Bacterial Quality of Runoff from Manured and Non-Manured Cropland

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ABSTRACT

INDICATOR bacteria concentrations in non-snowmelt runoff from adjacent manured and non-manured watersheds were monitored for 4 years. Significant differences in the quality of runoff from the manured and non-manured cropland were not consistently observed. Hydrological conditions greatly affected bacterial concentrations. Heavy runoff under wet weather conditions resulted in water quality degradation irrespective of cropping or manuring activity. Under relatively dry weather conditions, runoff from both the manured and non-manured cropland often met the recommended bacterial quality criteria for water to be used for recreation or as a source of public water supplies. The relatively better quality of manured cropland runoff in our study compared to other studies was attributed mainly to the management practice of dry weather manure application followed by immediate plowdown and the mostly level topography of the watersheds. Much lower indicator bacteria concentrations in long-term stored manure than in relatively fresh manure suggested a lower potential for runoff pollution from land application of the former.

INTRODUCTION

Runoff from agricultural land often reaches streams, rivers and lakes which are sometimes used for recreation such as swimming or as a source of public water supplies. Bacterial quality of runoff from agricultural land becomes a matter of increased concern when such land receives substantial inputs of animal manures. This is because of the potential for disease transmission by water-borne microorganisms of animal origin (Decker and Steele, 1966; Diesch, 1970). Recent literature reviews (Crane et al., 1983, Khaleel et al., 1980) indicate that relatively few studies have been conducted on bacterial pollution of runoff from manured land. Farm studies (Robbins et al., 1971, Barker and Sewell, 1973; Janzen et al., 1974) as well as plot studies (McCaskey et al., 1971; Kunkle. 1979; Culley and Phillips, 1982) have shown that bacterial concentrations in runoff from manured land generally exceed the recommended criteria for recreational use of water. Cattle grazing activity has also been implicated in bacterial pollution of runoff (Doran and Linn, 1979; Jawson et al., 1982). In most of these studies, no distinction was made in the bacterial quality of storm and non-storm runoff. Guidelines are required for manure management procedures that would minimize bacterial pollution of runoff, especially during the post-snowmelt flow period when the potential for degradation of recreational water by runoff is increased.

The objective of this work was to determine the bacterial quality of runoff from cropland under a large-scale manure plowdown program, and to compare this quality to that of runoff from adjacent non-manured cropland and uncultivated land. The study was conducted at the 1,100 ha Research Farm of The Animal Research Centre of Agriculture Canada, near Ottawa, Ontario. in response to a concern regarding the potential of runoff from the Farm to pollute downstream recreational water sources. Runoff bacterial quality data were obtained during the 1972-1975 period and reported earlier (Tennant et al., 1972; Patni and Hove, 1978; Patni et al., 1982). In this paper, the bacterial quality of the runoff from different areas is compared, and discussed in terms of the currently recommended criteria for recreational water quality. Factors and conditions that led to an improvement or deterioration in runoff bacterial quality are also discussed.

THE STUDY SITE

The Research Farm is located in the cool humid region of eastern Ontario. Liquid manure from a large population of livestock and poultry at this Farm is regularly plowed into the land for crop utilization and disposal each year. A site plan of the study area is shown in Fig. 1. Drainage water from the watersheds draining at Stations 2 and 3 is discharged ultimately into the Rideau River upstream of recreational areas. Drainage water from the watershed draining at Station 5 is discharged ultimately into the Ottawa River, upstream of a water treatment plant. Bacterial quality of surface water entering and leaving the Farm was monitored between April and November at a number of sampling stations each year from 1972 to 1975. These stations included runoff from three separate watersheds which were separated from each other and the surrounding area by the local drainage system. Additional stations, external to these watersheds, were also monitored but are not discussed here.

Station 2 watershed covered 434 ha and was cropped using liquid manure as well as chemical fertilizer. In addition, it received post-harvest disposal applications of large amounts of liquid manure during the summer and fall each year. During the April-to-November

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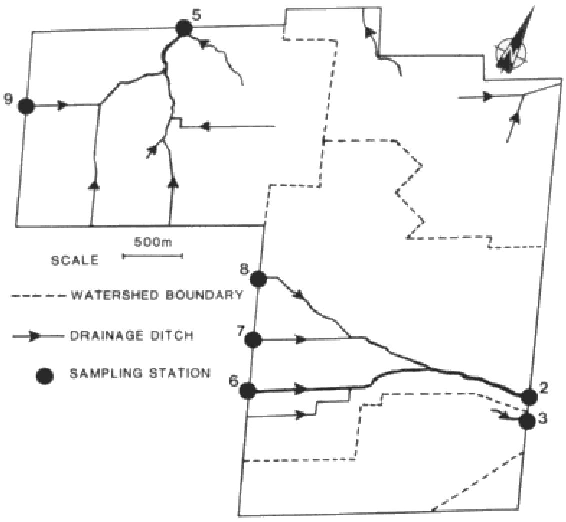

Fig. 1—Site plan of the study area.

post-snowmelt sampling period, water entered this watershed at Stations 6, 7 and 8 only. This flow into the test site was from adjacent uncultivated land and roadside drainage, and at Station 6 included some urban runoff during heavy flows in the early spring. About 60% of this watershed has poorly-drained. Dalhousie clay loam. 30% has imperfectly-drained Manotick sandy loam to loamy sand. and the balance has rapid-draining Uplands sandy loam to loamy sand soil. All except 50 ha of this watershed is tile drained.

Station 3 watershed covered 160 ha and was cropped using chemical fertilizer only during the study period except that 1800 m^3 of manure was applied to 20 ha of land 450 m west of the sampling station between Sept 21 and Oct. 7 in the first year of the study. Eighty percent of the Station 3 runoff samples for the year had been collected prior to this application of manure. Practically all of the watershed area has poorly-drained Dalhousie clay loam soil. The entire watershed is tile drained. All the runoff leaving Station 3 originates within the watershed. Most of it is derived from a 686 mm tile main which discharges into an open ditch 370 m upstream of Station 3.

Station 5 watershed covered 390 ha and was also cropped using chemical fertilizer only. Most of the water from adjacent uncultivated land entered this watershed at Station 9 which was monitored. About 60% of the watershed has poorly-drained Dalhousie clay loam soil. the balance being imperfectly-drained sandy loam to loamy sand (Manotick and Castor Associations). Parts of this watershed were tile drained during the study period. Respectively in 1972, 1973, 1974, and 1975, an area of 60, 120, 250 and 330 ha of this watershed was tile drained.

The land in the three watersheds is mostly level to very gently sloping with average slopes of 0.1%. Direct surface runoff was generally limited to the period of melting snow (when no water samples were collected) and to short-duration heavy rainfall events.

THE STUDY PROCEDURE

Manure Application and Land Use

Manure or fertilizer application and land use in the watersheds were determined according to the requirements for manure disposal and Reed crop production at the Farm. Fertilizer applications were made at the recommended rates for crops. Manure applications at the rate of 90 to 110 m^3/ha were made for crop utilization in the spring and for disposal during the summer and fall. Liquid manure with an average of 7 to 9% dry matter was plowed into the land immediately after application, and was not applied on frozen or snow-covered land. Of the total volume of manure incorporated, about 65% was from dairy cattle. 30% from sheep and 5% from poultry. About two-thirds of the applied manure was relatively fresh, from short-term (up to 6 weeks) storage under slotted floors inside barns. The balance of the applied manure was from long-term 6 to 30 weeks) winter storage in outdoor covered concrete tanks. Details of manure application in the Station 2 watershed (Fig. 1) are given in Table 1. Fields for manure plowdown were selected in rotation and only a part of the 32,000 m^3 of liquid manure produced annually at the Farm was applied within the watershed. Therefore, both the area manured and the volume of manure plowed varied from year to year. The manure application area was within 5 to 1000 m from the drainage ditches. The volume of manure incorporated was equivalent to a beef cattle population of about 13 to 19 cows per ha of manured area per day, taking into consideration the application period and the dilution of the manure.

TABLE 1. YEARLY MANURE APPLICATIONS IN THE 434 HA WATERSHED DRAINING AT STATION 2.

	Year			
Description	1972	1973	1974	1975
Area manured, ha	121	78	70	100
Volume of manure applied, m^3	23,600	13,700	17,000	16,800
Manure application period				
from	05-01	04-11	04-17	04-16
to	12-01	12-07	11-30	11-05
Manure application rate				
m^3/ha of manured area	195	176	240	168
m^3/ha of watershed area	54	32	39	39

Land use in the watersheds (Table 2) varied from year to year because of the crop rotation practiced at the Farm. In Table 2, the forage legume was essentially alfalfa, the legume grass was mainly clover with timothy and bromegrass, and the other grains were mainly barley and oats. A substantial part of Station 2 and 3 watersheds was in corn.

TABLE 2. PERCENT OF CULTIVATED AREA UNDER DIFFERENT CROPS IN WATERSHEDS DRAINING AT STATIONS 2, 3 AND 5.

		Percent of cultivated area in					
Year	Station	Corn	Forage legume	Legume -grass	Grass	Other grains	Fallow
1972	2	28	9	35	11	0	17
	3	85	0	15	0	0	0
	5	0	0	52	0	35	13
1973	2	21	9	38	10	15	7
	3	85	0	15	0	0	0
	5	0	0	61	0	6	33
1974	2	19	9	48	14	10	0
	3	85	0	15	0	0	0
	5	0	0	37	0	36	27
1975	2	52	22	13	9	0	4
	3	60	0	0	0	40	0
	5	0	36	17	0	34	13

TABLE 3. YEARLY AND LONG-TERM APRIL-TO-NOVEMBER MEAN MONTHLY PRECIPITATION AND YEARLY WATER SAMPLE COLLECTION PERIOD.

Year	Mean monthly precipitation, mm	Water sample collection period, month - date
1972	101.2	04-17 to 11-23
1973	87.2	03-22 to 12-06
1974	67.5	07-19 to 09-05
1975	83.4	04-15 to 11-26
30-year avg.	83.8	

TABLE 4. ANNUAL NUMBER OF RUNOFF SAMPLES COLLECTED AT DIFFERENT STATIONS FOR BACTERIAL ANALYSIS.

	No. of samples analysed (sampling days)*			
Sampling station	1972	1973	1974	1975
2	156 (72)	46	8	41
3	158 (73)	43	8	22
5	87 (72)	49	0	40
6	81 (67)	0	0	11
7	64 (53)	0	0	4
8	65 (54)	0	0	7
9	86 (72)	27	0	14

* For 1973, 1974 and 1975, number of samples analysed = number of sampling days.

Runoff Sample Collection and Analyses

Runoff samples were collected during the April-to-November non-snowmelt period only. Each year, the runoff duration and amount were greatly influenced by precipitation the mean monthly precipitation during the sampling months was 21% more in 1972 and 20% less in 1974 compared to the 30-year average for the region (Table 3). The number of samples collected (Table 4) was dependent on the existence of flow at a given station. Sampling was intense in 1972 because of an unusually large summer runoff caused by excessively wet conditions that resulted from 464 mm of rain in June. July and August. Due to resource constraints, 1973 sampling was limited to Stations 2, 3, 5 and 9 only, and 1974 sampling to 8 days at Stations 2 and 3 only. Sampling was resumed at all stations in 1975 but flow at the inlet Stations 6, 7, 8 and 9 was very little during the sampling period because of a dry summer. The sampling program was aimed at determining the bacterial quality of runoff from manured and non-manured watersheds used for feed crop production rather than at comparing the effects of the rates. times or frequency of precipitation. or other factors. Runoff conditions generally determined the sampling program.

Grab samples of runoff were obtained from just below the surface of water, about midway in the width of the drainage channels, in accordance with recommended procedures (American Public Health Association, 1971). Samples were collected in 225 ml sterile glass bottles, stored in insulated containers over icepacks, and shipped immediately to the laboratory for analysis. Samples collected in the morning were analysed for bacteria on the same day but samples collected in the afternoon were refrigerated overnight for analysis next morning. Water samples were normally collected once per day except in 1972 when the sample collection varied from once to five times per day, because of heavy runoff. Sampling frequency was generally once to three times per week depending on flow conditions. Samples were subjected to the Standard Methods (American Public Health Association, 1971) Membrane Filter (MF) procedure for the estimation of total and fecal coliforms (TC and FC) and fecal streptococci (FS). The membranes used were Gelman Metricel (GN-6). All test media used were Bacto Brand supplied by Difco Laboratories, Detroit, MI.

Manure Sample Collection and Analyses

Samples of well-mixed liquid manure were collected at the time of loading into vacuum tankers for hauling to fields for plowdown. Bacterial counts per gram of wet manure were estimated in representative samples using the methods outlined above. All manure samples were blended for two minutes (ten-fold dilution in a standard phosphate buffer) in a sterile Waring Blendor prior to analyses.

RESULTS AND DISCUSSION

Indicator Bacteria in Applied Manure

Bacteria counts in applied manure varied over a wide range, by up to 6 orders of magnitude. Counts of indicator bacteria in about 160 samples each of relatively fresh and long-term winter-stored manure incorporated in the Station 2 watershed are shown in Table 5. Long term storage reduced the median counts of all three indicator bacteria by more than 99%. Long-term storage consisted of undisturbed storage, that is, storage without regular additions of fresh manure to stored manure. Reduction in bacterial counts was not consistent when fresh manure was added to manure that was already in storage

TABLE 5. INDICATOR BACTERIA COUNTS IN RELATIVELY FRESH AND LONG-TERM STORED MANURE APPLIED TO STATION 2 WATERSHED IN 1972-1975

Bacteria type	Count per g wet weight of applied manure					
	Relatively fresh*			Long-term stored †		
	Median	Min.	Max.	Median	Min.	Max.
Total coliforms	1.3×10^6	6.4×10^4	3.3×10^7	6.5×10^3	<100	2.1×10^6
Fecal coliforms	0.5×10^6	1.9×10^4	1.3×10^7	0.1×10^3	<10	5.2×10^4
Fecal streptococci	0.2×10^6	7.0×10^3	3.1×10^6	1.2×10^3	<100	3.1×10^6

* 0 to 6 weeks old from in-the-barn storage.
† 6 to 30 weeks old from long-term storage in outdoor concrete tanks.

TABLE 6. COUNTS OF INDICATOR BACTERIA AND FC:FS RATIO IN RUNOFF.

Year	Sampling station	MF count per 100 ml, of sample*													
		Total coliforms				Fecat coliforms				Fecal streptococci				FC:FS ratio	
		GM	Median	Min.	Max.	GM	Median	Min.	Max.	GM	Median	Min.	Max.	GM	Median
1972	2	3,900	3,500	2	1,000,000	180	160	<2	43,000	730	490	12	800,000	0.25	0.25
	3	860	1,000	2	100,000	43	53	<2	5,100	180	250	<2	48,000	0.25	0.21
	5	1,200	1,300	16	1,000,000	140	130	<2	1,000,000	380	310	4	73,000	0.37	0.36
	6	1,200	1,200	18	85,000	84	80	<2	23,000	800	750	6	270,000	0.10	0.10
	7	940	960	6	110,000	57	56	<2	4,200	480	480	4	210,000	0.12	0.12
	8	1,300	1,600	6	200,000	84	110	<2	9,000	550	520	8	73,000	0.15	0.13
	9	1,300	1,400	2	330,000	150	140	<2	71,000	560	490	<2	240,000	0.27	0.23
1973	2	2,600	3,200	10	1,000,000	460	400	4	860,000	400	400	<2	270,000	1.13	1.00
	3	1,900	1,400	170	330,000	200	180	4	2,300	70	72	<2	42,000	2.90	2.00
	5	1,300	1,800	30	100,000	190	280	2	8,300	140	190	<2	18,000	1.32	1.46
	9	570	600	22	100,000	95	92	8	20,000	120	160	2	20,000	0.76	0.54
1974	2	17,000	13,000	1,400	270,000	2100	2,100	550	24,000	3,700	2,300	250	100,000	0.56	0.73
	3	7,500	6,000	1,900	40,000	990	840	380	5,200	1,200	1,300	310	7,700	0.83	0.85
1975	2	2,200	2,700	30	280,000	170	120	<2	24,000	260	290	4	82,000	0.66	0.60
	3	2,200	2,700	50	24,000	140	150	10	1,200	130	180	<2	4,400	1.06	0.53
	5	1,100	1,300	20	60,000	120	190	<2	4,300	210	250	<2	15,000	0.58	0.46
	6	890	1,200	1,200	13,000	36	78	<2	760	140	98	14	3,500	0.26	0.21
	7	250	110	26	15,000	10	5	<2	330	64	37	4	3,200	0.16	0.15
	8	190	44	44	14,000	8	4	<2	230	46	42	4	1,800	0.18	0.19
	9	670	1,100	40	15,000	76	110	<2	4,400	180	130	12	9,000	0.41	0.49

* MF = membrane filter; GM = geometric mean; FC and FS values of <2 were taken as 2 in the calculation of the GM and the FC:FS ratio.

(data not presented). The manured watershed received a substantial loading of indicator bacteria every year based on the annual volumes applied (Table 1) and the bacterial concentrations (Table 5). This loading was essentially from the application of relatively fresh manure. Reliable estimates of actual loadings could not be obtained because of the extreme variability of the bacterial counts in the applied manure. Results in Table 5 suggest that the potential for bacterial pollution of runoff due to land application of manure is greater from relatively fresh than from long-term stored manure.

Bacterial Quality of Runoff Water

Counts of TC, FC and FS at all stations (Table 6) varied over a wide range each year, by up to 3 to 6 orders of magnitude, regardless of manuring and cropping activity. This range was generally the widest in 1972 when prolonged wet weather conditions existed frequently. Bacterial concentrations tended to increase following heavy rainfall events presumably because of increased transport of bacteria in surface runoff. However, a consistent relationship between the amount of rainfall and bacterial concentration or concentration changes was not evident. Bacterial concentrations sometimes decreased with rainfall which suggested a dilution effect. The wide variation in runoff bacterial counts (Table 6) is not surprising considering the several complex and interacting factors that govern bacterial transport in runoff. These factors include: intensity and amount of precipitation, slope of land, sunlight, temperature, vegetation cover on land, soil physical and chemical properties, abundance of native wildlife, etc. (Burge and Parr, 1980: Crane et al., 1983). When manure is applied on land, additional factors that affect bacterial transport are: manure type (species), age and forth (solid, liquid), time and degree of contact with soil, time and method of application, distance of application site from sampling location, etc. Wide variation in bacterial concentrations have also been reported by others in runoff from non-manured land (Harms et al. 1975), manured land (Kunkle, 1970, 1979; Robbins et al. 1971: Jansen et al., 1974), slurry-irrigated land (Barker and Sewell, 1973), pasture land (Doran and Linn, 1979: Jawson et al., 1982), and mixed agricultural land (Beak, 1977). In our study, the presence of fecal bacteria is runoff from the non-manured watersheds was likely due to the native animal and bird population that is common to the agricultural areas of the region. Canada geese, ducks, seagulls, groundhogs, muskrats, etc. were observed in all watersheds, including the manured watershed. Seagulls converged in large numbers for short periods of time on freshly plowed fields to feed on exposed worms. Bacterial loads from gull droppings can be significant (Gould and Fletcher, 1978). The total loading of fecal bacteria from wildlife would, in general, be limited because of the small fecal output, transient nature of at least some of the loading such as that from migratory birds, and bacterial dieoff in the widely dispersed fecal material due to drying and solar radiation. The total loading from the applied manure was large because of the very large volumes that were incorporated each year (Table 1) and the high bacterial counts (Table 5). It is possible, however, that the fecal contribution from wildlife to the watershed drainage systems was dominant at times of heavy rain after-prolonged wet, cool and cloudy conditions because of increased transport of fecal material in surface flow. Such conditions existed frequently during the summer of 1972.

Bacterial counts tend to have a log normal distribution. For this reason, the preferred statistic for summarizing bacterial concentration data is the geometric mean (GM) rather than the arithmetic mean (American Public Health Association, 1980). The GM or the median value of the counts in a number of samples generally yields a value in which the effect of individual extreme values is minimized. Although the GM and median values were often different (Table 6), they were mostly of the same order of magnitude. Considering the bacterial numbers involved and the nature of the bacterial enumeration procedure, a difference of an order or magnitude or more in the GM or median concentrations between different stations indicates substantial differences in runoff bacterial quality. The GM and median counts of all the three indicator bacteria were mostly greater in runoff from the manured cropland (Station 2) than non-manured cropland (Stations 3 and 5). However, the counts were of the same order of magnitude at Stations 2, 3 and 5 except for counts (hat were one lower order of magnitude at Station 3 for FC in 1972, FS in 1973, and TC and FC in 1974 (Table 6). Lower counts at Station 3 were, at least in part, due to a large portion of the runoff being derived from a 686 mm tile main upstream of the sampling location. The opportunity for removal of bacteria in runoff by percolation through the soil profile was greater in the Station 3 watershed than in Stations 2 and 5 watersheds. Also, the length of open drainage ditches, which bacteria laden overland flow could reach, was much less per unit watershed area for Station 3 than for Stations 2 and 5 (Fig. 1).

An analysis of variance of logarithmically transformed bacterial concentrations revealed significant year-to-year ($P < 0.05$) and station-to-station ($P < 0.01$) variation in the transformed mean concentrations (arithmetic means of log bacteria counts) of all three indicator bacteria. These variations can be explained by differences in the hydrologic, weather, cropping. tillage and other conditions which affected bacterial transport to runoff. Application of Waller-Duncan's test (Waller and Duncan, 1969) to the station effect revealed Station 2 to be the major source of variation. The Student t-test was used to further compare the yearly mean concentrations at Station 2 (manured cropland) with those at Stations 3 and 5 (non-manured cropland) and Stations 6, 7 and 8 (water entering the Station 2 watershed). In addition, the yearly mean concentrations at Station 5 were compared with those at Station 3 and Station 9 (water entering the Station 5 watershed). The results are shown in Table 7. The limited data for 1974 were not used for this comparison as these were not representative of the April-to-November rainfall runoff period. Table 7 reveals that the mean concentrations of the three indicator bacteria at Station 2 were not significantly ($P > 0.05$) different from those at Stations 3 and 5 every year. Possible reasons for lower bacterial concentrations at Station 3 than at Stations 2 and 5 were discussed above. fn two out of three years, the mean TC, FC and FS concentrations were not significantly ($P > 0.05$) different at Stations 2 and 5. These results and the mostly similar order-of magnitude GM and median bacterial concentrations at Stations 2, 3 and 5 (Table 6) suggest that. in our study. the potential for bacterial pollution of cropland runoff due to large-scale plowdown of manure was not much different from that due to cropping without application of manure.

Changes in runoff bacterial quality resulting from manured and non-manured cropping activity can be considered by comparing the water quality at "inlets" (Stations 6, 7, 8 and 9) and "outlet" (Stations 2 and 5) locations in the manured and non-manured watersheds (Fig. 1). The GM and median bacterial concentrations at the outlet stations were of the same or one higher order of magnitude than those at the respective inlet stations (Table 6). In 1975, under relatively dry weather conditions. the GM counts of all three indicator bacteria increased from the inlet stations to the outlet stations. However, in 1972, such an increase was clearly evident only for FC and TC in the manured cropland (Station 2 compared to Stations 6, 7 and 8). Changes in FS concentration were not consistent. Results in Table 7 show that significant differences in the mean concentrations were most frequent for FC and least frequent for FS. Furthermore. mean concentrations of all the three indicator bacteria were not significantly ($P>0.05$) different at the inlet (Station 9) and outlet (Station 5) locations of the non-manured cropland. These results suggest that FC may be better than FS as an indicator of the effect of manure plowdown on the bacterial quality of runoff, and that cropping without manure applications is unlikely to alter runoff bacterial quality.

The mean bacterial concentrations in runoff from the two non-manured watersheds (Stations 3 and 5) were not significantly different ($P > 0.05$) except for FC and FS in 1972 (Table 7). Lower FC and FS mean concentrations at Station 3 than at Station 5 in 1972 may have been, in part, due to differences in bacterial transport due to differences in the surface and subsurface runoff in the two watersheds. Only 15% of the Station 5 watershed was tile drained in 1972 compared to 100% of the Station 3 watershed, and as noted before, the length of drainage ditches per unit area was greater in the former than the latter.

areas were 88%, 100% and 15% of the areas in Station 2, Station 3 and Station 5 watersheds. respectively, that year. Bacteria counts under dry and wet conditions are summarized in Table 8 in terms of 10, 50 (median) and 90 percentile levels. Rainfall-induced runoff increased counts

TABLE 7. **DIFFERENCES IN MEAN BACTERIA COUNTS IN RUNOFF AT DIFFERENT STATIONS IN 1972, 1973 AND 1975.**

Sampling stations compared		Differences* in means for								
		Total coliforms			Fecal coliforms			Fecal streptococci		
		1972	1973	1975	1972	1973	1975	1972	1973	1975
2 vs.	3	S	NS	NS	S	S	NS	S	S	NS
	5	S	NS	NS	NS	S	NS	NS	S	NS
	6	S	—	NS	S	—	S	NS	—	NS
	7	S	—	S	S	—	S	NS	—	NS
	8	S	—	S	S	—	S	NS	—	NS
5 vs.	3	NS	NS	NS	S	NS	NS	S	NS	NS
	9	NS	NS	NS	NS	NS	NS	NS	NS	NS

* S = significant (P < 0.05); NS = not significant (P > 0.05); — = no data.

Bacterial counts in runoff from the manured land in our study (Station 2. Table 6) arc one to two orders of magnitude lower than the counts in runoff from manured land in other studies (Robbins et al., 1971; McCaskey et al., 1971: Barker and Sewell, 1973; Kunkle, 1979). Relatively better bacterial quality of the runoff in our study can he attributed plainly to two factors. The first factor was the management practice of dry-weather manure application followed by immediate plowdown. This practice would reduce bacterial transport in overland flow by reducing manure bacteria concentrations al the soil surface. Incorporation may also have increased adsorption and fixation of bacteria on soil particles. The second factor was the level-to-gently-sloping land in the watershed, which would limit the opportunity for surface runoff mainly to heavy rainfall events. Thus, sediment-associated bacterial transport was probably low. A large part of the runoff in our study was derived from tile drains. Another study at our study site showed that tile effluents from manured fields generally had low indicator bacteria concentrations (Patni et al., 1984).

Runoff Quality Under "Dry" and "Wet" Weather Conditions

Abnormally heavy runoff conditions often existed at all stations in 1972. To determine the effect that such conditions had on bacterial concentrations, a total of 20 of the 73 sampling dates in 1972 were designated as representing "wet" conditions based on 13 mm or more of rain in the preceding 48-h period. The remaining data were considering to be obtained under "dry" conditions. The terms "wet" and "dry" are used here merely to separate the days with relatively heavy runoff from those with smaller, but still considerable runoff. The proportion of surface runoff relative to subsurface runoff would be higher under the wet than the dry conditions. Tile-drained

at all stations at all percentile levels by one to two orders of magnitude over counts under dry conditions. All stations had poor water quality under wet conditions. The presence or absence of manuring activity or the extent of tile drainage in the watershed appeared to have little effect on bacterial quality of runoff. Bacterial contribution from wildlife probably dominated under wet conditions. Under dry conditions. water quality at Station 2 was similar to the quality at other stations with respect to FC and FS, but TC counts were significantly (P < 0.05) higher. Differences of one to two orders of magnitude in bacterial concentrations between the wet and dry period runoff were also common at all stations in the later years, although in a few instances, notably at Station 3, the differences were not so large. Results in Table 8 again emphasize the importance of hydrological conditions on the bacterial quality of runoff.

FC:FS Ratio

Geldreich et al. (1968) proposed that an FC:FS ratio of less than 0.7 in runoff indicated contamination of animal origin whereas a ratio greater than 4 indicated human origin. Ratios in between represented pollution from indeterminate sources. The GM and median FC:FS ratios in runoff (Table 6) were low at all stations and any major difference between the manured and non-manured cropland was not evident. Slightly higher ratios in cropland runoff (Stations 2, 3 and 5) in 1973 than in other years may have resulted from a greater carryover of fresher fecal material in surface runoff during the brief but intense rainfall events that were more common that year. It has been shown that EC but not the ES concentrations in runoff decrease with increasing age of manure (Kunkle. 1979; Thelin and Gifford, 1983). The percent of all samples collected at Stations 2, 3, 5, 6, 7, 8, and 9 that had FC:FS ratio Tess than 0.7 was respectively 65, 64, 62, 91, 99, 89 and 78: the percent of samples that had TC:FS ratio greater than 4 was respectively only 2, 9, 5 0, 0, 0, and 4. There was no human fecal input in the watersheds. This suggests that when animal manure is the only source contributing fecal bacteria to runoff, the value of the FC:FS ratio often exceeds 0.7 but a value of 4 may be exceeded very infrequently.

TABLE 8. BACTERIA COUNTS IN RUNOFF AT 10, 50 AND 90 PERCENTILE LEVELS DURING WET AND DRY PERIODS IN 1972.

Sampling station	Number of days	Number of samples	Period*	Total coliforms 10	Total coliforms 50	Total coliforms 90	Fecal coliforms 10	Fecal coliforms 50	Fecal coliforms 90	Fecal streptococci 10	Fecal streptococci 50	Fecal streptococci 90
				MF count per 100 mL of water at three percentile levels								
2	52	105	dry	140	1,800	21,000	6	90	270	24	160	990
	20	51	wet	2,500	18,000	370,000	150	1,500	24,000	1,500	9,400	130,000
3	53	107	dry	23	550	4,700	< 2	24	200	4	99	480
	20	51	wet	440	4,000	40,000	41	160	990	280	1,100	5,700
5	53	57	dry	69	590	4,000	6	74	250	14	150	810
	19	30	wet	1,300	4,300	58,000	160	600	8,500	730	3,900	28,000
6	48	51	dry	44	470	2,100	2	32	160	18	200	2,800
	19	30	wet	1,400	9,900	60,000	100	430	8,700	1,400	13,000	160,000
7	34	38	dry	20	250	3,200	< 2	14	140	6	100	1,300
	19	26	wet	900	7,300	50,000	50	580	2,300	720	5,600	65,000
8	36	40	dry	16	630	8,300	< 2	80	440	22	200	850
	18	25	wet	960	5,400	39,000	76	210	930	500	3,300	59,000
9	52	56	dry	28	420	8,200	2	51	990	13	200	2,200
	20	30	wet	860	5,000	160,000	110	570	15,000	500	2,900	88,000

* See text for explanation of dry and wet periods.

TABLE 9. PERCENT OF CROPLAND RUNOFF SAMPLES WITH INDICATOR BACTERIA COUNTS AT VARIOUS SELECTED LEVELS.

Year	Sampling station	1000*	5000 †	100*	200‡	1000 †
		Percent of samples with MF count less than				
		TC per 100 mL		FC per 100 mL		
1972	2	29	55	37	58	79
	3	47	80	65	80	96
	5	44	79	39	66	90
1973	2	39	54	24	35	61
	3	42	79	30	51	86
	5	33	92	27	41	90
1975	2	32	68	44	56	85
	3	36	73	36	64	91
	5	43	80	45	50	88

* Recommended limit for recreation water (Ontario Ministry of the Environment, 1978).

† Recommended limit for raw water source for drinking water supplies (Department of the Environment, 1972).

‡ Recommended limit for recreation water (Health and Welfare Canada, 1983).

Runoff Water Quality with Respect to Recommended Criteria

The percentage of cropland runoff samples meeting the recommended limits for TC and FC concentrations in water to he used for direct-contact recreation or as a source for treated drinking water supplies is shown in Table 9. Data for 1974 are again excluded because of the very limited sampling that year. Each year, about a quarter 10 half or more of the samples at each station met the recommended limits for direct-contact recreation water. The limits for public water supplies were met by more than half to 90% of the samples at each station. The percentage of the sampling days (Table 4) on which the recommended limits for the two types of water use were met was nearly the same (1972) or the same as the percentage of samples that met these limits (Table 9). The limits were likely Diet more frequently than indicated by the percentage of samples of acceptable quality because more samples were collected during periods of high flow rates compared to low flow rates, and higher bacterial concentrations were generally associated with the former. Although runoff from the manured cropland (Station 2) almost always had the smallest percentage of samples that met the recommended limits for the two types of water use, the difference between the manured and non-manured cropland was not significant (P > 0.1) based on an analysis of variance. Comparison of the recommended limits in Table 9 to the bacterial concentration distribution in Table 8 suggests that under wet weather conditions, runoff bacterial quality at all stations was unacceptable for recreational use. In other studies (Harker and Sewell, 1973: Harms et al., 1975: Doran and Linn, 1979), agricultural land runoff met the criteria for recreational else very infrequently. However, these criteria were often met in our study.

CONCLUSIONS

The manure management procedures that were used in this study and some specific features of the study site appeared to be important factors that influenced the bacterial quality of runoff. The applied liquid manure was plowed under immediately after application, and it was not applied on frozen or snow-covered land, nor was it applied when the soil was excessively wet. This tended to reduce bacterial transport in surface runoff. Both the manured and non-manured watersheds had level to very gently sloping land (0.1 % average slope), and at least two of the three watersheds were extensively tile-drained. This tended to increase the proportion of subsurface flow in runoff compared to surface flow. The following conclusions can he made for conditions similar to those of this study.

1. Potential for bacterial pollution of runoff due to manure

plowdown appears to be greater from the use of relatively fresh manure than long-term stored manure because of much higher indicator bacteria counts in the former.

2. The potential for bacterial pollution of cropland runoff due to manure plowdown is not much different from that when no manure is used. Fecal bacteria are almost always present in runoff from non-manured cropland, presumably because of the presence of native wildlife on such land.

3. The FC group appears to be better than the FS group as an indicator of fecal contamination of runoff from manured land.

4. Hydrological conditions appear to strongly influence runoff bacterial quality. Under prolonged wet conditions, runoff induced by heavy rainfall leads to bacterial concentration increases of one to two orders of magnitude resulting in water quality deterioration irrespective of manuring or cropping activity. Contribution of fecal bacteria by native wildlife appears to be dominant under such conditions.

5. When (domestic or wild) animal manure is the only source contributing fecal bacteria to runoff, the value of the FC:FS ratio may exceed 0.7 frequently but a value of 4 may be exceeded only rarely.

6. The recommended bacterial quality criteria for water to be used for recreation or as a source of public water supplies can be often met by cropland runoff under relatively dry weather conditions when runoff is not excessive. However, these criteria are unlikely to be met under prolonged wet weather conditions, especially under severe runoff conditions, irrespective of manuring or cropping activity.

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