)					
EN/FC					
Dry	1.00	0.26	5.00	0.28	21
Wet	1.17	0.50	10.00	0.20	33
Significance—not significant ($P > 0.05$)					
Allen Drain					
FC/FS					
Dry	0.38	0.54	1.00	0.04	7
Wet	0.39	0.66	4.23	0.02	19
Significance—not significant ($P > 0.05$)					
EC/FC					
Dry	0.82	0.17	2.90	0.92	7
Wet	1.07	0.23	2.90	0.29	19
Significance—not significant ($P > 0.05$)					

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Table 2—*continued*

	Mean (Geom.)	Geometric S.D. ($\log_{10}$)	Maximum	Minimum	N
EN/FC					
Dry	0.80	0.41	8.00	0.36	7
Wet	1.71	0.60	20.00	0.16	19
Significance—not significant ($P > 0.05$)					
Traver Drain					
FC/FS					
Dry	0.29	0.27	0.63	0.14	7
Wet	0.34	0.32	0.79	0.11	10
Significance—not significant ($P > 0.05$)					
EC/FC					
Dry	1.00	0.18	1.41	0.41	7
Wet	0.82	0.18	1.43	0.42	10
Significance—not significant ($P > 0.05$)					
EN/FC					
Dry	2.98	0.24	6.77	1.37	7
Wet	1.87	0.50	9.14	0.27	10
Significance—not significant ($P > 0.05$)					
Fuller Drain					
FC/FS					
Dry	0.58	0.28	1.00	0.17	7
Wet	0.53	0.42	1.03	0.07	9
Significance—not significant ($P > 0.05$)					
EC/FC					
Dry	1.22	0.15	2.00	1.00	7
Wet	1.08	0.13	2.00	0.69	9
Significance—not significant ($P > 0.05$)					
EN/FC					
Dry	1.35	0.24	4.00	1.00	7
Wet	1.54	0.24	4.00	1.00	9
Significance—not significant ($P > 0.05$)					
North Campus Drain					
FC/FS					
Dry	0.75	0.11	1.00	0.49	7
Wet	0.33	0.28	1.12	0.13	15
Significance—yes at $P = 0.01$ level					
EC/FC					
Dry	1.04	0.12	1.40	0.67	7
Wet	0.98	0.21	2.42	0.36	15
Significance—not significant ($P > 0.05$)					
EN/FC					
Dry	1.50	0.33	7.00	0.69	7
Wet	2.30	0.29	6.22	0.63	15
Significance—not significant ($P > 0.05$)					
Gallup Park (downstream)					
FC/FS					
Dry	1.53	0.36	7.22	0.29	21
Wet	1.63	0.51	230.00	0.07	142
Significance—not significant ($P > 0.05$)					
EC/FC					
Dry	0.99	0.20	2.60	0.33	21
Wet	0.88	0.27	12.00	0.07	142
Significance—not significant ($P > 0.05$)					
EN/FC					
Dry	0.47	0.40	1.71	0.07	21
Wet	0.50	0.52	19.00	0.01	142
Significance—not significant ($P > 0.05$)					
Ann Arbor wastewater effluent					
FC/FS					
Dry	0.78	0.41	3.12	0.19	7
Wet	0.86	1.05	9.50	0.002	9
Significance—not significant ($P > 0.05$)					
EC/FC					
Dry	0.92	0.21	2.05	0.53	7
Wet	1.01	0.14	2.00	0.63	9
Significance—not significant ($P > 0.05$)					
EN/FC					
Dry	1.47	0.52	7.55	0.26	7
Wet	0.76	0.47	4.00	0.11	9
Significance—not significant ($P > 0.05$)					

Table 3. Bacterial indicator organism levels, wet periods—1985. Gallup Park Stations

	Mean (Geom.) No. 100 ml	Geometric S.D. ($\log_{10}$)	Maximum No./100 ml	Minimum No./100 ml	*N*
		Day 0—following rain			
Fecal coliforms	1810	0.84	41,000	50	48
E. coli	1720	0.76	34,000	60	48
Fecal streptococci	1730	0.84	52,000	15	48
Enterococci	1730	0.83	45,500	20	48
		Day 1			
Fecal coliforms	520	0.62	16,000	24	45
E. coli	430	0.56	10,000	30	45
Fecal streptococci	210	0.84	24,000	4	45
Enterococci	150	0.85	19,000	2	45
		Day 2			
Fecal coliforms	200	0.48	1700	18	36
E. coli	160	0.36	1500	20	36
Fecal streptococci	94	0.44	1100	10	36
Enterococci	71	0.53	700	6	36

periods with the exception of the North Campus FC/FS ratio. FC/FS mean ratios for the storm drains are for the most part less than 0.7 suggesting animal rather than human origin, while the river stations and treatment plant effluent are all below the ratio of 4.0 suggestive of human sources. Schmidt and Spencer (1986) reported on finding relatively few illegal domestic discharges into Allen Drain

Particular attention was given to the Gallup Park observations because the FC/FS ratio was 1.63, a value much higher than the upstream storm drains and river stations. Table 3 lists the indicator organism levels for the Gallup Park stations for days 0, 1 and 2, following precipitation. Also, Table 4 includes the indicator organism ratios for these same conditions. It is apparent from Table 4 that the FC/FS ratio increases from day 0 to day 1 (statistically significant at $P = 0.01$ level) primarily due to the more rapid disappearance of the fecal streptococci over the fecal coliforms. These observations are consistent with the work of Geldreich and Kenner (1969). Moreover, the EN/FC ratio decreases significantly from day 0 to day 1 primarily due to the more rapid disappearance of the enterococci.

Review of the geometric mean EC/FC ratios shows them to be in the range of 0.82–1.34, well above the ratio of 0.63 calculated using the U.S. EPA recommended level of *E. coli*. Greater variation occurs in

Table 4. Bacterial indicator organism ratios, wet periods—1985. Gallup Park stations

	Mean (Geom.)	Geometric S.D. ($\log_{10}$)	Maximum	Minimum	*N*
		Day 0—following rain			
FC/FS	1.04	0.46	14.09	0.07	48
EC/FC	0.95	0.31	12.00	0.25	48
EN/FC	0.96	0.48	19.00	0.08	48
		Day 1			
FC/FS	2.46	0.56	230	0.13	45
EC/FC	0.84	0.18	2.00	0.29	45
EN/FC	0.29	0.50	2.00	0.007	45
		Day 2			
FC/FS	2.15	0.43	41.00	0.19	36
EC/FC	0.79	0.31	2.67	0.09	36
EN/FC	0.35	0.42	2.33	0.02	36

this ratio for individual samples. It is recognized that *E. coli* is a subgroup of the fecal coliform group. However, each test is performed separately and independently. Thus, it is possible to have a higher *E. coli* value for a given sample as a result of variation in the testing tehniques. The U.S. EPA (1986) indicated that using the fecal coliforms at the maximum geometric mean of 200 per 1000 ml, would cause an estimated 8 illness per 1000 swimmers at fresh water beaches. They indicate that this relationship is approximate and is based on applying ratios of the geometric means of the various indicators from the EPA studies to the 200 per 100 ml fecal coliforms criterion. The *E. coli* and enterococci criteria were developed using this currently accepted illness rate. The equations developed by Dufour (1984) were used to calculate the geometric mean indicator densities corresponding to the accepted gastrointestinal illness rates. With this background in mind and considering the results of the present study, the use of the EPA criteria of 126 organisms/100 ml of *E. coli* in the Huron River in the Ann Arbor, Michigan area would constitute a more restrictive condition than that imposed by the present level of 200/100 ml of fecal coliforms. The EN/FC ratios are also well above the ratio of 0.165 calculated using the U.S. EPA recommended enterococcal level. Additional results from other areas are necessary to refine the *E. coli* and enterococci levels for water quality standard development purposes, if the intent is to maintain the currently accepted illness rate.

The U.S. EPA (1986b) as part of their proposed bacteriological ambient water quality criteria indicate the criteria are calculated as the geometric mean of a statistically sufficient number of samples, generally not less than five samples equally spaced over a thirty day period. Recommendations on bacterial criteria monitoring are included in the U.S. EPA (1986a) ambient water quality criteria for bacteria document. Sample size is a factor in a test for statistical significance, and more than the minimum of five samples may well be necessary to demonstrate statistical significance in a given case. The closer two sets of data being subjected to tests for statistical significance are to one another in level, the greater are the requirements for individual number of observations. A second element is the inherent variability in indicator bacteriological data.

The size of the data base which the U.S. EPA used in deriving their criteria is not readily available to the writers. Dufour (1984) summarizes bacterial indicator densities at Lake Erie, Pennsylvania bathing beaches during 1979, 1980 and 1982, and bacterial indicator densities at Keystone Lake, Oklahoma bathing beaches, 1979–1980. However, the individual number of observations for each summary has not been included.

The experimental design for the present investigation was partially dependent on precipitation levels occurring during the 1985 summer period. Tests for statistical significance were conducted on data collected under these conditions and must be interpreted in this light.

Physical-chemical observations summarized in Table 5 reflect the source of the sample, i.e. river water, storm drain or treatment plant effluent. Generally, the turbidity and suspended solids levels are higher in the drains and Gallup Park stations during wet periods as compared to dry periods. Also, the conductivity levels at these same locations are lower during wet periods, no doubt reflecting more surface discharge than ground water discharge. Data is included for the Barton–Argo (Upstream), Allen Drain, Gallup Park (Downstream), and the Ann Arbor Wastewater Treatment Plant effluent. Allen Drain is representative of the other storm drains in the area. Documentation of the physical-chemical levels in the study area is included to complement the bacteriological data.

CONCLUSIONS

(1) Wet weather bacterial indicator densities are statistically significantly higher ($P < 0.05$) than the dry weather levels at all Huron River and storm drain outlets in the Ann Arbor, Michigan area, except for the Fuller Drain and the Ann Arbor wastewater treatment plant effluent.

(2) The mean level for all bacterial organisms is statistically significantly higher ($P < 0.05$) at Gallup

Table 5. Physical—chemical levels, 1985

	Mean	S.D.	Maximum	Minimum	N
Barton–Argo (upstream)					
Water temp. (°C)					
Dry	22.5	2.5	26.0	17.0	21
Wet	23.2	3.1	28.0	17.0	33
Significance—not significant ($P > 0.05$)					
Dissolved oxygen (mg/l)					
Dry	9.1	1.1	12.0	7.6	21
Wet	8.7	0.9	11.5	6.9	32
Significance—not significant ($P > 0.05$)					
Conductivity (μmhos/cm)					
Dry	597	20	630	550	21
Wet	575	36	620	460	33
Significance—yes at $P = 0.05$ level					
pH					
Dry	8.2	0.2	8.7	7.9	21
Wet	8.2	0.2	8.7	7.9	33
Significance—not significant ($P > 0.05$)					
Turbidity (NTU)					
Dry	3.0	0.8	5.0	1.8	21
Wet	3.4	0.9	5.0	1.5	33
Significance—not significant ($P > 0.05$)					
Total solids (mg/l)					
Dry	370	10	389	351	19
Wet	362	12	384	326	29
Significance—yes at $P = 0.05$ level					
Suspended solids (mg/l)					
Dry	5.2	2.8	13.5	2.5	19
Wet	5.2	4.3	24.0	1.0	29
Significance—not significant ($P > 0.05$)					
Allen Drain					
Water temp. (°C)					
Dry	18.0	2.2	20.0	14.0	7
Wet	19.0	2.8	27.0	15.0	19
Significance—not significant ($P > 0.05$)					
Dissolved oxygen (mg/l)					
Dry	8.5	0.6	9.3	7.4	7
Wet	8.2	1.0	11.1	6.3	16
Significance—not significant ($P > 0.05$)					
Conductivity (μmhos/cm)					
Dry	1066	134	1200	800	7
Wet	713	318	1330	170	19
Significance—yes at $P = 0.01$ level					

continued

Table 5—*continued*

	Mean	S.D.	Maximum	Minimum	N
pH					
Dry	8.0	0.4	8.4	7.4	7
Wet	7.7	0.3	8.4	7.3	18
Significance—not significant ($P > 0.05$)					
Turbidity (NTU)					
Dry	16.5	14.9	47.0	5.5	7
Wet	31.1	23.4	87.0	5.8	19
Significance—not significant ($P > 0.05$)					
Total solids (mg/l)					
Dry	695	104	831	516	7
Wet	481	172	783	176	17
Significance—yes at $P = 0.01$ level					
Suspended solids (mg/l)					
Dry	23.6	28.6	84.0	2.0	7
Wet	52.0	68.6	280.0	1.0	17
Significance—not significant ($P > 0.05$)					
Gallup Park (downstream)					
Water temp. (°C)					
Dry	22.6	2.2	25.0	17.6	21
Wet	23.4	2.9	29.0	18.0	142
Significance—not significant ($P > 0.05$)					
Dissolved oxygen (mg/l)					
Dry	8.4	0.9	10.6	7.0	21
Wet	7.7	1.1	10.2	5.8	34
Significance—yes at $P = 0.01$ level					
Conductivity (μmhos/cm)					
Dry	611	21	640	580	21
Wet	584	56	630	330	130
Significance—yes at $P = 0.05$ level					
pH					
Dry	8.2	0.2	8.7	8.1	21
Wet	8.2	0.2	8.7	7.6	67
Significance—not significant ($P > 0.05$)					
Turbidity NTU					
Dry	4.0	1.0	5.8	2.5	21
Wet	8.6	9.0	60.0	1.8	130
Significance—yes at $P = 0.05$ level					
Total solids mg/l					
Dry	378	19	403	314	21
Wet	356	32	395	265	37
Significance—yes at $P = 0.01$ level					
Suspended solids					
Dry	5.3	2.2	10.0	0.5	21
Wet	11.6	7.1	35.0	2.0	37
Significance—yes at $P = 0.01$ level					
Ann Arbor wastewater effluent					
Water temp. (°C)					
Dry	22.4	1.8	24.0	19.0	7
Wet	22.3	2.0	23.0	19.0	9
Significance—not significant ($P > 0.05$)					
Dissolved oxygen (mg/l)					
Dry	7.8	0.3	8.2	7.6	7
Wet	7.4	0.5	8.3	6.8	8
Significance—not significant ($P > 0.05$)					
Conductivity (μmhos/cm)					
Dry	1070	61	1160	990	7
Wet	1022	54	1110	960	9
Significance—not significant ($P > 0.05$)					
pH					
Dry	7.4	0.2	7.7	7.2	7
Wet	7.4	0.2	7.7	7.2	9
Significance—not significant ($P > 0.05$)					
Turbidity (NTU)					
Dry	1.5	0.9	3.3	0.6	7
Wet	1.2	0.7	2.3	0.6	9
Significance—not significant ($P > 0.05$)					
Total solids (mg/l)					
Dry	677	55	731	586	7
Wet	644	50	742	565	9
Significance—not significant ($P > 0.05$)					
Suspended solids (mg/l)					
Dry	2.9	3.7	10.7	0.5	7
Wet	0.9	0.9	3.0	0.1	9
Significance—not significant ($P > 0.05$)					

Park (downstream) than at Barton–Argo (upstream) on the Huron River, reflecting discharges from the urban storm drains.

(3) No statistical significance ($P > 0.05$) was found between the mean bacterial indicator levels at Barton–Argo (Huron River upstream) and the Ann Arbor wastewater treatment plant effluent, indicating that the storm drains rather than the wastewater treatment plant are primarily responsible for the elevated river levels.

(4) The FC/FS (fecal coliforms/fecal streptococci) ratios for the storm drains are low and suggestive of more animal than human sources.

(5) Bacterial indicator organism levels in Gallup Park (Huron River) for days 0, 1 and 2 following precipitation indicate a more rapid disappearance of the fecal streptococci and enterococci than the fecal coliforms and *E. coli*.

(6) The geometric mean EC/FC (*E. coli*/fecal coliforms) ratios are in the range of 0.82–1.34, well above the ratio of 0.63 calculated using the U.S. EPA recommended level of *E. coli* of 126/100 ml to the present fecal coliform level of 200/100 ml. Greater variation exists in this ratio for individual samples. If the intent is to maintain the currently accepted illness rate, additional results from other area are necessary to refine the *E. coli* and enterococci levels for water quality standard development purposes.

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