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RESPONSE OF FECAL BACTERIA AND WATER CHEMISTRY IN AN AGRICULTURAL DRAIN TO REMEDIAL CONSTRUCTION ACTIVITIES ON LIVESTOCK FARMS.

Prepared for

Ausable Bayfield Conservation Authority

Exeter, Ontario

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SUMMARY

Remedial construction activities, aimed at restricting the loadings of agricultural and domestic waste to agricultural waterways, were conducted in the autumn of 1986 by the Ausable Bayfield Conservation Authority on three farms (one dairy and two livestock operations) in the headwaters of the Desjardine Drain, Huron County, Ontario. A significant improvement in the bacterial (Escherichia coli, fecal streptococci) and chemical (biological oxygen demand, nutrients) water quality conditions was measured the following summer immediately downstream from each farm, relative to an upstream reference site. However, only improved bacterial water quality conditions were noted downstream of all farming operations in the drainage basin. The study suggests that the utilized remedial construction activities could reduce the loadings of fecal bacteria to Lake Huron beaches, but would have little effect on the loadings of organic matter and nutrients.

RECOMMENDATIONS

1) Bacterial sampling should continue over of the summer of 1988, to ascertain whether the observed increasing trend in bacterial concentrations during the summer of 1987 was simply a seasonal event or the beginning of the return to pre-1987 concentrations.

2) Flows should be measured at the sampling sites along the drain so that loadings of fecal bacteria, BOD and nutrients can be estimated. Past flows may be estimated by establishing a correlation between discharge and turbidity and conductivity. These data will be required for the management of water quality conditions at the Lake Huron beaches.

3) A better understanding of the survival and downstream transport of fecal bacteria is necessary to insure that the selection of farms for remedial construction activities will maximize the reduction of bacterial loadings to the beaches while minimizing the costs.

4) A better understanding of the relationship between manure spreading activities (i.e. application rate, distance from drain, soil type, type of manure, spreading season) and loadings of organic matter and nutrients to agricultural drains is necessary so that better management practices can be developed to reduce water quality impairment of agricultural waterways from this source.

5) The precision of the estimated changes in the bacterial and chemical concentrations resulting from the remedial construction activities (see Tables 1 and 4) should be improved by comparing the changes at the three sampling sites (Sites 2, 3 and 4 in Figure 1) with those from three sampling sites that were not affected by the remedial construction activities (e.g. the upstream reference site, Site 1 in Figure 1, and two additional sites on the southern branch of the Desjardine Drain).

INTRODUCTION

In the summer of 1983, several beaches along the Lake Huron shoreline of southern Ontario were closed to swimming because of elevated bacterial concentrations. A subsequent study by the Ministry of the Environment (Palmateer and Huber 1985) revealed that the creeks and rivers that drained interior agricultural areas were the primary source of fecal bacteria for the beaches. It concluded that improvements in the bacterial water quality of Lake Huron beaches would largely depend on better agricultural management of livestock manure, a rich source of fecal bacteria, particularly within the drainage basins of the Ausable and Maitland rivers.

In 1986, therefore, the Ausable Bayfield Conservation Authority began the Target Sub-basin Study under the Provincial Rural Beaches Strategy Program of the Ministry of the Environment (Hocking 1987). One objective of the study was to measure the response of bacterial and chemical water quality conditions to remedial construction activities aimed at restricting the loadings of dairy and livestock wastes to agricultural waterways. This report documents the changes that occurred in the Desjardine Drain, following the 1986 remedial construction activities an three livestock farms located in the headwaters of the drain. Specifically, it addresses two questions:

1) What effect did the remedial construction activities have on the bacterial and chemical water quality conditions of the Desjardine Drain; and

2) Can the remedial construction activities improve the bacterial and chemical water quality conditions at the Grand Bend beaches?

METHODS

Remedial Construction Activities:

From August 18 to November 21, 1986, remedial construction activities were undertaken on the Pickering, Ratz and McCann farms in the headwaters of the Desjardine Drain (Figure 1) to prevent agricultural and domestic wastes from directly entering the drain. At the Pickering Farm, a dairy operation, the remedial activities included the installation of an enclosed manure storage yard and a covered concrete storage tank for milkhouse and yard run-off wastes, eavestroughing to prevent roof-water draining into the yards, fencing to prevent cattle from accessing the drain and a domestic septic system. At the McCann Farm, a beef cattle operation, they included the installation of an enclosed manure storage yard that was drained into a new covered tank and a septic system. At the Ratz Farm, a cow-calf and feeder operation, they included the construction of a covered manure storage yard and fencing to prevent cattle from accessing the drain. The Ratz's septic system was found to be operational. However, the septic system on the neighbouring Sullivan Farm was found to be faulty and replaced. Details of the construction activities and their associated costs are available in Hocking (1987).

Bacterial and Water Chemical Data:

This report will focus on the data collected from June 9 to August 20, 1986, (pre-remedial data) and from June 1 to August 24, 1987, (post-remedial data) at five sites along the Desjardine Drain (Figure 1). Site 1, the reference site, was located at the head of the drain, upstream of all the farms. Sites 2-4 were located downstream of the Pickering, Ratz and McCann farms, respectively. Site 5 was located downstream of all nine farms in the drainage basin. These sites correspond to stations DE-02CN2, DE-02CN, DE-02B, DE-02CS and DE-01C in Hocking (1987).

Water samples for bacterial, i.e. fecal coliform, *Escherichia coli, fecal streptococci*

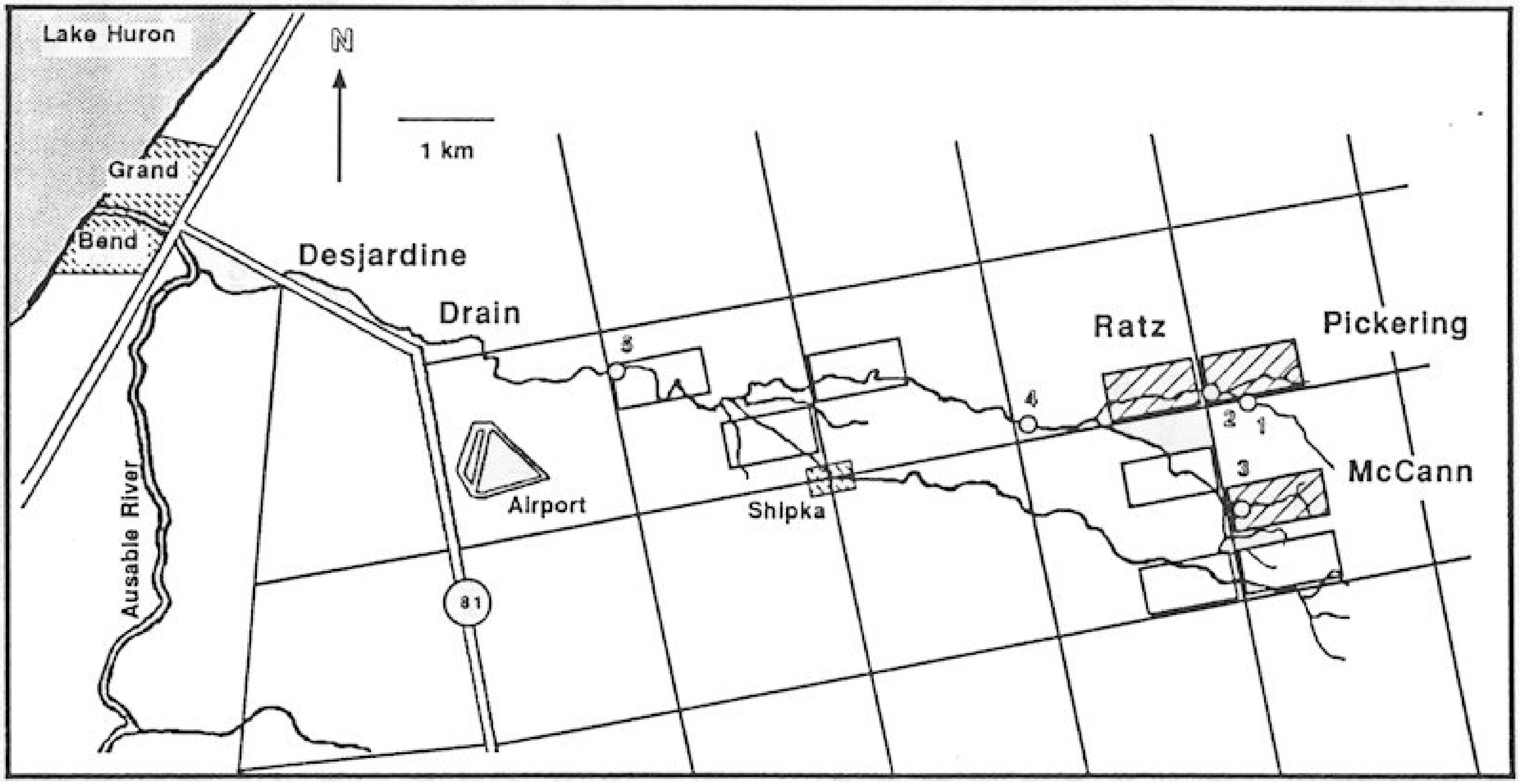

Figure 1: Location of sampling sites along the Desjardine Drain. Numbers refer to the five sampling sites (1=Upstream, 2=Pickering, 3=McCann, 4=Ratz, 5=Downstream). Rectangles indicate farms within the drainage basin. Striped rectangles indicate those farms where remedial construction activities were undertaken in the autumn of 1986.

and chemical, i.e. biological oxygen demand (BOD), turbidity, total Kjeldahl nitrogen (TKN), ammonia, nitrite, nitrate, total phosphorus (TP), soluble reactive phosphorus (SRP), pH, chloride and conductivity, analyses were generally collected twice weekly during both summer periods. Samples were analyzed according to the Ontario Ministry of the Environment's Handbook of Analytical Methods (MOE 1983) at their laboratory in London, Ontario.

Changes in the water quality conditions at the upstream reference site, Site 1, between years were assumed to reflect differences in the environmental conditions between years, whereas changes in the water quality conditions at sites 2-4 were assumed to be a result of the remedial construction activities conducted on each farm. Water quality conditions at the downstream site, Site 5, were examined to determine whether the effects of the remedial activities at the three farms resulted in improved conditions downstream of the remaining sources of contamination in the drainage basin, i.e. a dairy, livestock, two cash crop and two swine farms.

Statistical Analyses:

An analysis of covariance (ANCOVA) was used to test the overall null hypothesis that the difference in bacterial concentrations between years was similar among all five sampling sites. The analysis was conducted by pairing sampling dates at each site between years and then regressing the difference in the log-transformed concentrations (concentration in 1987 minus that in 1986) on the sampling date (covariate). Assuming that the slopes of the five regressions were similar, i.e. all sites were similarly affected by seasonal changes in the environment over the summer (homogeneity of variance assumption), the adjusted difference in bacterial concentrations between years was compared among sites.

If the ANCOVA indicated that the difference in bacterial concentrations significantly ($p < 0.05$) varied among sites, then non-orthogonal linear contrasts were used to test the following null hypotheses: 1) that the mean weighted (weighted by the number of paired samples from each site) difference in bacterial concentrations downstream of the three farms was equal or greater then that observed at the upstream reference site (i.e. the remedial activities did not reduce the bacterial contamination in the drain immediately downstream from each of the three farms); and 2) that the difference in bacterial concentrations at the downstream site was equal or greater then that observed at the upstream reference site (i.e. the effect of the remedial activities did not reduce the bacterial contamination in the drain downstream of all nine farms in the drainage basin).

E. coli and fecal streptococci concentrations were used as measures of the bacterial contamination in the drain. These variables were log-transformed to satisfy the assumptions of normality, additivity and homoscedasticity required by the statistical models. Plots of residuals and leverage were used to detect outliers within the data.

Discriminant analysis of covariance (DAC) was used to examine changes in chemical water quality conditions between years at the five sites. This multivariate technique partitioned the variance of the eleven measured water chemical variables among the 10 site-years (e.g. Upstream-86, Upstream-87, Pickering-86, Pickering-87, etc.). Thus changes in the chemical water quality conditions at each site between years could be examined once differences between sites were factored from the data. As in the previous analysis, sampling date was used as a covariate to remove any seasonal trends from the data. The resultant discriminant axes simply represent linear combinations of the water chemical variables that maximize the variance among the site-years. A water quality interpretation of each axis was made based on the correlation coefficients (r) between the axis and the original water chemical variables. Water chemical variables that were strongly correlated with a discriminant axis that described a significant proportion of the variance were subsequently analyzed in the same manner described for the bacterial variables to determine whether the temporal changes observed in the DAC were significant. Except for pH, all variables were log-transformed to satisfy the assumptions of normality, additivity and homoscedasticity required by the statistical models. Plots of residuals and leverage were used to detect outliers within the data.

RESULTS

Bacteria:

Summer concentrations of *E. coli* and fecal streptococci at the reference site (Figures 2-5) were similar between survey years (ANCOVA; $p > 0.25$). The mean concentration of *E. coli* was 290 per 100 mL in 1986 and 320 per 100 mL in 1987, values exceeding the Ministry of the Environment's guidelines of 100 fecal coliforms per 100 mL, while the mean concentration of fecal streptococci was 1800 and 1300 per 100 mL in 1986 and 1987, respectively.

In contrast, the bacterial concentrations at the sites downstream of the three farms decreased significantly following the remedial construction activities (Figures 2-5) relative to the reference site (linear contrast: site 1 vs. sites 2,3,4; $p < 0.001$). The greatest decrease in bacterial levels was noted below the Pickering Farm, while the smallest decrease was noted below the Ratz Farm (Tables 1 and 2). Similarly, bacterial concentrations at the downstream site decreased following the remedial activities (Tables 1 and 2), although only the concentration of *E. coli* showed a significant reduction relative to the reference site (linear contrast: site 1 vs. site 5; $p = 0.023$).

Water Chemistry:

The first three discriminant axes described 85.1% of the total variation in the water chemistry data. The first discriminant axis, DA1, accounted for 46.7% of the total variance and showed a strong negative linear correlation with conductivity and a strong positive correlation with turbidity (Table 3). Since discharge is generally positively correlated with turbidity and negatively correlated with conductivity (Prairie and Kalff 1988), this axis appears to account for the difference in discharge among the five sites (Figure 6). For example, the two headwater sites, Site 1 and Site 3, which are expected to have the lowest discharge, have the lowest values along this axis, whereas the farthest downstream site, Site 5, which is expected to have the greatest discharge of the five sites, has the highest value along the axis.

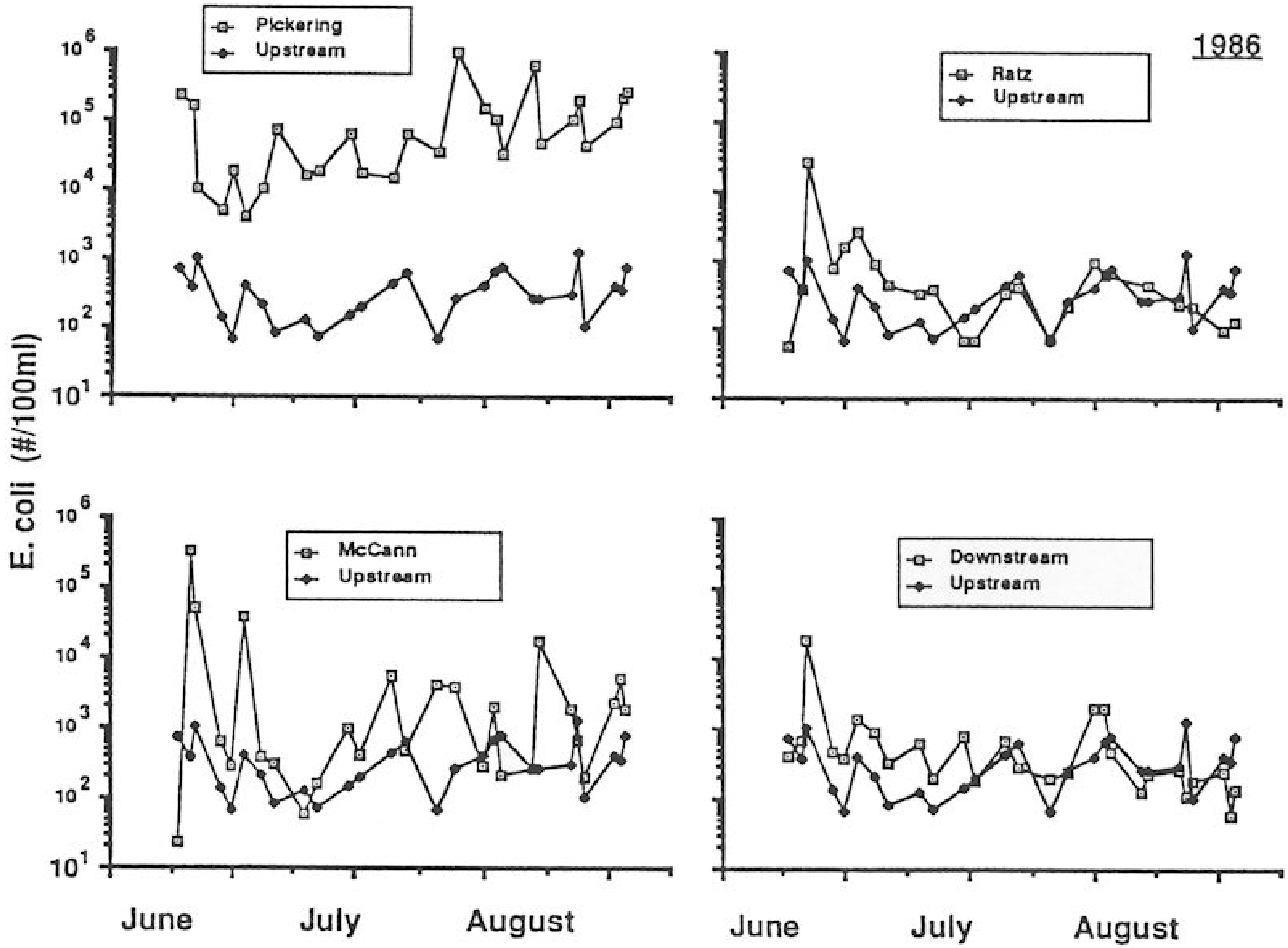

Figure 2: Concentration of *Escherichia coli* at five sampling sites along the Desjardine Drain from June through August, 1986. See Figure 1 for location of sampling sites.

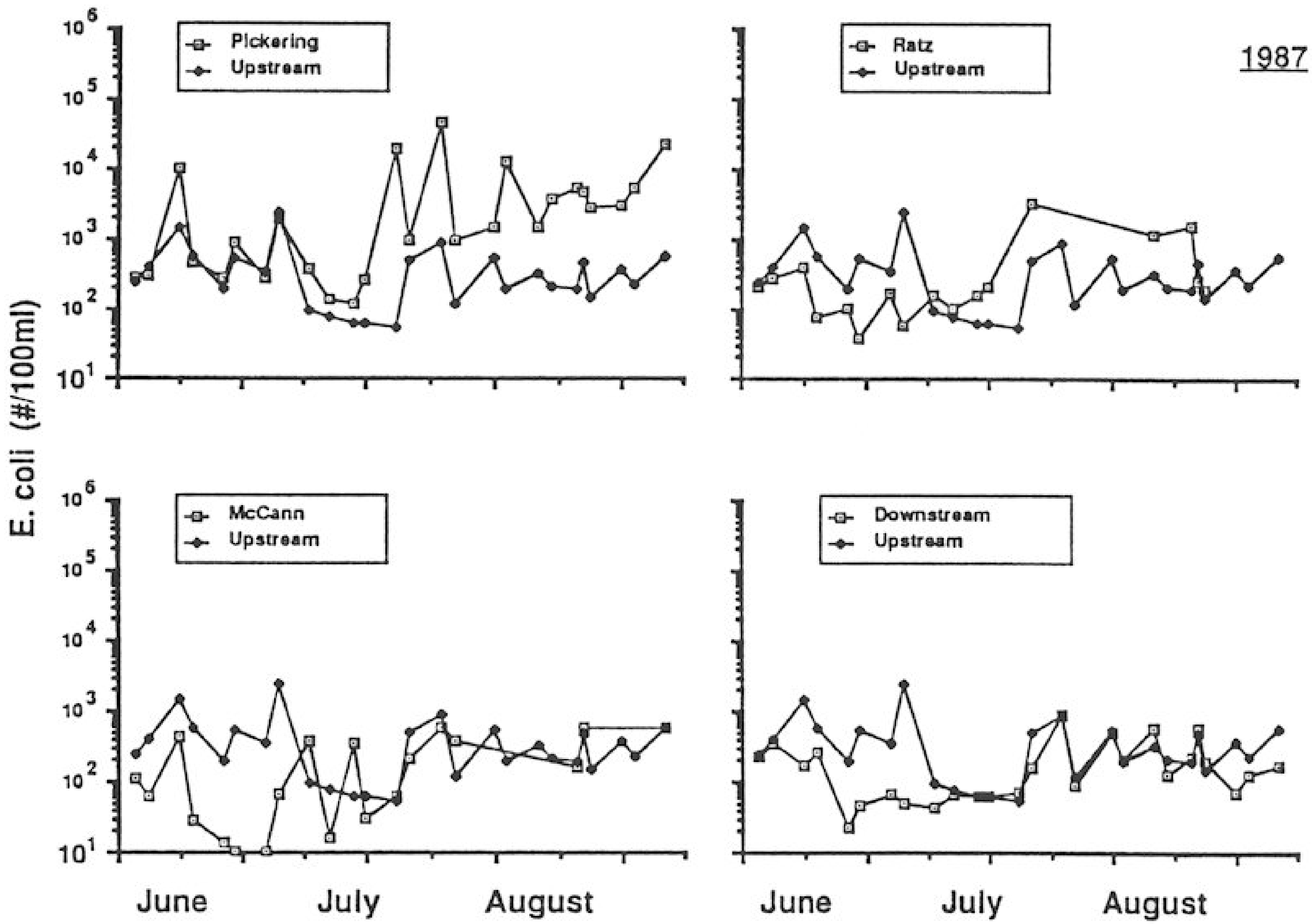

Figure 3: Concentration of *Escherichia coli* at five sampling sites along the Desjardine Drain from June through August, 1987. See Figure 1 for location of sampling sites.

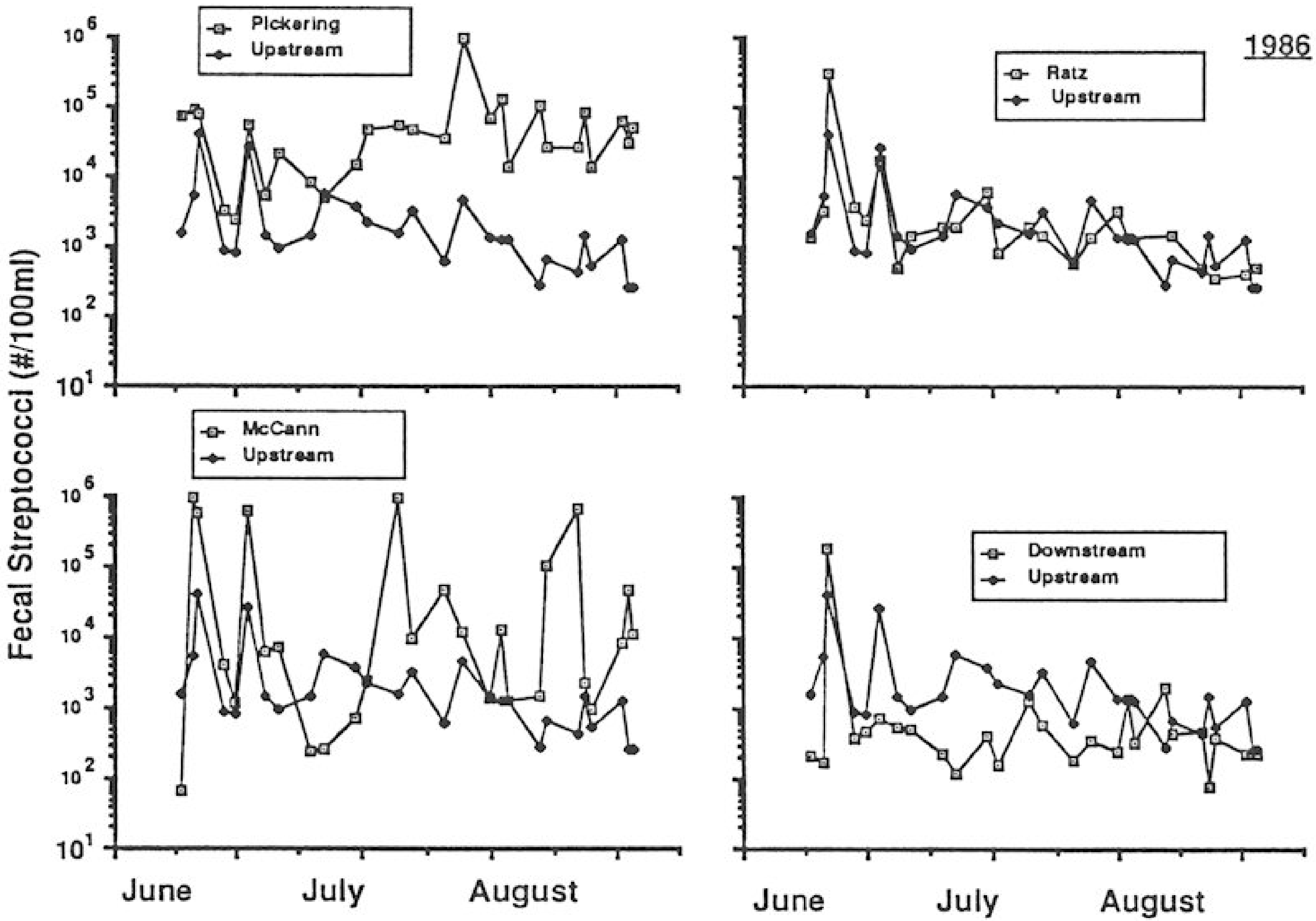

Figure 4: Concentration of fecal streptococci at five sampling sites along the Desjardine Drain from June through August, 1986. See Figure 1 for location of sampling sites.

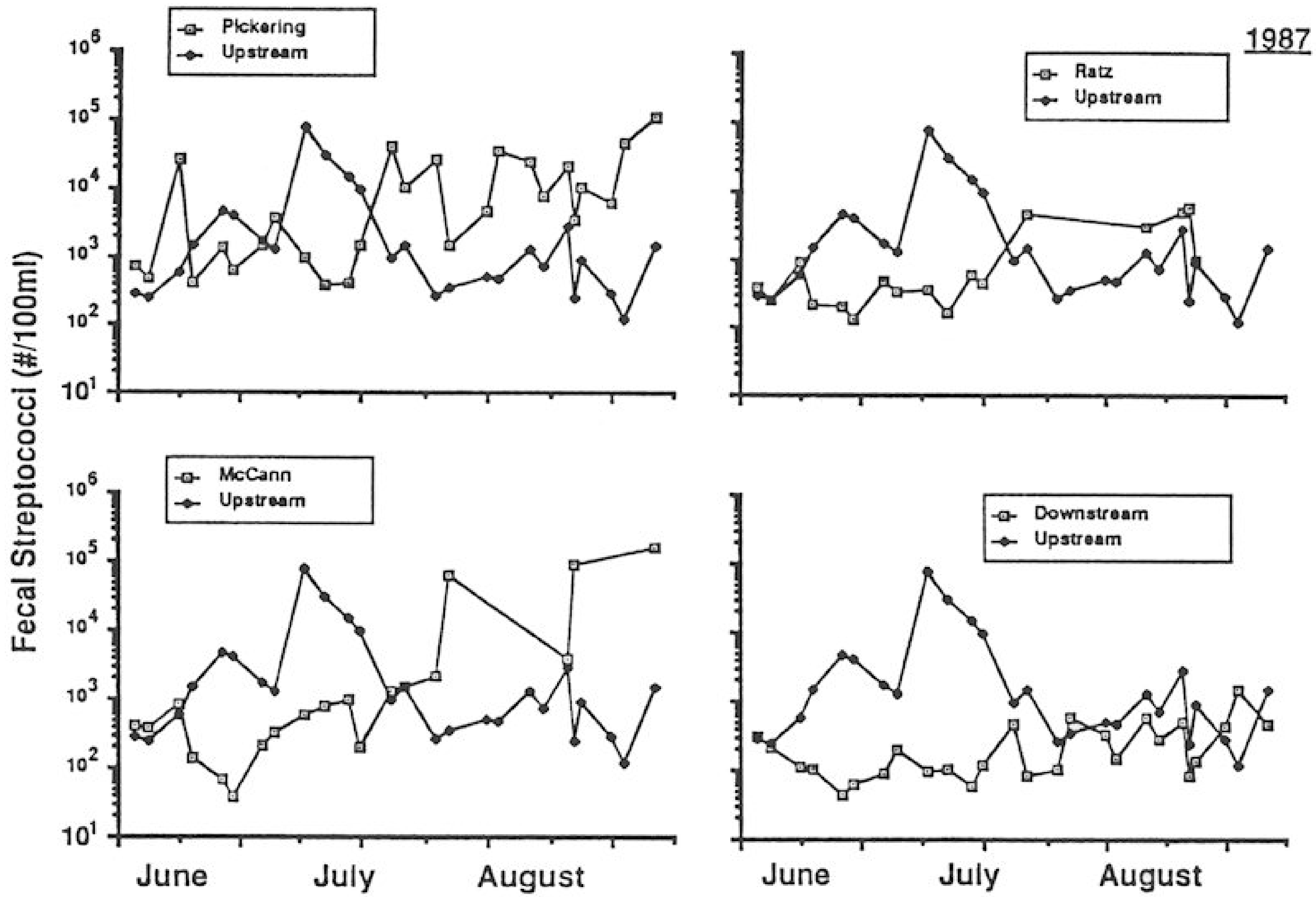

Figure 5: Concentration of fecal streptococci at five sampling sites along the Desjardine Drain from June through August, 1987. See Figure 1 for location of sampling sites.

Table 1: Mean percent change (adjusted for seasonal trend) in the summer concentrations of *Escherichia coli* and fecal streptococci at five sampling sites along the Desjardine Drain from 1986 to 1987. Farm Mean represents the average of the Pickering, Ratz and McCann sites weighted by the number of samples collected from each site. ns = not significantly lower than the Upstream site;

* = significantly ($p<0.05$) lower than the Upstream site;
** = significantly ($p<0.01$) lower than the Upstream site.

	SAMPLING SITES					
	Upstream	Farm Mean	Pickering	Ratz	McCann	Downstream
BACTERIA						
E. coli	5.2	-76.0**	-97.2	-29.9	-90.0	-68.7*
Fecal Streptococci	-8.5	-77.4**	-86.2	-57.7	-83.9	-65.1 ns

Table 2: Mean (geometric) summer bacterial concentrations (number per 100 mL) at five sampling sites along the Desjardine Drain in 1986 and 1987. See Figure 1 for location of sampling sites.

	SAMPLING SITES									
	Upstream		Pickering		Ratz		McCann		Downstream	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
BACTERIA										
E. coli	290	320	33000	2300	380	310	1100	150	700	170
Fecal Streptococci	1800	1300	29000	750	1900	980	10000	1600	650	190

Table 3: Correlations (r) between the measured water chemical variables and the first three discriminant axes.

	DISCRIMINANT AXIS		
	1	2	3
Conductivity	-0.506	-0.001	-0.102
Turbidity	0.483	-0.246	-0.091
Total-P	0.152	-0.640	-0.176
TKN	0.384	-0.611	0.034
Ammonia	0.125	-0.555	-0.105
Soluble Reactive-P	-0.142	-0.522	-0.190
BOD	0.315	-0.127	0.106
pH	0.209	0.615	-0.277
Nitrate	-0.325	0.050	-0.717
Nitrite	-0.023	-0.035	-0.172
Chloride	-0.153	0.070	0.247

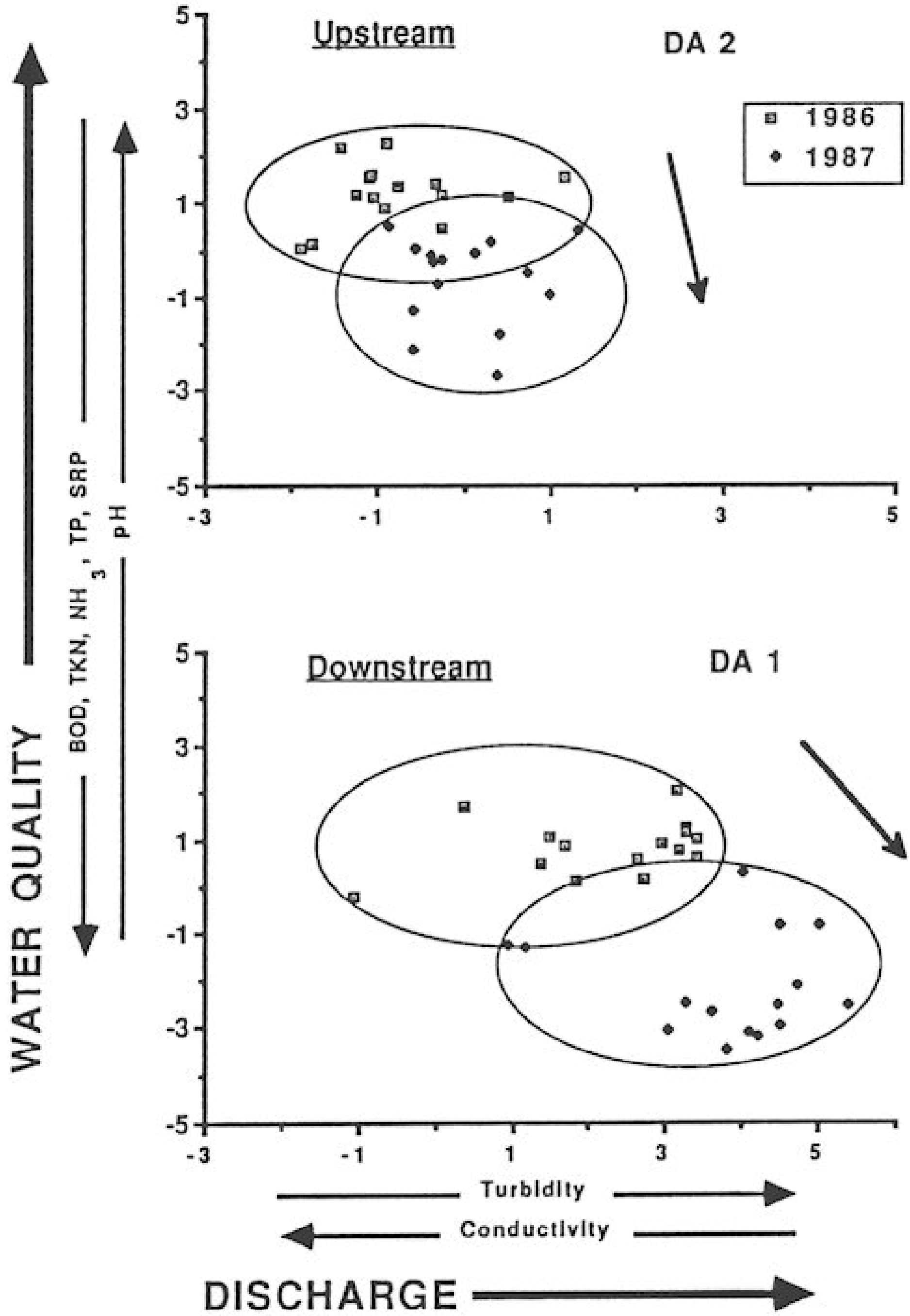

Figure 6: Plot of sampling sites in discriminant space in 1986 and 1987 as defined by water chemistry measurements. Each point represents a single sample.

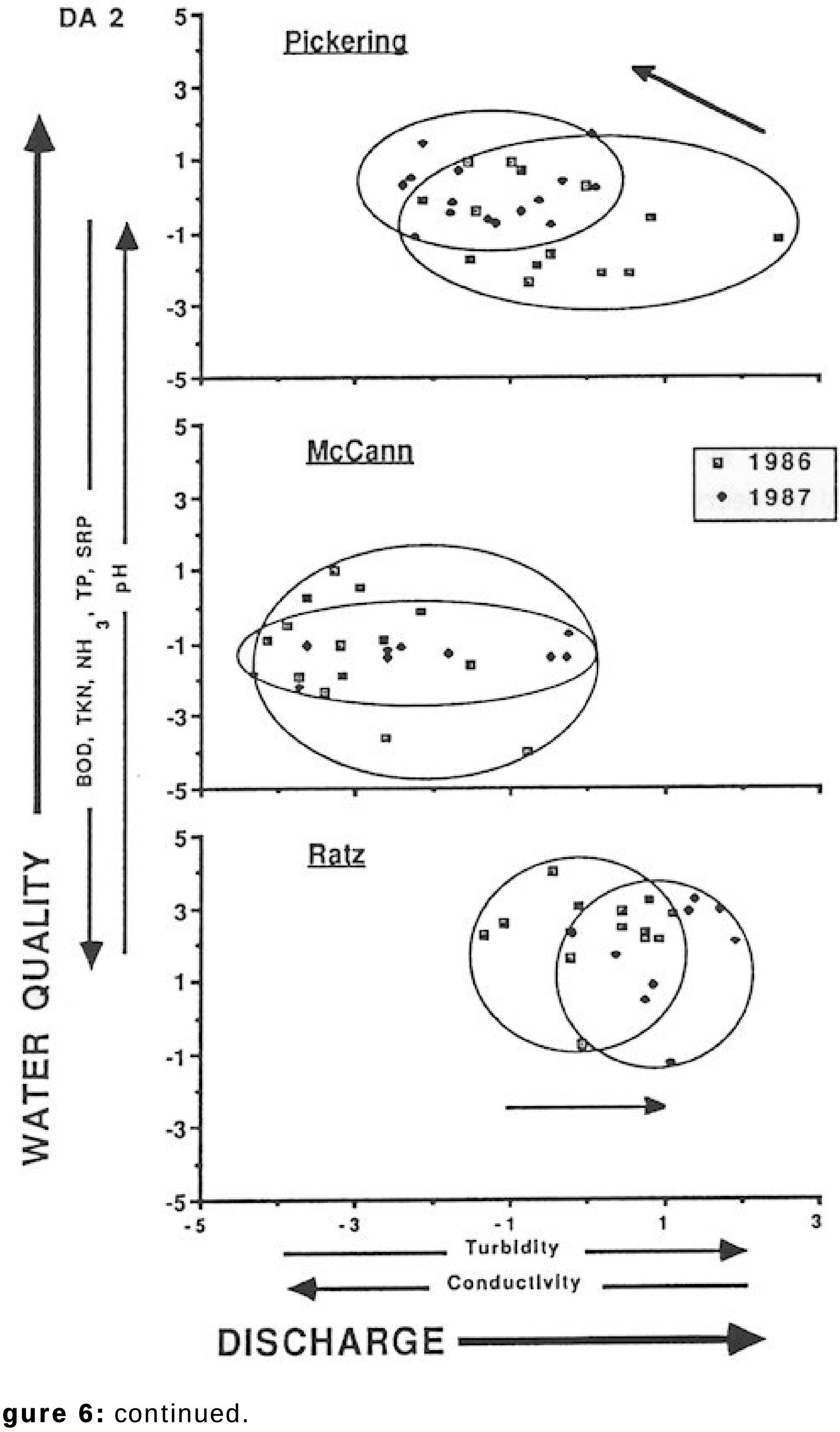

Figure 6: continued.

The second discriminant axis, DA2, accounted for 24.1% of the variance and was negatively correlated with BOD, TKN, ammonia, total phosphorus (TP) and soluble reactive phosphorus (SRP) and positively correlated with pH (Table 3). This axis appears to reflect the water quality conditions at each site. A reduction in BOD, TKN, ammonia, TP, and SRP concentrations and an increase in pH suggests a reduced loading of agricultural wastes and consequently an improvement in water quality conditions. Figure 6 shows that water quality conditions at both the upstream, Site 1, and downstream, Site 5, sites declined from 1986 to 1987, as concentrations of BOD, TKN, ammonia, TP and SRP greatly increased and pH decreased (Tables 4 and 5).

The reduction in water quality may have occurred both as a result of increased loadings of agricultural wastes, via manure spreading activities, or farm-yard runoff, etc., and reduced rainfall (Table 6), which would have decreased the volume of water in the drain. In contrast, the remedial construction activities appeared to have prevented a similar reduction in water quality conditions downstream of the three farms (Figure 6). Mean change in the concentration of BOD, TKN, ammonia and TP downstream of the farms was significantly different (linear contrasts: site 1 vs sites 2, 3, 4; $p < 0.001$) from that at the reference site (Table 4); while the concentrations of these variables increased markedly at the upstream reference site from 1986 to 1987, the mean concentrations of these variables actually decreased downstream of the farms following the remedial construction activities. The greatest response to the remedial activities occurred downstream of the Pickering Farm, whereas the smallest response was measured downstream of the Ratz Farm (Table 4), where the best water quality conditions were observed (Figure 6; Table 5).

The third discriminant axis, DA3, accounted for 14.3% of the total variance and was negatively correlated with nitrate (Table 3). However, a water quality interpretation of this axis was not evident and thus it was not considered further.

Table 4: Mean percent change (adjusted for seasonal trend) in the summer values of water chemical values at five sampling sites along the Desjardine Drain from 1986 to 1987. Farm Mean represents the average of the Pickering, Ratz and McCann sites weighted by the number of samples collected from each site.

ns = not significantly (p>0.05) lower than the Upstream site;
nsl = not significantly (p>0.05) greater than the Upstream site;
*** = significantly (p<0.001) lower than the Upstream site.

	SAMPLING SITES					
	Upstream	Farm Mean	Pickering	Ratz	McCann	Downstream
CHEMICAL VARIABLE						
BOD	344.6	-2.1***	-24.0	49.2	-22.0	224.4 ns
TKN	81.5	-4.4***	-30.8	21.2	4.2	204.0 ns
Ammonia	277.0	-34.0***	-77.1	-4.3	-9.2	419.6 ns
Total-P	152.7	-3.4***	-69.4	85.9	-4.7	238.3 ns
Soluble Reactive-P	106.9	32.9 ns	-82.1	255.0	-28.9	93.5 ns
pH	-22.9	-9.3 nsl	-18.3	0.0	-7.1	-29.1 nsl

Table 5: Mean (geometric) summer values of water chemical variables at five sampling sites along the Desjardine Drain in 1986 and 1987. See Figure 1 for location of sampling sites.

Conductivity values expressed in µmhos/cm @25°C; turbidity values expressed in formazin units; pH values are unitless; other values expressed in mg/L.

	SAMPLING SITES									
	Upstream		Pickering		Ratz		McCann		Downstream	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
CHEMICAL VARIABLE										
BOD	0.607	2.713	2.006	1.844	0.905	1.229	1.335	1.013	2.164	8.776
TKN	0.672	1.306	1.250	0.963	0.647	0.833	0.979	1.018	1.200	4.221
Ammonia	0.019	0.098	0.127	0.051	0.019	0.025	0.150	0.182	0.089	0.624
Total-P	0.051	0.126	0.335	0.131	0.034	0.051	0.151	0.131	0.110	0.468
Soluble Reactive-P	0.016	0.030	0.192	0.046	0.004	0.011	0.091	0.073	0.020	0.043
pH	7.93	7.62	7.86	7.66	8.26	8.36	7.64	7.62	8.10	7.73
Conductivity	796	721	822	890	725	567	945	885	660	509
Turbidity	10.4	19.1	21.9	11.1	7.6	6.6	4.3	5.8	57.3	117.0

Table 6: Monthly rainfall accumulations (mm) at Shipek , Ontario from May to September in 1986 and 1987.

	1986	1987
May	37.0	41.5
June	70.5	30.5
July	109.0	29.0
August	113.5	85.5
September	274.0	102.0

DISCUSSION

By controlling runoff of milkhouse and livestock wastes from farmyards and repairing faulty domestic septic systems, the remedial construction activities improved the overall bacterial and chemical water quality conditions of the Desjardine Drain immediately downstream of the farms (Tables 1 and 4). Despite these improvements, however, the mean summer concentration of E. coli and total phosphorus at these sites (Tables 2 and 5) still exceeded the Ministry of the Environment's Provincial Water Quality Guidelines (MOE 1984) of 100 fecal coliform bacteria per 100 mL and 0.030 mg/L total phosphorus. Furthermore, fecal bacterial concentrations showed an increasing trend over the summer (Figures 3 and 5). It is uncertain whether this observed increase is simply a seasonal event (e.g. bacterial survival may be related to number of sunlight hours) or the start of a return to pre-1987 levels. An addition year of sampling, i.e. June through August 1988, will be necessary to answer this question.

The reduced improvement in bacterial and chemical water quality conditions downstream of the Ratz's Farm may be attributable to the failure of another farm's septic system that discharges to the drain just upstream of Site 4. Prior to the start of this project, this system was found to be operational and the storage tank was pumped out. However, in the spring of the 1988, it was discovered to be faulty and had to be repaired. Thus at some point during the project the system failed and this may account for the lower measured reduction in *E. coli*, BOD and nutrient concentrations relative to the other farm sites.

Negative correlations between *E. coli* concentration and chemical water quality conditions downstream of each farm prior to the remedial construction activities (Figure 7) suggest that organic matter, nutrients and fecal bacteria entered the drain by the same mechanisms. The absence of these relationships following the remedial constructions activities (Figure 7) imply that farmyard runoff and discharges from faulty septic systems were prime sources of organic matter, nutrients and fecal bacteria. This is further substantiated by the lack of negative correlations between

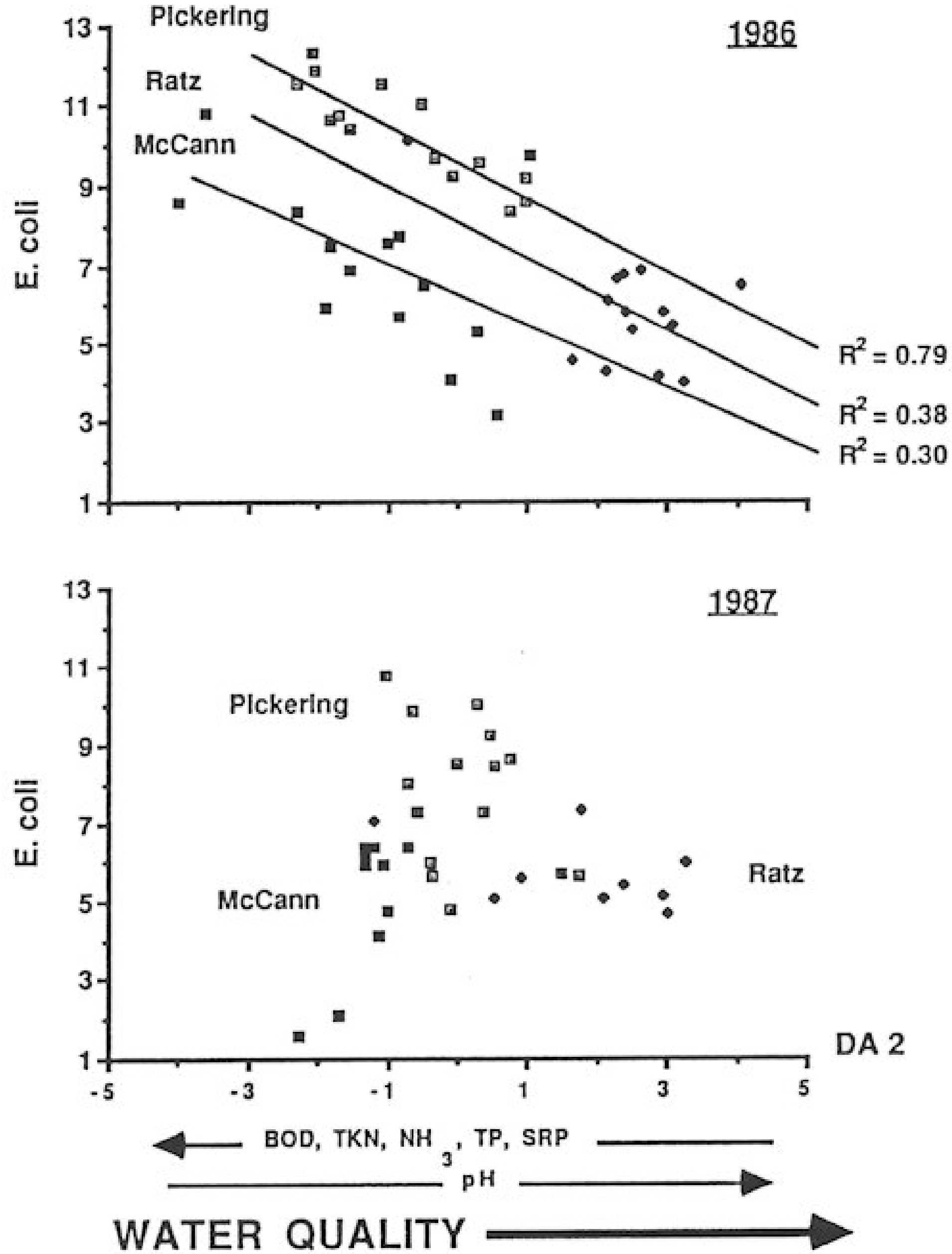

Figure 7: Relationships between concentration (numbers per 100 mL.) of *E. coli* (log axis) and water quality as represented by discriminant axis 2 (see Figure 6) downstream of the Pickering, McCann and Ratz farms in 1986 and 1987. See Figure 1 for location of sites.

these variables at the upstream reference site, which was unaffected by farmyard runoff and domestic waste discharges, and by the presence of negative correlations between these variables at the downstream site, which was affected by both farmyard runoff and domestic septic wastes both years (Figure 8).

The lower concentrations of fecal bacteria at the downstream site following the remedial activities (Table 2) indicate that a reduction in loadings of agricultural and domestic wastes to the drain will result in lower downstream concentrations of bacteria. This suggests that the utilized remedial construction activities can reduce the loadings of fecal bacteria transported to Grand Bend via the Ausable River, and consequently can have a positive effect on the quality of water along the beaches.

To manage the bacterial water quality conditions at the beaches, however, measurements of bacterial loadings at sampling sites will be required instead of concentrations. In addition, estimates of loading reductions in fecal bacteria for different types of farm operations (e.g. dairy, livestock, swine, poultry) and faulty domestic septic systems should be obtained to determine the total cost of the remedial activities required to maintain the loadings of bacteria to the beaches below a critical level. Furthermore, a better understanding of the survival and downstream transport (drift) of fecal bacteria is necessary to insure that the selection of farms for remedial construction activities will maximize the reduction of bacterial loadings to the beaches at the lowest cost. For example, remedial construction activities should only be conducted on farms where the transport time (days) for fecal bacteria to the beaches is less than their maximum survival time (days).

In contrast to the fecal bacteria, no improvement in the chemical water quality conditions was observed at the downstream site, relative to the upstream reference site, following the remedial construction activities (Tables 4 and 5). This indicates that the reduction in loadings of agricultural and domestic wastes resulting from the utilized remedial construction activities will probably have ro effect on loadings of organic matter and nutrients transported to Grand Bend beaches. One possible explanation for

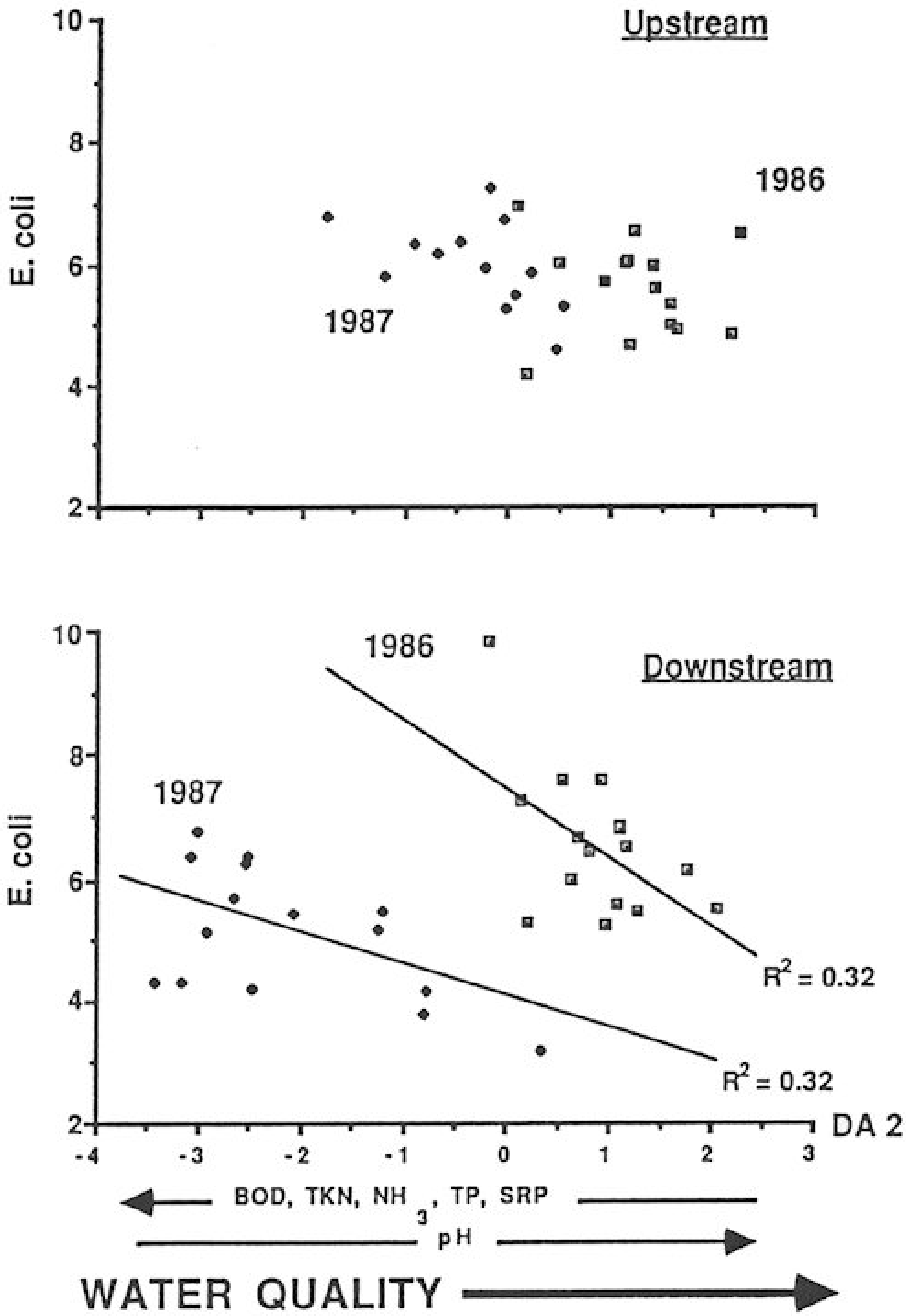

Figure 8: Relationships between concentration (numbers per 100 mL.) of *E. coli* (log axis) and water quality as represented by discriminant axis 2 (see Figure 6) at the Upstream and Downstream sites in 1986 and 1987. See Figure 1 for location of sites.

the localized improvement of chemical water quality conditions downstream of the farms, is the spreading of stored manure from the farms onto fields within the drainage basin of the drain. Organic matter and nutrients, therefore, that previously entered the drain through farmyard runoff, may have simply entered the drain downstream of the farms through tile drainage. For example, manure was spread over the fields of the Ratz and McCann farms in late June of 1987 (D. Hocking, Ausable Bayfield Conservation Authority, personal communication). Thus the loadings of organic matter and nutrients to the drain may have been similar before and after the remedial construction activities, only the point-of-entry to the drain changed. This suggests the need for a better understanding of the relationship between manure spreading activities (i.e. application rate, distance from drain, soil type, type of manure (cattle, swine), spreading season) and loadings of organic matter and nutrients to the drain, so that better management practices can be developed to reduce water quality impairment of agricultural drains from this source.

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