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PHYSICAL QUALITY AND SEDIMENT TRANSPORT IN DRAINAGE WATER FROM A MANURED AND FERTILIZED CROPPING OPERATION

Key Words: Animal wastes, Livestock manures, Agriculture, Water quality

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ABSTRACT

Results of a three-year investigation on the effect of large-scale plowdown of liquid manure on the physical quality of drainage water and sediment transport in a 594 ha agricultural watershed are presented. It was found that with proper management good drainage water quality can be maintained. Specific conductivity measurements can be used for quick estimates of the dissolved solids content in water. The bulk of the annual sediment transport takes place during the snowmelt runoff. The amount of sediment transport is greatly influenced by hydrological conditions of flow.

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* Contribution No. 746
Dedicated to Dr. Bert B. Migicovsky on the occasion of his retirement.

INTRODUCTION

Agricultural operations have been considered to be a major source of potential water pollutants.[1] Sediment and nutrient contributions from such operations have been identified as areas of major concern.[2] Large livestock operations, unless carefully controlled, can lead to the deterioration of environmental quality. Few studies have been carried out in the past to determine the effect of livestock wastes in large-scale cropping operations on drainage water quality and pollutant transport in large watersheds. A number of studies exist on small-scale or plot-size investigations but these may not adequately represent runoff and drainage in large watershed areas because the effects of lateral surface and subsurface inputs, and subsurface inflow-outflow characteristics may be different.[3]

Furthermore, in the case of large watersheds, reliable information on manure applications is generally not available and land use practices are often only approximately known. In the present study such information was readily available because it is a controlled land use operation. As a contribution to Task Group C of the International Joint Commission's Reference Group on Pollution from Land Use Activities, a study was initiated in April 1975 at the Greenbelt Farm of the Animal Research Institute, Agriculture Canada, Ottawa, to determine the physical and chemical quality of, and pollutant transport to drainage water in a large intensively cropped area where large quantities of liquid manure have been incorporated into land every year since 1968. In this paper, results relating to the physical quality of the drainage water and solids transport are presented for the period between April 1975 and December 1977.

EXPERIMENTAL

Study site: The study was carried out in a 594 ha drainage area shown in Figure 1. Four incoming streams were monitored at Stations 6, 7, 8 and 22. Two outgoing streams were monitored at Stations 2 and 3. Water entering the area was from adjacent uncultivated land, roadside drainage, and at Station 6, included some urban runoff as well. Water leaving the drainage area at Station 2 was from cropped land into which large quantities of manure were incorporated. Water leaving at Station 3 was from about 160 ha on the south side within the 594 ha drainage area. No manure was applied to this area since 1974. Cropped fields constituted 569 ha or 96% of the drainage area, the remainder being roads and roadside ditches. All but 8% of the drainage area is tile drained. The land is mostly flat or very gently sloping. About three-quarters of the area has clay loam soil, the rest being mainly sandy loam or loamy sand.

Land use practice: Most of the cropped area is normally under a 3-5 year rotation of corn and mixed legume-grass, with some fields in small grain. Table 1 shows the land use practice during the three year experimental period.

Typical fertilizer applications appropriate for the crop were made each year except for some fields under corn which received manure applications only. Liquid manure was incorporated into the soil in selected fields by the immediate plowdown technique from mid-April to mid-December each year. Table 2 shows

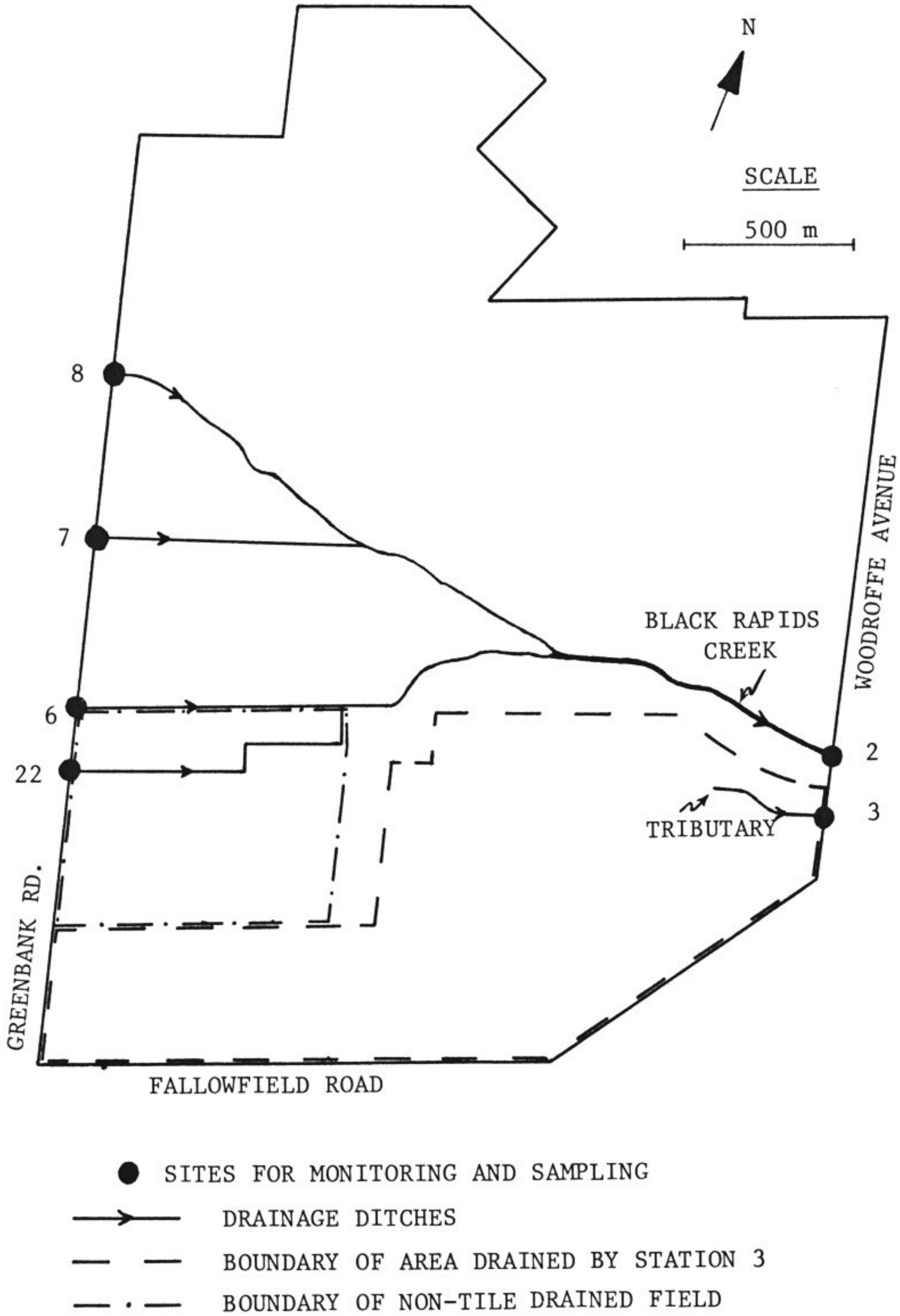

Figure 1. Drainage area for the study of water quality.

Table 1. Percent of cultivated area under different crop types.

Year	Corn	Legumes	Mixed Legumes & grass	Grass	Small grain	Idle
1975	54.5	26.8	9.6	6.3	0	2.8
1976	32.6	18.9	26.7	1.6	17.4	2.8
1977	36.3	32.5	16.1	1.6	10.7	2.8

the volumes and average dry matter content of the manure plowed since 1971.

Of the total volume of manure incorporated about 65% originated from dairy cattle, 30% from sheep and 5% or less from poultry.

Sample collection and flow measurement: Grab samples of water were collected and flow rates were manually obtained at the six stream stations. The frequency of water sample collection and flow rate measurement varied from twice per day

Table 2. Manure applications in area draining into Black Rapids Creek.

Year	Volume m^3	Dry matter average %	Area plowed ha
1971	24,700	9.3	155
1972	23,600	9.3	121
1973	13,700	7.4	78
1974	17,000	9.0	70
1975	16,800	8.6	100
1976	21,300	8.5	141
1977	22,200	8.4	106

during very high flows to once per week at low flows. Flow rates were obtained by velocity-area measurements using a Price Type AA current meter for high flows and a Pygmy meter for low flows. Generally, all streams had very little or no flow from late spring to early fall.

Sample analyses: Water samples were examined for the following physical quality parameters: temperature, pH, dissolved oxygen, specific conductivity, total residue (formerly total solids), total non-filtrable residue (formerly suspended solids) and volatile non-filtrable residue (formerly volatile suspended solids). Standard Methods[4] were used for the above determinations. Temperature was determined in the field with a mercury-in-glass thermometer. pH was determined in the field using a Radiometer Model PHM29 portable pH meter with a Radiometer combination electrode. Dissolved oxygen was determined *in situ* with a YSI Model 51A portable dissolved oxygen meter.

Specific conductivity was determined in the field in 1975 and in the laboratory in 1976 and 1977 using a YSI Model 33 portable conductivity meter. Specific conductivity readings were adjusted to 25°C. Residue determinations were done in the laboratory, ten miles from the Farm. The samples were stored in a cooler with ice packs immediately after collection in the field and brought to the laboratory within four hours of collection. Total residue was determined by evaporating the sample at 103 to 105°C in an oven. Non-filtrable residue was determined by filtering a portion of the sample through a Reeve Angel 934AH glass fibre filter paper and drying at 103 to 105°C. Volatile portion of the non-filtrable residue was determined by igniting the residue on the glass fibre filter paper in a muffle furnace at 550°C. Sample filtration was carried out on the day of the sample collection or the following day.

RESULTS AND DISCUSSION

Water quality: Results for the entire study period from April 1975 to December 1977 are summarized in Tables 3 and 4. Most of the flow occurred at Stations 2, 3 and 6. Flow at Station 22 lasted for a few days only during the initial snowmelt period. Year to year variations in the parameters listed were not significant. For all stations, increased scatter in values for all parameters was observed during the snowmelt runoff.

Mean water temperatures (not shown in Table 3) at Stations 2, 3, 6, 7 and 8 varied from 5.3 to 9.4°C with extremes of 0° and 31°C. Mean and median pH values were near neutral at all stations and met the Canadian objectives for raw water supplies.[5] No noticeable effect of manure usage or chemical fertilizer usage on pH was detectable. Mean and median dissolved oxygen values exceeded 10 mg/l at all stations and near saturation conditions existed most of the time. Low dissolved oxygen values are usually associated with the presence of excessive amounts of readily biodegradable material. The data on dissolved oxygen indicated that contribution of such material from the livestock operations was not excessive. The permissive criterion for dissolved oxygen in surface water is reported to be > 4 mg/L for U.S.A.[6]

Slight increase in the specific conductivity of water leaving the drainage area indicated some contribution of dissolved ionic material to the drainage water. Water draining from the chemically fertilized area (Station 3) had a higher mean conductivity compared with other stations.

Table 3. Stream water physical quality results.

Parameter	Sampling station	No. of samples	Mean	Std. dvn.	Median	Min.	Max.
pH	2	211	7.3	0.6	7.3	6.7	8.8
	3	185	7.3	0.4	7.2	6.6	8.6
	6	185	7.3	0.4	7.3	6.0	8.3
	7	86	7.1	0.3	7.0	6.7	8.1
	8	123	7.2	0.4	7.2	6.7	8.2
	22	24	7.2	0.2	7.3	6.8	7.6
Dissolved oxygen mg/L	2	178	11.0	2.3	11.0	4.7	14.5
	3	156	11.3	1.9	11.2	4.6	14.5
	6	157	11.3	2.1	11.3	5.0	14.8
	7	86	11.9	1.9	12.5	6.0	14.8
	8	119	10.6	2.8	11.2	4.5	14.7
	22	27	12.3	1.7	13.2	7.9	14.0
Specific conductivity micromhos per cm @ 25°C	2	190	468	135	496	109	708
	3	163	522	163	555	92	1054
	6	173	458	125	499	120	841
	7	86	383	147	434	45	580
	8	117	383	149	454	43	570
	22	27	332	154	290	173	711
Total residue (TR) mg/L	2	170	340	123	343	52	937
	3	148	384	153	373	93	1272
	6	158	308	129	308	46	1520
	7	80	264	87	281	39	466
	8	95	260	83	272	1	404
	22	22	231	102	238	28	424

Table 4. Stream water non-filtrable residue results.

Parameter	Sampling station	No. of samples	Mean	Std. dvn.	Median	Min.	Max.
Total non-filtrable residue (SR) mg/L	2	168	31	78	12	0	757
	3	146	21	32	10	0	284
	6	153	15	18	8	0	115
	7	81	16	31	9	0	274
	8	99	15	22	8	0	138
	22	23	11	16	9	0	76
Volatile non-filtrable residue (VSR.) mg/L	2	159	8	11	6	0	87
	3	138	9	14	4	0	102
	6	149	5	8	3	0	67
	7	81	7	14	4	0	115
	8	96	7	12	3	0	80
	22	23	8	17	3	0	79
SR / TR %	2	163	9.2	14.7	4.0	0	94.0
	3	144	6.7	10.6	2.3	0	65.5
	6	150	5.6	8.3	2.7	0	71.4
	7	80	7.6	12.6	3.7	0	88.1
	8	95	6.8	12.8	3.3	0	83.8
	22	22	5.8	11.4	2.5	0	54.3
VSR /SR %	2	157	44.7	29.0	39.5	0	100
	3	136	42.9	31.0	36.3	0	100
	6	147	41.8	31.8	38.4	0	100
	7	81	41.5	29.8	35.3	0	100
	8	96	42.4	29.2	33.3	0	100
	22	23	42.7	31.8	33.3	0	100

Data on total, non-filtrable and volatile non-filtrable residues also indicated some contribution from the cropping activity in the drainage area but again the contribution was not excessive. The mean concentrations of non-filtrable residue were lower than the reported mean concentrations of 40 to 1021 mg/L in runoffs from agricultural land under corn, oats or alfalfa brome grass,[7] and of 1147 mg/L in river water.[8] The Canadian objective for the concentration of total dissolved solids in raw water sources is < 500 mg/L.[5] Both the mean and median concentrations of total solids (total residue) were well below this objective. At all stations, on the average, non-filtrable residue constituted less than 10 per cent of the total residue. The results indicate that the volatile fraction in the non-filtrable material in the drainage water from the manured area (Station 2) was practically the same as that in the water from the chemically fertilized area (Station 3) and the non-cultivated area (Stations 7 and 8).

The reasonably good physical quality of the drainage water from the intensively cropped and manured watershed can be attributed principally to the management factors of immediate plowdown of manure into soil following application, restriction of manure applications to relatively dry periods, provision for manure storage during wet weather and winter, rotation of fields for manure applications, and manure applications away from stream banks.

Correlations: A positive correlation was obtained between specific conductivity and total dissolved solids, calculated by taking the difference between total residue and total non-filtrable residue, for both the incoming streams and the outgoing streams.

Linear regression was used to relate specific conductivity and dissolved solids by the relation

$$S = A + BL \quad (1)$$

where S is dissolved solids in mg/L, L is specific conductivity in micromhos per cm at 25°C, B is the slope of the regression line, and A is a constant. The results are summarized in Table 5.

The intercept A would be nearly zero if the dissolved material consisted of ionic compounds only. The values for A can be regarded as an approximate measure of non-ionic dissolved material. A relationship of the form

$$S = B'L \quad (2)$$

has been suggested for the estimation of dissolved solids in natural water, with the constant B' ranging from 0.54 to 0.96.[9] Least-square determination of B' from the data of this work gave values of 0.63, 0.64, 0.61, 0.62 and 0.60 for

Table 5. Summary of linear regression analyses for dissolved solids and specific conductivity at 25°C.

Station	Data pairs n	Slope B	Intercept A	Correlation coefficient r	Mean S mg/L
2	147	0.49	72.3	0.75	307
3	132	0.63	12.8	0.80	352
6	140	0.50	54.3	0.72	284
7	79	0.44	81.7	0.68	253
8	92	0.43	78.4	0.72	242

Stations 2, 3, 6, 7 and 8 respectively, which indicated that Equation (2) masked the differences in dissolved solids content of water from different sources. Therefore if conductivity is used as an indicator of total dissolved solids in drainage water, it is advisable that a correlation be obtained using Equation (1) rather than Equation (2), for each water type, otherwise substantial errors can be expected. Rapid and simple conductivity measurements could then be employed for quick estimates of dissolved solids content, which itself is one indicator of water quality. To ensure uniformity in routine work, it is advisable that regular comparisons be made of the dissolved solids estimated from conductivity measurements with actual determinations based on the time-consuming residue-on-evaporation method or by summation of ionic concentrations. In addition, conductivity measurements can be used to determine long term trends in water quality,[10] as a means of estimating ionic strength in natural waters,[11, 12] and for analytical quality control.[13]

Solids transport: Flows at stream stations and concentrations of total and non-filtrable residue were used to determine the amount of solids transported at each station on a given day. Data for the days on which flow measurements and samples were not obtained, were estimated based on the available data for the preceding and the following periods. Daily transports at the inlet and outlet stations were combined to obtain the yearly net transport or contribution to the drainage water from the cropping and manuring activity. The results are shown in Table 6.

Table 6. Solids contribution to drainage water from mixed farming*.

Description	Year	Inlet total	Outlet total	Net transport	Contribution rate per ha
Total residue (TR) kg	1975*	128,800	340,500	211,700	356
	1976	130,100	757,600	627,500	1056
	1977	115,900	372,400	256,500	432
Non-filtrable residue (SR) kg	1975*	8,300	36,400	28,100	47
	1976	12,400	245,000	232,600	392
	1977	4,300	38,700	34,400	58
SR / TR %	1975*	6.4	10.7	13.3	-
	1976	9.5	32.3	37.1	-
	1977	3.7	10.4	13.4	-

*Results for 1975 do not include contribution from snowmelt.

Distribution of the yearly net transport of solids between the snowmelt and the rainfall periods is shown in Table 7. The snowmelt period was considered to end when the snow-cover on the ground was gone.

Table 7. Distribution of annual net solids transport between snowmelt and rainfall periods

Year	Total residue transport		Non-filtrable residue transport	
	Snowmelt %	Rainfall %	Snowmelt %	Rainfall %
1976	86.5	13.4	91.7	8.3
1977	60.8	39.2	79.8	20.2

Results in Table 6 show that considerably more solids were contributed to the streams in 1976 compared to 1977. Total precipitation (935 mm in 1976 and 927 mm in 1977) and land use practice were comparable in both years. Results in Table 7 show that the bulk of the annual transport of solids in 1976 took place during the snowmelt period. Spring of 1976 was characterized by a rapid thaw combined with rainfall which caused heavy flows and flooding. In contrast, the spring of 1977 was characterized by a slow thaw followed by a freeze-up, so heavy flows were for a much shorter period of time. The hydrological conditions of longer periods of heavy, and consequently turbulent, flows in 1976 resulted in a greater net transport of solids to the streams compared to 1977.

Harms *et al.* reported[7] average yearly runoff contributions, from cropped land, for total residue to range from 32 to 334 kg/ha/yr and for non-filtrable residue from 4 to 286 kg/ha/yr, the contribution rate increasing from alfalfa-brome grass to pasture to cultivated land. Although these figures cannot be directly compared to the figures in Table 6 because of different conditions of soil, drainage, precipitation and cropping, the contribution rates from the two studies are of comparable order of magnitude.

The ratios of non-filtrable residue (SR) to total residue (TR) in Table 4, based on the mean concentrations in the samples, and in Table 6, based on the total annual transports, are comparable for the water entering and leaving the watershed except in 1976 for the water leaving the watershed. In 1976, on the average, non-filtrable residue was 12% and 7.8% of the total residue in water samples from Stations 2 and 3 respectively, whereas on the basis of annual transport, the same proportion was 32.3% (Table 6) for the combined transport at both these stations.

This shows that although non-filtrable residue may constitute a small proportion of the total residue on the average in water samples during a year, it does not necessarily follow that non-filtrable residue would constitute a small proportion of the total residue transported during the year.

Table 7 shows that 80% or more of the annual non-filtrable residue transport occurred during the snowmelt period in both 1976 and 1977, irrespective of the flow conditions. Therefore measures to control non-filtrable residue transport during the snowmelt period can considerably reduce the annual contribution of non-filtrable residue, which in turn determines the sediment contribution, to agricultural drainage water.

CONCLUSIONS

Careful and proper management can prevent excessive deterioration of the physical quality of drainage water from cropping and livestock operations requiring large-scale land application of manures. Specific conductivity measurements can be used for quick estimates of dissolved solids content of agricultural drainage water. Hydrological conditions of flow can greatly affect solids transport from agricultural land. The bulk of the annual sediment transport occurs in the short period of snowmelt runoff.

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