1978-02-01

Pollutant Transport to Subsurface and Surface Waters in an Integrated Farm Operation: PLUARG Special Study No. 22, Report for the period 1975-1977

International Reference Group on Great Lakes Pollution from Land Use Activities

Canada. Department of Agriculture

N. K. Patni

F. R. Hore

INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES

INTERNATIONAL
JOINT
COMMISSION

POLLUTANT TRANSPORT TO SUBSURFACE AND SURFACE WATERS IN AN INTEGRATED FARM OPERATION

POLLUTANT TRANSPORT TO
SUBSURFACE AND SURFACE WATERS
IN AN INTEGRATED FARM OPERATION

PLUARG Special Study No. 22

Report for the period 1975-1977

Principal Investigator

N.K. Patni, Research Scientist
Animal Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario K1A 0C6

Associate Investigator

F.R. Hore, Research Scientist
Engineering and Statistical Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario K1A 0C6

February 1978

DISCLAIMER

The study discussed in this document was carried out as part of the efforts of the Task Group C of the Pollution from Land Use Activities Reference Group (PLUARG), an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Findings and conclusions are of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

N. K. Patni

Prepared by: N.K. Patni
Research Scientist
Animal Research Institute
Ottawa, Ontario

Approved by: R.S. Gowe
Director
Animal Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario, K1A 0C6

ACKNOWLEDGEMENTS

This study was partly supported with funds made available to the Animal Research Institute (ARI) by Agriculture Canada on behalf of the Task Group C of the Pollution from Land Use Activities Reference Group of the International Joint Commission.

The assistance and support of the Animal Research Institute Administration and Resources Staff, without which this study would not have been possible, is gratefully acknowledged. M. Leuty, D. Armstrong, S. Kelly, M. Moen, M. Baker and others at ARI assisted in data collection and computation.

J. Gall of the Engineering and Statistical Research Institute assisted with the installation and maintenance of flumes, and recording of meteorological data.

Bacteriological examination of water, manure and soil samples was carried out by the staff of the National Capital Region Laboratory Services of the Environmental Protection Service of Fisheries and Environment Canada, under the direction of Dr. A.D. Tennant and Mr. H.R. Toxopeus.

Chemical analyses of manure and crop samples were carried out by the Analytical Services Section of the Chemistry and Biology Research Institute.

A few water samples were analyzed for herbicide content at the Pesticide Residue Testing Laboratory, Guelph, of the Ontario Ministry of Agriculture and Food, under the direction of Dr. R. Frank.

Agricultural Watershed Studies Coordinators, Dr. D.R. Coote and Mrs. E. MacDonald provided liaison with PLUARG.

Mrs. Iris Hellard and Mrs. Christine Charbonneau typed the manuscript.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Introduction:

A study was conducted at the Greenbelt Farm of the Animal Research Institute of Agriculture Canada to determine pollutant transport to subsurface and surface waters in an integrated farm operation involving large-scale livestock operations.

Objectives of the study were:

1) to determine if subsurface pollutant transport in a small field could be extrapolated to a large field, other conditions such as manuring, cropping practice, soil characteristics, etc., being the same for both fields.

2) to determine the difference in pollutant transport in tile drainage water under a largely coarse-textured soil compared to a fine-textured soil under similar conditions of manuring and cropping practice.

3) to determine pollutant transport to surface water in a 594 ha drainage area under a closely controlled cropping operation.

Pollutant transport to subsurface tile drainage water from land application of animal manure was studied at three fields, with similar tile drainage, that were subjected to the same cropping practice. The quality of tile drainage water was compared for three manured fields and one non-manured field. Pollutant transport to surface water in a 594 ha drainage area (with 569 ha of cultivated fields) from application of animal manures and chemical fertilizers, was studied by monitoring surface water entering the drainage area at four locations and leaving at two locations. Water samples were checked for temperature, pH, conductivity, total, suspended and volatile suspended solids, total Kjeldahl, ammonia and nitrate nitrogen, total phosphorus in raw and filtered samples, potassium, dissolved oxygen and indicator bacteria. A study of soil properties and nutrient accumulations or transformations in the soil was not included in this study. Information on soil types and profiles in the study area was however available from other sources.

Findings reported here cover the period from April 1975 to October 1977. All the flow data were not obtained in 1975 due to delays in delivery of current meters for stream flow measurement and flumes for tile flow measurements.

Findings:

I. Subsurface tile drainage water:

1) About 90% or more of the annual flow occurred during the spring runoff. In 1976, respectively for the clay and sandy soil fields, water drained by tile drainage was about 1/5 and 1/10 of the total annual precipitation. The number of flow periods and their duration were found to be different in the small and large clay fields even with the same precipitation, soil type and tile drainage system. On the basis of single-day peak flows, the small clay field had 0.8 to 2.2 (average 1.4) times the runoff per unit area compared to the large clay field and 2.0 to 4.9 (average 3.3) times the runoff compared to the small sandy field (six comparisons each). On the basis of rainfall-induced peak flow events lasting for a few days, the small clay field had 1.1 to 1.8 (average 1.2) times the runoff per unit area compared to the large clay field and 2.1 to 3.8 (average 2.6) times the runoff compared to the small sandy field (six comparisons each).

2) Manure application rates of about 500 kg N/ha/yr (application split between spring and fall) for three successive years on corn fields did not lead to excessive or unacceptable deterioration of physical or chemical quality of tile drainage water with the exception of nitrate-nitrogen, the concentration of which was found to be dependent on prior history of manure application. Application of manure at the above rate for three successive years resulted in acceptable concentration of NO_3-N in a field with a prior history of relatively low rates of nitrogen applications whereas the same rate of manure application resulted in unacceptably high NO_3-N concentration in a sandy soil field with a prior history of heavy nitrogen applications for about ten years. However, in the former case, mean NO_3-N concentration increased from 1.6 mg/l in 1975 to 3.6 mg/l in 1976, and to 5.1 mg/l in 1977. Physical and chemical quality of water from the chemically fertilized field was generally comparable to the quality of water from two manured fields which did not have heavy manure applications in the past several years prior to this study.

3) Because of variations in amounts and periods of flow from similarly drained and cropped fields, and different previous nutrient application histories, nutrient transports in the different fields were not always comparable although they were of the same order of magnitude.

4) The amount of nutrients (N, P, K) removed in tile drainage water was not significant compared to the amount of nutrients applied in manure. Nutrients removed by the crop and the tile drainage water accounted for only about 15 to 40 percent of the nutrients applied in manure. Under the conditions of the study, it is likely that a larger proportion of the unaccounted-for nutrients remained in the soil compared to the proportion entering other sinks. Manure application rates of about 500 kg N/ha/yr over a number of successive years would therefore have a potential of polluting groundwater. Increasing concentration of NO_3-N mentioned in (2) above could be due to the release of increased residual nitrogen in the soil.

5) Bacteriological quality of tile drainage water from both manured as well as non-manured fields met recreational water quality objectives except during periods of heavy flow following rainfall when bacterial counts increased irrespective of field treatment or soil type.

Bacterial numbers varied widely in manure samples examined in 1975, depending on the age of manure. Therefore it was not possible to estimate mean bacterial application rates on soils. Fecal coliform numbers were found to reduce considerably during storage of manures. Bacterial examination of soil samples (in 1975 only) at different depth levels, before and after manure applications, indicated a decrease in numbers with depth. Also, the number was lower in spring compared to fall, probably because of lower initial counts in spring-applied manure. With respect to change in bacterial numbers with time after application of manure, a regression analysis indicated that, in general, total coliform numbers tended to increase but fecal coliform and fecal streptococcus numbers tended to decrease, and standard plate counts tended to remain static or increase slightly. Unsuitability of total (as opposed to fecal) coliform as pollution indicators was demonstrated.

6) Atrazine and its degradation product, de-ethyl atrazine was detected in tile drainage water 2½ years after the last application in one field. Generally the concentration was quite low. Butylate (Sutan) was not detected in tile water after first year of application on sandy nor on clay soils. Amount of atrazine and de-ethyl atrazine removed in drainage water was insignificant compared to the amount applied.

7) No viruses were isolated in two samples each of tile water from manured fields and winter-stored dairy cattle manure, tested in 1975.

II. Surface stream drainage water:

1) Bulk of the flow occurred during the spring runoff with the heaviest flows restricted to a few days only.

2) For most parameters tested, the quality of stream water leaving the intensively cropped drainage area of Black Rapids Creek was better than or close to acceptable quality for surface water supplies although a slight increase in N, P and K concentrations was noted. The reasonably good quality of water was attributed to management factors associated with manure handling. It may also be noted that about three-quarters of the drainage area has fine-textured soil, and that the drainage area is mostly flat and largely tile drained.

3) Stream water samples were examined in 1975 for bacteriological quality. Bacteriological quality of water draining from a manured area was found to be comparable to water draining from non-manured drainage areas of the Farm confirming an earlier finding that plowdown of large quantities of manure indicated no bacteriological deterioration of surface waters. Generally, water entering and leaving the drainage area was of good bacteriological quality.

4) Total solids, suspended solids, nitrogen, phosphorus and potassium losses

of about 1000, 400, 24, 1 and 16 kg/ha/yr respectively were estimated for 1976. At these rates, 16, 2 and 14 percent respectively of the applied N, P and K were lost to surface drainage water. Most of such loss occurred in spring runoff. Loss estimates for 1977 were considerably lower than estimates for 1976.

It appears that flow pattern during heavy spring flows, which is dependent on ambient temperature and precipitation, influences pollutant and nutrient contributions to surface streams. Spring of 1976 was characterized by a rapid thaw resulting in very heavy flows and floods. Spring of 1977 was characterized by a thaw followed by freeze-up, so that there were fewer days with very heavy flows. Higher contribution of solids (total and suspended), N, P and K was observed in the spring of 1976 compared to the spring of 1977.

Conclusions:

1) Nutrient transport to subsurface tile drainage in manured fields given the same cropping treatment is not always directly comparable but data from one field can be used to make an order-of-magnitude estimate for another field.

2) Previous nutrient application history influences the quality of, and total transport to tile drainage water.

3) Under a corn crop on flat, fine-textured soil with a previous history of low rates of nitrogen application, manure applications at the rate approximating 500 kg N/ha/yr (split into spring and fall applications) can be made for up to three successive years without causing excessive or unacceptable deterioration in subsurface water quality.

4) Bacteriological quality of subsurface and surface water is not influenced by manure applications when manure is incorporated into soil immediately after application except following heavy rainfall events.

5) Intensive integrated farming involving large applications of liquid manure by the plowdown technique in relatively flat land with largely fine-textured soil does not generally impair stream water quality to unacceptable levels. However, substantial quantities of nitrogen and potassium can be lost annually depending on the conditions of flow. Most of this loss occurs in spring runoff.

6) Calculation of annual pollutant and nutrient transport by the use of annual mean concentrations and total annual flows needs caution because of the influence of very heavy flows for very few days on total annual transport.

INTRODUCTION

This Report covers the results of a Research Project at the Greenbelt Farm of the Animal Research Institute of Agriculture Canada in Ottawa. The study was initiated in response to the research needs on Great Lakes Pollution as identified by the International Joint Commission's International Reference Group on Pollution from Land Use Activities (PLUARG). The general objective was to obtain information on water pollution potential of animal production operations in Ontario by determination of nutrient and pollutant transport to surface stream water and subsurface tile drainage water in a large-scale, closely controlled farming operation which utilizes large quantities of animal manures in a land-recycling system. The study was partly supported by funds provided by Agriculture Canada on behalf of PLUARG.

Specific objectives of the study were:

1) To determine if subsurface pollutant transport in a small field can be extrapolated to a large field, other conditions (manure application rates, cropping practice, soil characteristics, etc.) being the same for both fields.

2) To determine the difference in pollutant transport in tile drainage water under a largely coarse-textured soil, compared to a fine-textured soil under similar conditions of manuring and cropping.

3) To determine pollutant transport and nutrient loss to surface water in a 594 ha watershed under a closely controlled cropping operation.

The above specific objectives were set up to provide information required for the following two objectives in the Detailed Studies Program[1] of PLUARG Task Group C Agricultural Watershed Studies.

1) To determine the effects of the soil, land use and associated practices on ambient concentrations and loading rates of selected pollutants from agriculture.

2) To develop relationships so that the information derived can be utilized in a predictive sense and extrapolated to other areas.

The results reported and discussed here are on the quality of water from subsurface tile drainage and surface stream drainage, and on the quantity of nutrients and pollutants transported in these waters. For three selected manured fields a nutrient balance is reported in terms of nutrient application in manure and removal in crop and the tile drainage water. The results reported on water quality and on pollutant and nutrient transport cover the period from April 1975 to August 1977. Some other results reported are up to the end of 1977.

DATA COLLECTION METHODS

Study Sites:

The study was carried out within a 594 ha drainage area of the 1140 ha Greenbelt Farm of the Animal Research Institute of Agriculture Canada in Ottawa, Ontario. Surface and subsurface water from this selected area drains into the Black Rapids Creek which itself flows into the Rideau River. Areas selected for the study of the subsurface and surface water are shown in Figures 1 and 2 respectively.

Subsurface water: The locations of the sampling and monitoring stations in the selected fields are shown in Figure 1. A summarized description of each field is given in Table 1. Field stations were identified as follows:

Station F4 - drains large "clay" field, manured	(27.5 ha)
Station 15 - drains small "clay" field, manured	(4.1 ha)
Station F10 - drains small "sandy" field, manured	(5.6 ha)
Station 13 - drains large "clay" field, fertilized	(132 ha)

During April and May in 1975, tile mains were intercepted and wooden sampling wells, 1.2 m by 1.2 m by 2.4 m deep were installed at Stations F4 and F10. Flows were measured at Station F4 with a Parshall Flume during the high flow periods and an H Flume during the low flows. Flows at Stations F10 and 15 were measured with HS and H flumes respectively. Flow was not measured at Station 13 which consisted of a catch basin with a manhole through which samples were collected. Stage heights in the flumes were continuously recorded using eight-day, clock-wound, portable Belfort Model 5-FW-1 liquid level recorders. To prevent seizure of the float in the stilling wells of the flumes due to freezing, flameless catalytic propane heaters were installed inside the sampling wells during the winter months.

Surface water: The area draining into the Black Rapids Creek has four streams entering the area at Stations 6, 7, 8 and DOT, as shown in Figure 2, and two streams leaving 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 area at Station 2 was from intensively cropped land into which large quantities of manure were incorporated in selected areas each year. Water leaving at Station 3 was from about 160 ha on the south side of the drainage area. Stream banks at selected stations were supported by plywood boards to provide a controlled cross-sectional area across which flow-depth and velocity measurements were made with a cup-type

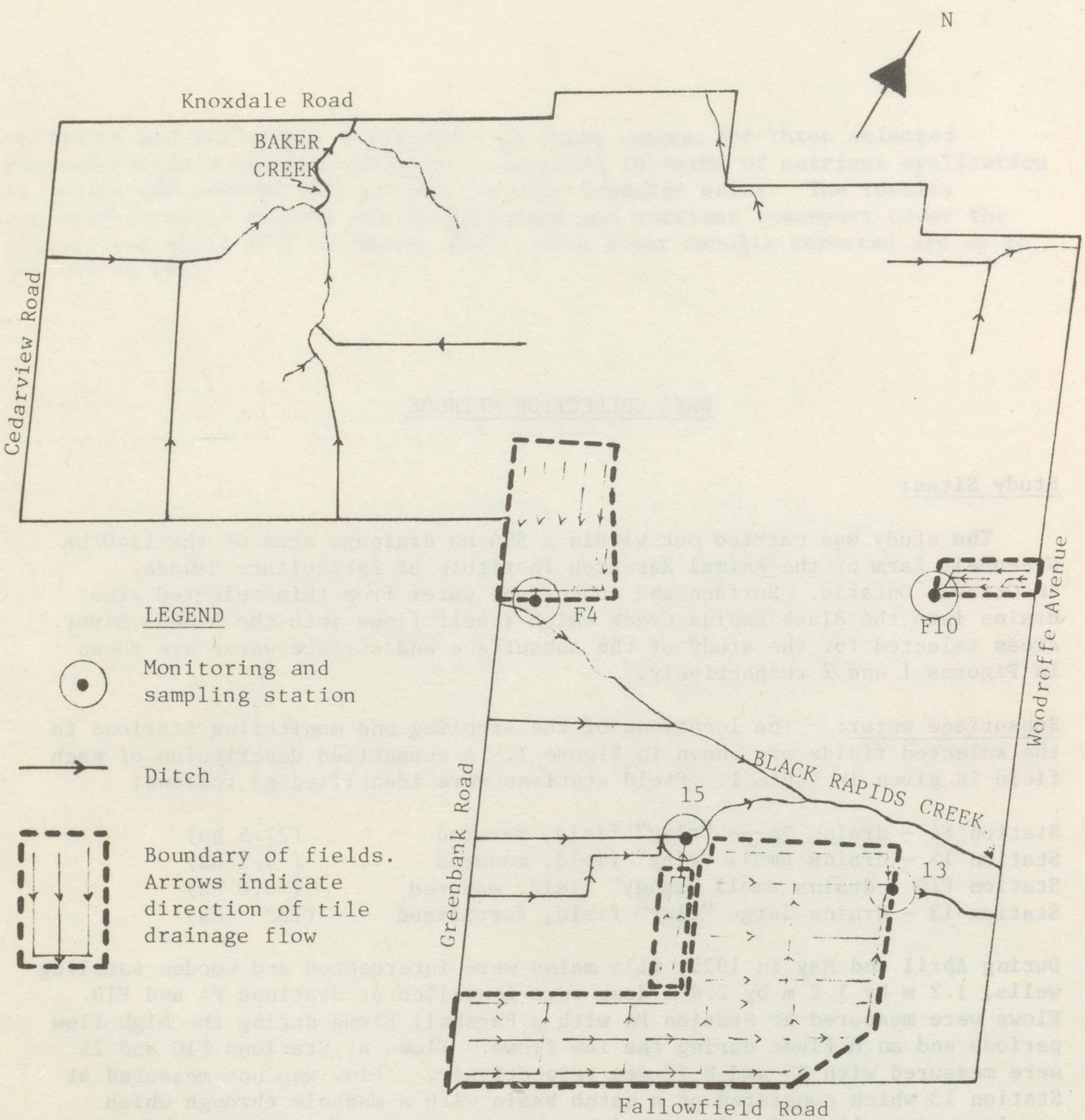

Figure 1. Location of fields for study of subsurface tile water.

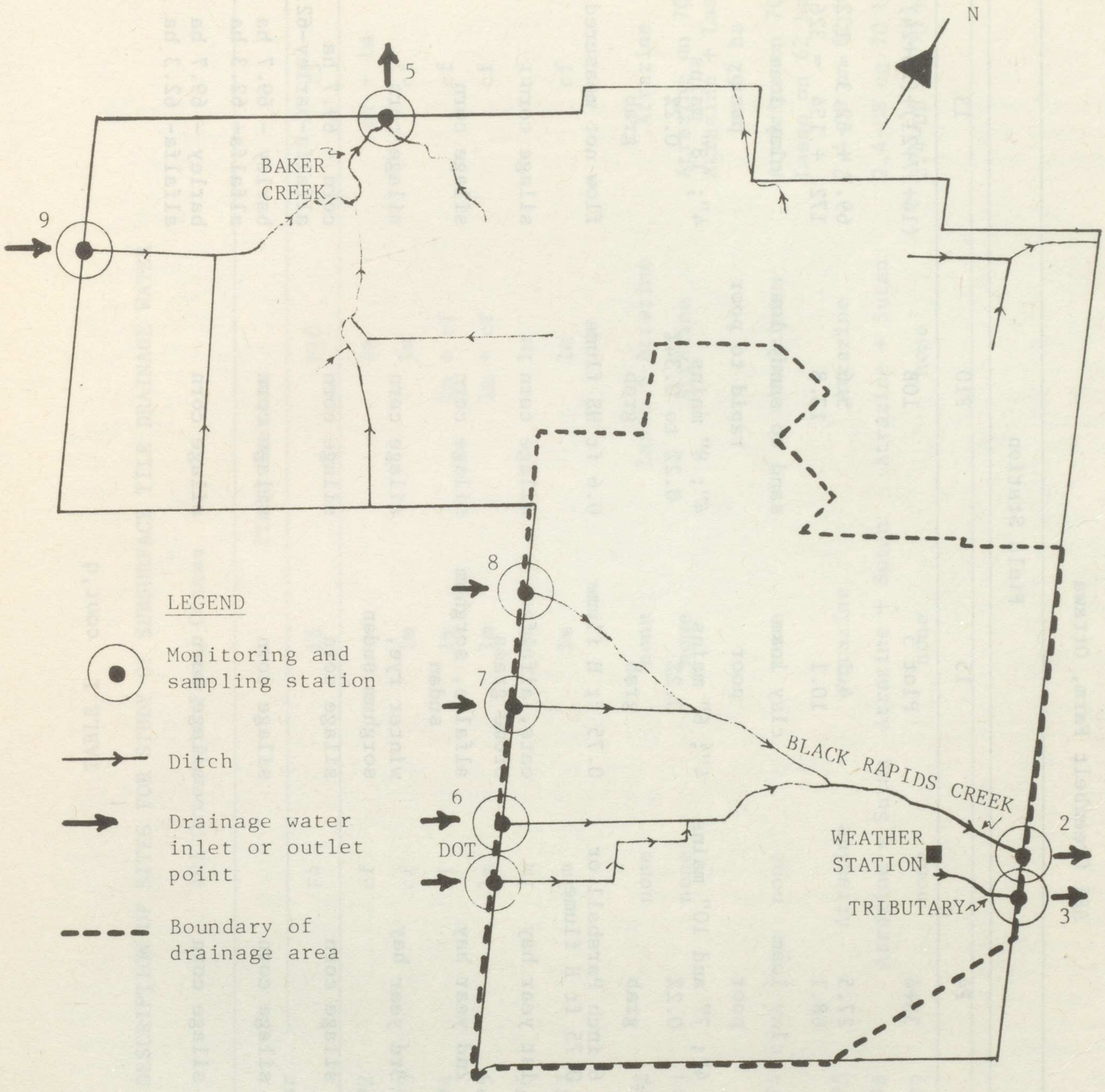

Figure 2. Location of Black Rapids Creek drainage area within the Greenbelt Farm, Animal Research Institute, Ottawa, for study of surface water.

TABLE 1

SUMMARY DESCRIPTION OF SITES FOR STUDY OF SUBSURFACE TILE DRAINAGE WATER

ARI Greenbelt Farm, Ottawa

Description	Year	Field Station			
		F4	15	F10	13
Field number(s) or name		3B+4	Plot 5	10B	(14+17+21)+(20+24)
Area drained - ha		27.5	4.1	5.6	69.7 + 62.3 = 132
- acres		68.1	10.1	13.8	172 + 154 = 326
Surface soil texture		clay loam	clay loam	sand to sandy loam	clay loam
Drainage class		poor	poor	rapid to poor	poor
Drainage tile - size		4"; 7" and 10" mains	4"; 6" mains	4"; 8" mains	4"; 18" mains
- slope		0.2%	0.2%	0.2% to 0.34%	0.2%
Sampling method		grab	grab	grab	grab
Flow measurement method		6 inch Parshall or 0.75 ft H flume	0.75 ft H flume	0.6 ft HS flume	flow not measured
Cropping history	1972	1st year hay	oats, alfalfa brome grass	silage corn	silage corn
	1973	2nd year hay	alfalfa, sorghum sudan	silage corn	silage corn
	1974	3rd year hay	winter rye, sorghum sudan	silage corn	silage corn
	1975	silage corn	silage corn	silage corn	corn - 69.7 ha alfalfa-barley-62.3 ha
	1976	silage corn	silage corn	silage corn	barley - 69.7 ha alfalfa- 62.3 ha
	1977	silage corn	silage corn	silage corn	barley - 69.7 ha alfalfa- 62.3 ha

TABLE 1 cont'd

SUMMARY DESCRIPTION OF SITES FOR STUDY OF SUBSURFACE TILE DRAINAGE WATER

ARI Greenbelt Farm, Ottawa

Description	Year	Field Station			
		F4	15	F10	13
Nutrient application history	1972	cf	-	lm	cf + lm
	1973	cf	lm	lm	cf
	1974	cf	lm	lm + cf	cf
lm = liquid manure cf = chemical fertilizer	1975	lm	lm	lm + cf	cf
	1976	lm	lm	lm	cf
	1977	lm	lm	lm	cf
Pesticide application history	1972	none	none	Lasso + Atrazine	Atrazine
	1973	none	none	Atrazine	Atrazine on 70 ha Atrazine + Lasso on 62 ha
	1974	none	none	Atrazine	Atrazine on 70 ha Lasso on 62 ha
	1975	Atrazine	Atrazine	Atrazine	2,4-DB on 62 ha
	1976	Atrazine + Sutan	Atrazine + Sutan	Atrazine + Sutan	2,4-DB on 70 ha
	1977	none	none	none	2,4-DB on 70 ha

current meter to compute flow rates. Staff gages were installed at the stream stations for recording stage heights. The stream stations required annual cleanup and spreading of crushed stone on the stream bed between the boards.

Cropped fields constitute 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 drainage area has clay loam soil, the rest being mainly sandy loam or loamy sand. More information on the soil types and profiles in the drainage area is given in Appendix I. The drainage area has a small resident population of wild animals such as groundhogs, beavers and foxes. In addition, migratory birds also use parts of the Farm during their stopovers. Daily meteorological information for the study site was recorded at a weather station located between the Black Rapids Creek and its tributary (Figure 2).

Figure 2 shows two additional locations, Stations 9 and 5 for the inlet and outlet respectively of the Baker Creek which drains the north-west quadrant of the Farm, which was essentially a non-manured area of the Farm during the study period. Stream water samples from these two stations were examined for bacteriological quality in 1975.

Procedures:

Sampling and analyses: Procedures for water sample collection and analyses[2,3] were common for both the subsurface and surface waters. Grab samples were collected for the determination of: temperature, pH; specific conductivity; total, suspended (or non-filtrable) and volatile suspended solids (or residue); total Kjeldahl, ammonia and nitrate nitrogen; total phosphorus in unfiltered and filtered samples; potassium; and dissolved oxygen (in stream water only). A few of the above parameters were not determined in 1975 in either the tile drainage or the stream drainage water. Details of the sampling and analytical methodology are given in Appendix II. Additional water samples were examined for total and fecal coliforms, fecal streptococci, and Standard Plate Counts at 20° and 35°C, at the National Capital Region Laboratories of the Environmental Protection Service. Samples were delivered to the laboratory within four hours of collection and preserved, if necessary. The frequency of water sample collection varied from twice per day during very high flows to once per week at low flows. All the drainage tiles and streams had very little or no flow from late spring to early fall.

Subsurface water: For the three manured fields, generally the same field procedures were followed each year. Well-mixed dairy cattle liquid manure was plowed into the fields in spring before planting and in fall after harvest. Although an application rate of 224 kg N/ha in each of two applications (total of 448 kg/ha/yr) was intended, the actual application rates varied somewhat. This was due to factors associated with soil, weather and machinery conditions, and the size of the operation which required land incorporation of 3,400 to 4,100 cubic meters (750,000 to 900,000 imperial gallons) of liquid manure from 15 to 20 different locations in a three to four week period. The volume of manure applied to a field was determined from the dimensions of the storage tank being emptied or by the number of tanker loads plowed and the average discharge from each tanker. About 30 to 50 composite samples of manure applied to the fields were obtained each spring and fall. Dry matter, total Kjeldahl nitrogen and ammonia nitrogen were determined in liquid manure samples after thorough mixing. Phosphorus and potassium were determined in dry manure samples. From the tanker load volumes and their representative composite manure sample analyses, application rates were calculated for nitrogen, phosphorus and potassium for each manured field.

The three manured fields were planted with the same variety of silage corn at the same rate (about 54,000 plants/ha) each year. When the crop was harvested in fall, total yields were determined by weighing every wagon load of harvested crop removed from each field. A composite crop sample was obtained and dry matter content was determined. The dry sample was used to determine the total nitrogen, total phosphorus and potassium content. By relating the sample analyses to the weight of crop that they represented, yields of dry matter, nitrogen, phosphorus and potassium were obtained for the crop removed from each field.

Herbicide applications at the same rate were made on the three fields (usually post-emergent) in 1975 and 1976 only. A few water samples were tested for herbicide content during these two years.

Cropping activity in the fields drained by Station 13 was left to the operational requirements of the Farm but with the requirement that only chemical fertilizer and no manure be applied. Thus the crops grown and nutrient application rates to these fields were different from the manured fields.

Continuous daily flow rates of the tile drainage water were obtained from the stage-discharge relationships for the individual flumes. During the initial flush of the snowmelt runoff, flooding of some flumes was caused by water backed up from the downstream side. Whenever possible, flow estimates were made for the few days of flooding on the basis of hydrograph trends and the consideration that the flow through the tiles during such period would be restricted due to the head of water on the downstream side. Water levels of upto 1.5 m above the tile outlets were noticed at times.

During the 1975 field year, bacteriological tests were carried out on the manure plowed into the fields and the soil from these fields. Soil samples at different depths and at different times after the manure application were examined.

Surface water: Information was collected on the type, composition and rate of manure and chemical fertilizer applications in the area draining into the Black Rapids Creek and its tributary. Stream 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. The frequency of stream flow measurement varied from twice per day during very high flows to once per week during low flows. Bacteriological examination of stream water samples was conducted in 1975 only.

EXPERIMENTAL RESULTS

Experimental results presented in this section are upto August 31, 1977 for water quality and pollutant transport. Data on manure and fertilizer applications and crop yields cover the period upto the end of 1977. Discussion of results and interpretation of data are covered in the next section.

Precipitation:

Both the surface and subsurface flows were influenced by precipitation. Daily precipitation for the year 1975, 1976 and 1977 is shown in Figures 3a, b and c respectively. The maximum daily precipitation during the study period was recorded on May 22, 1975. Cumulative total annual precipitation amounted to 990, 935 and 927 mm in 1975, 1976 and 1977 respectively.

Subsurface water:

Flows: Daily flow rates of tile drainage water are shown in Figures 4a, b and c for Station F4, in Figures 5a, b and c for Station 15, and in Figures 6a, b and c for Station F10. Flow rates at Stations F4 and F10 were not obtained for the entire year in 1975 because of the absence of flumes during part of the year, although water samples were obtained for most of the time. A few days of flooding were experienced at all four tile stations in 1976, and at three of the four stations in 1977, due to backed up water during the initial flush of snowmelt runoff.

Tile drainage water quality: Results of water quality analyses (1975-1977) are given in Appendix Table A1. Results for six specific water quality parameters for the individual years 1975, 1976, and 1977 are given in Appendix Table A2. Results of bacteriological parameters for water quality are given in Appendix Table A3. Herbicide application history and herbicide concentration in water samples are given in Appendix Tables A4 and A5 respectively.

Nutrient application rates: Application rates of nitrogen, phosphorus and potassium in the four experimental fields during the experimental period (1975-1977), and prior to that (since 1971), are discussed in the next section.

Bacteriological examination of manure and soil samples: A total of 77 samples of manure applied to the fields in spring and fall and 302 samples of soil from these fields were examined for bacteriological parameters in 1975 by

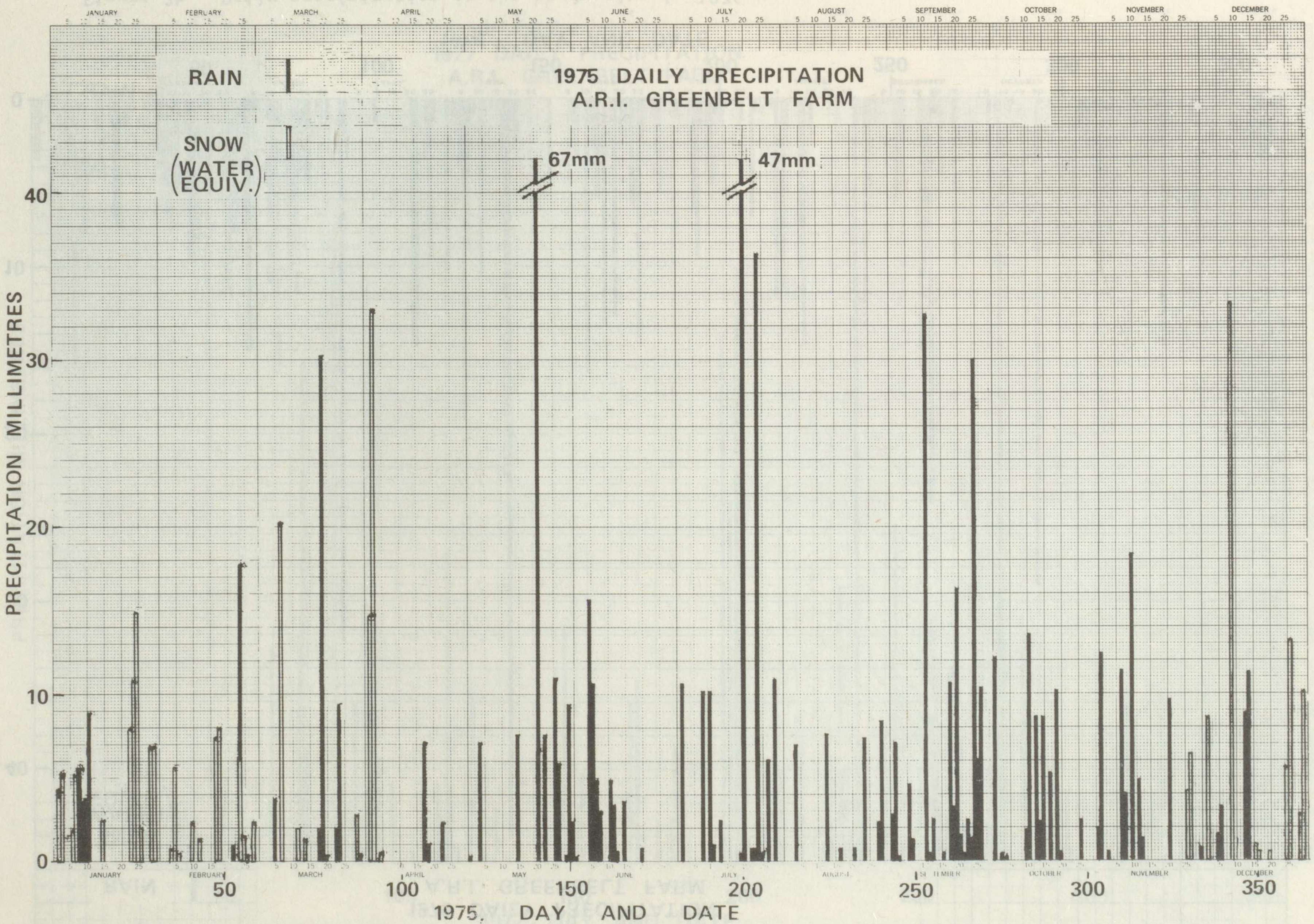

Figure 3a. Daily precipitation at the study site in 1975.

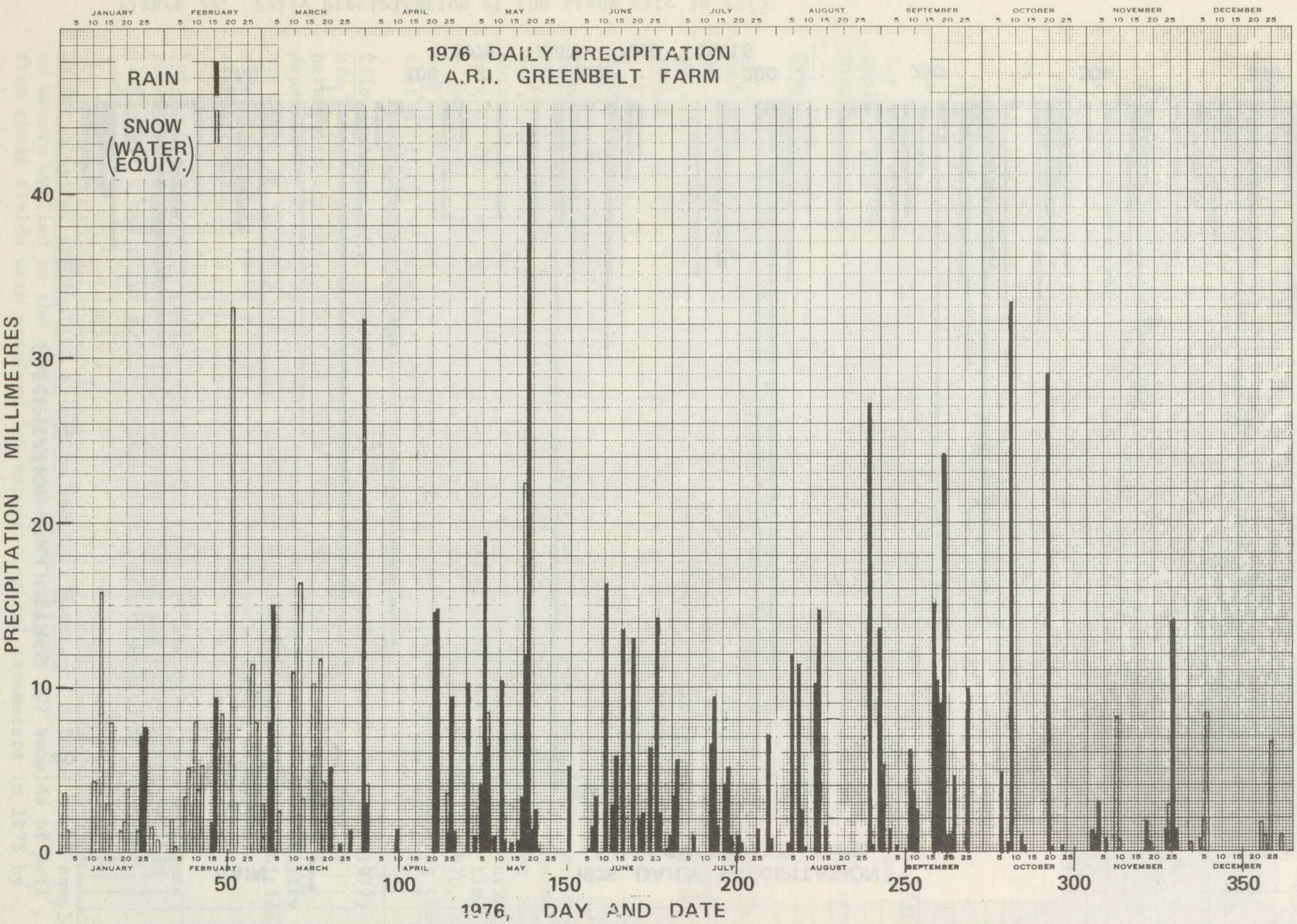

Figure 3b. Daily precipitation at the study site in 1976.

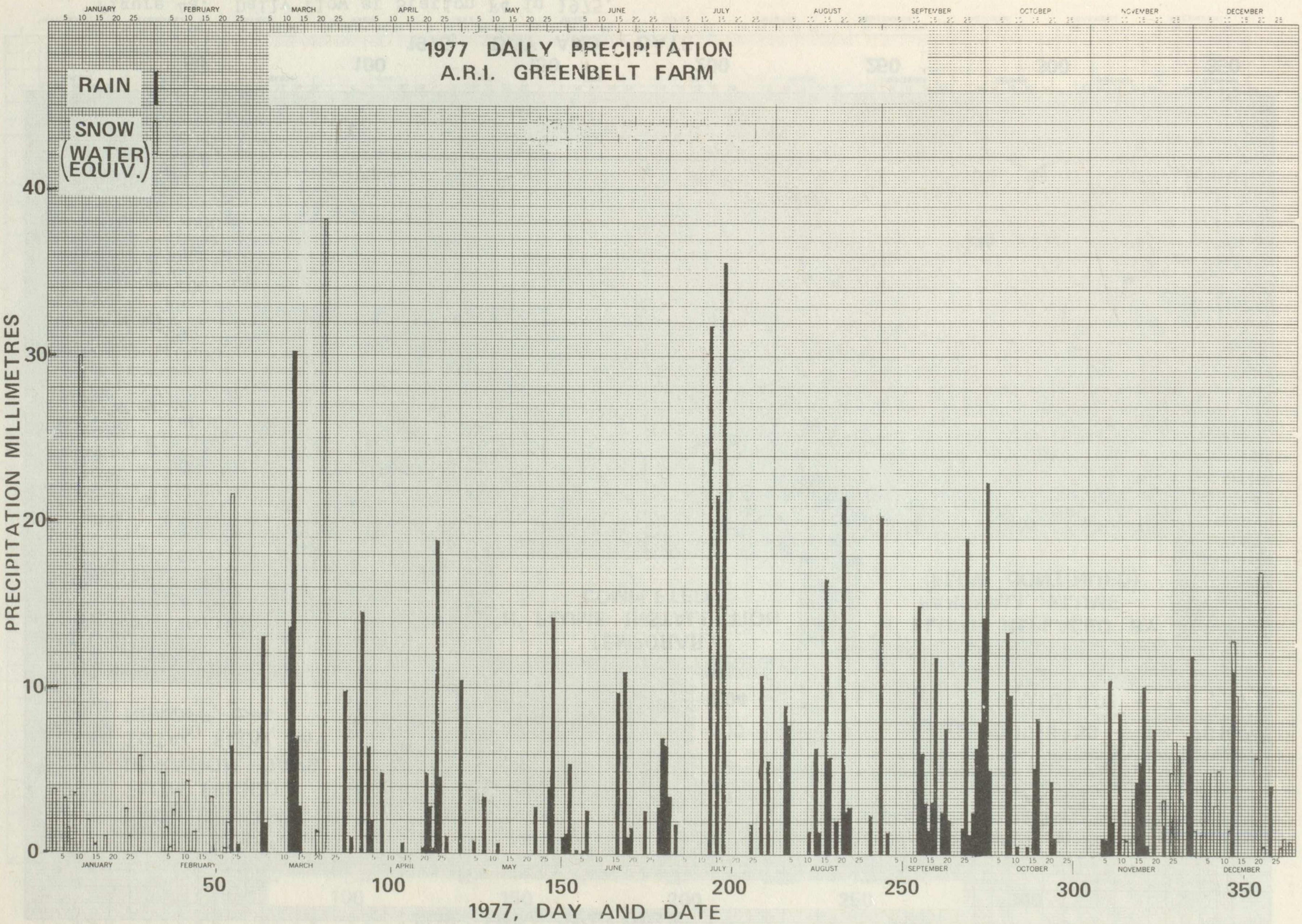

Figure 3c. Daily precipitation at the study site in 1977.

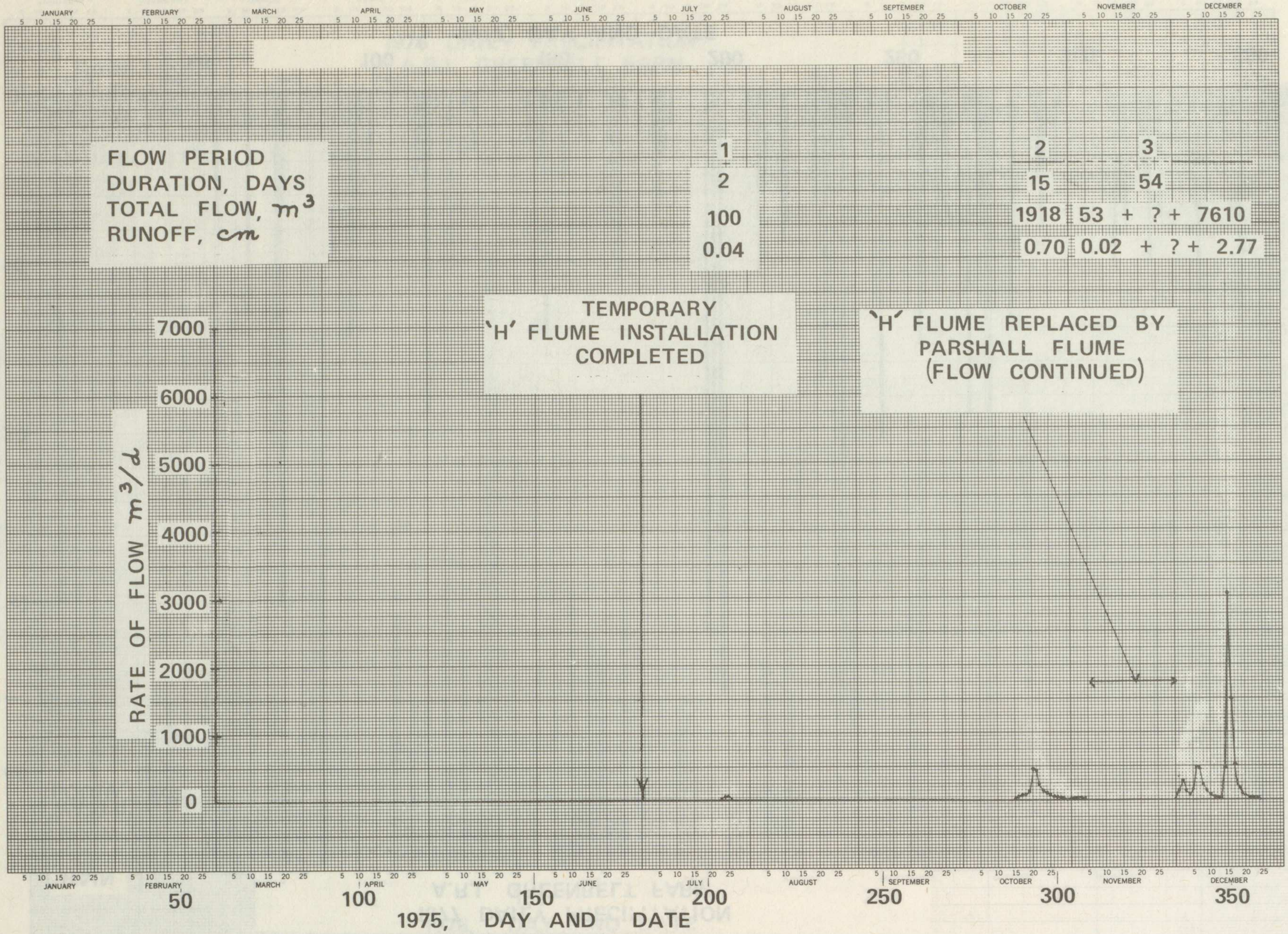

Figure 4a. Daily flow at Station F4 in 1975.

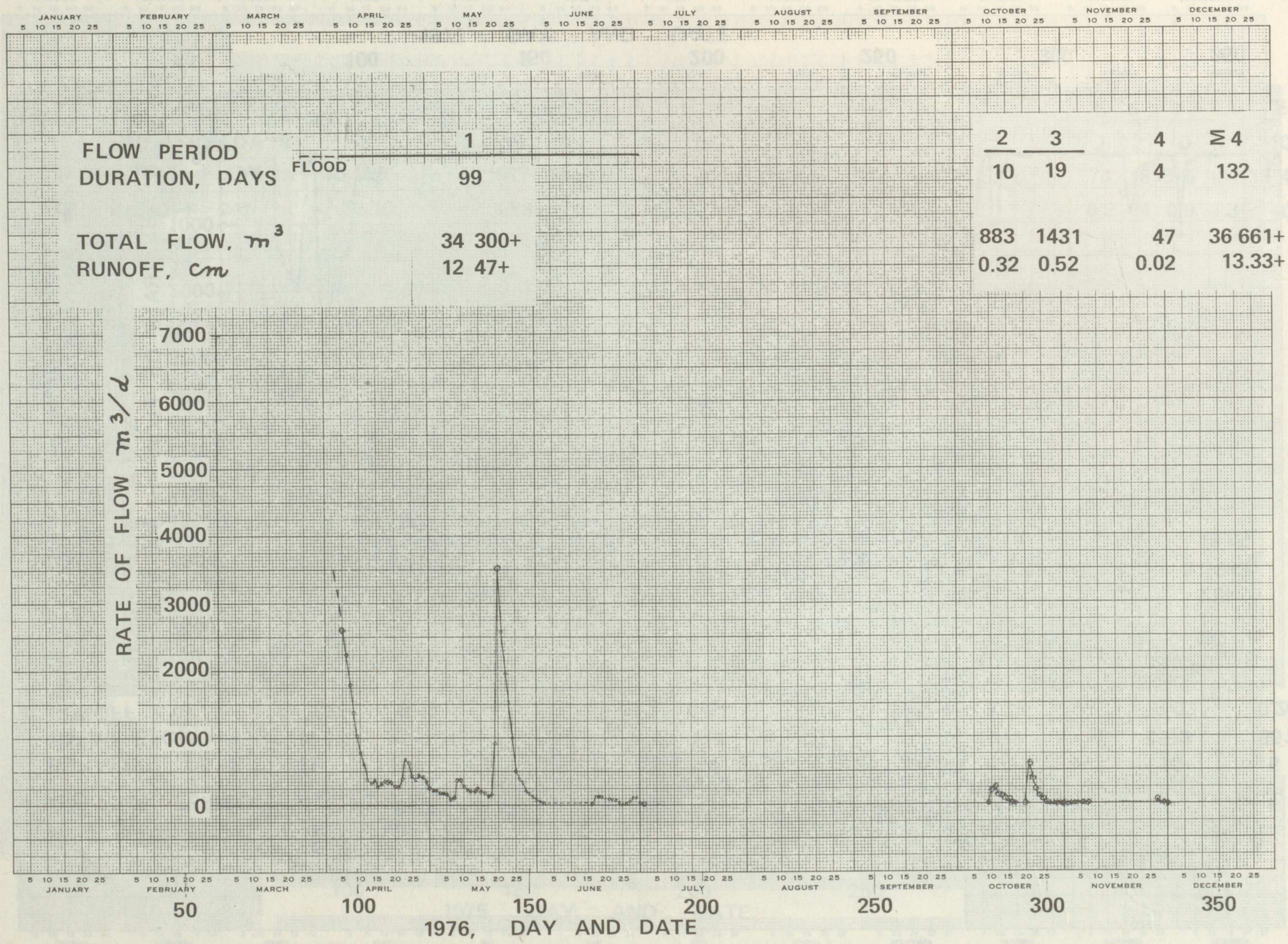

Figure 4b. Daily flow at Station F4 in 1976.

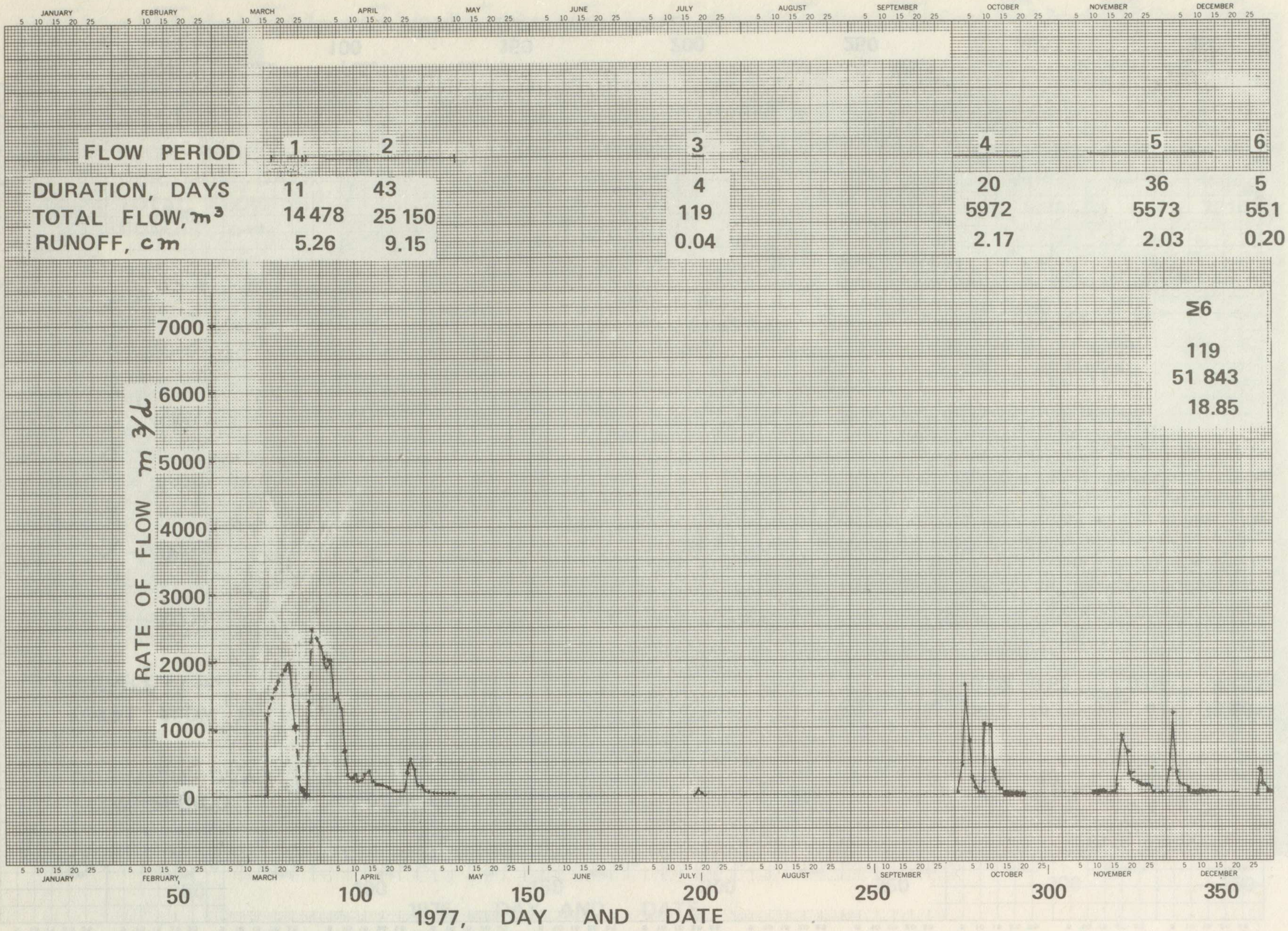

Figure 4c. Daily flow at Station F4 in 1977.

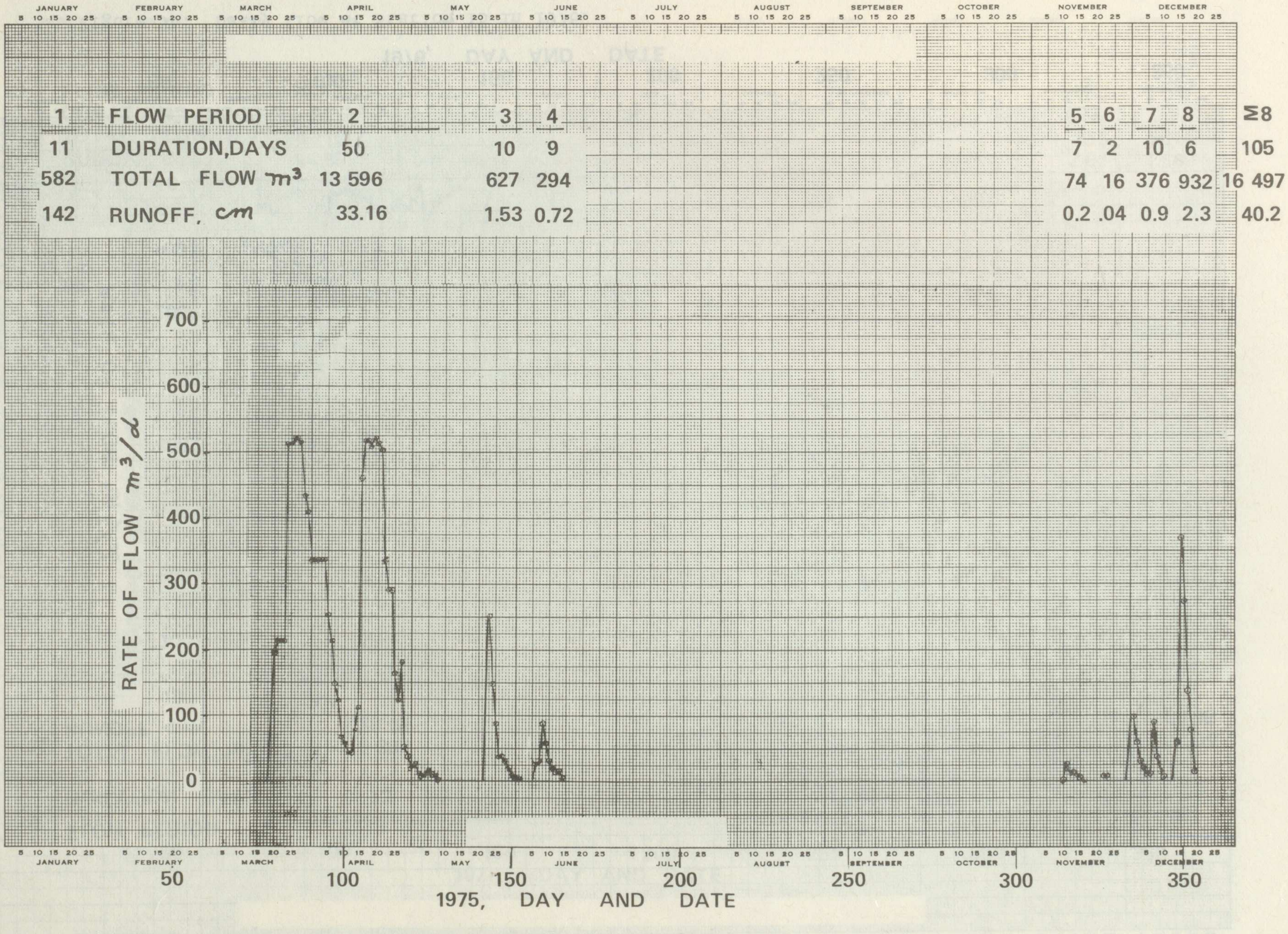

Figure 5a. Daily flow at Station 15 in 1975.

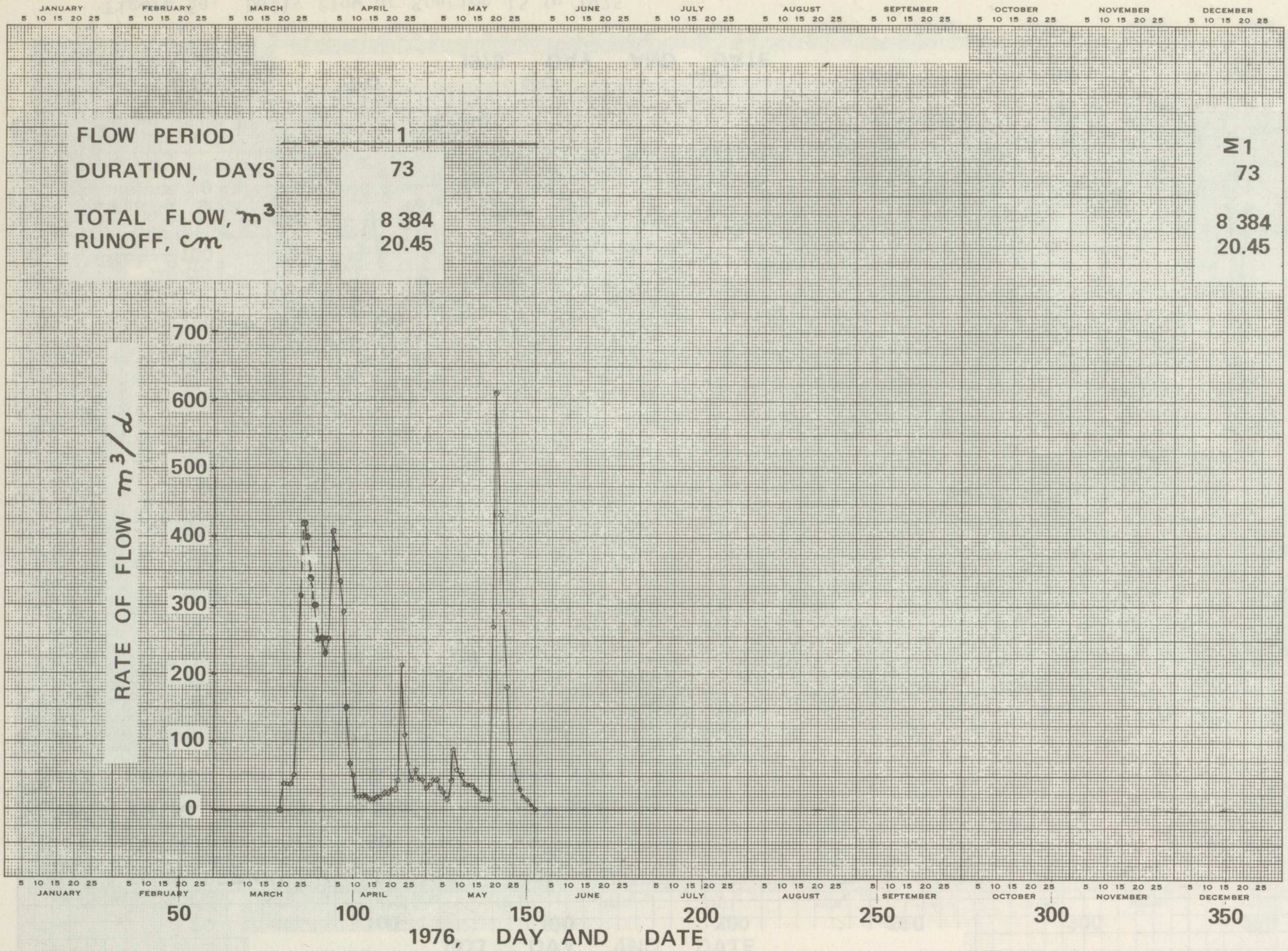

Figure 5b. Daily flow at Station 15 in 1976.

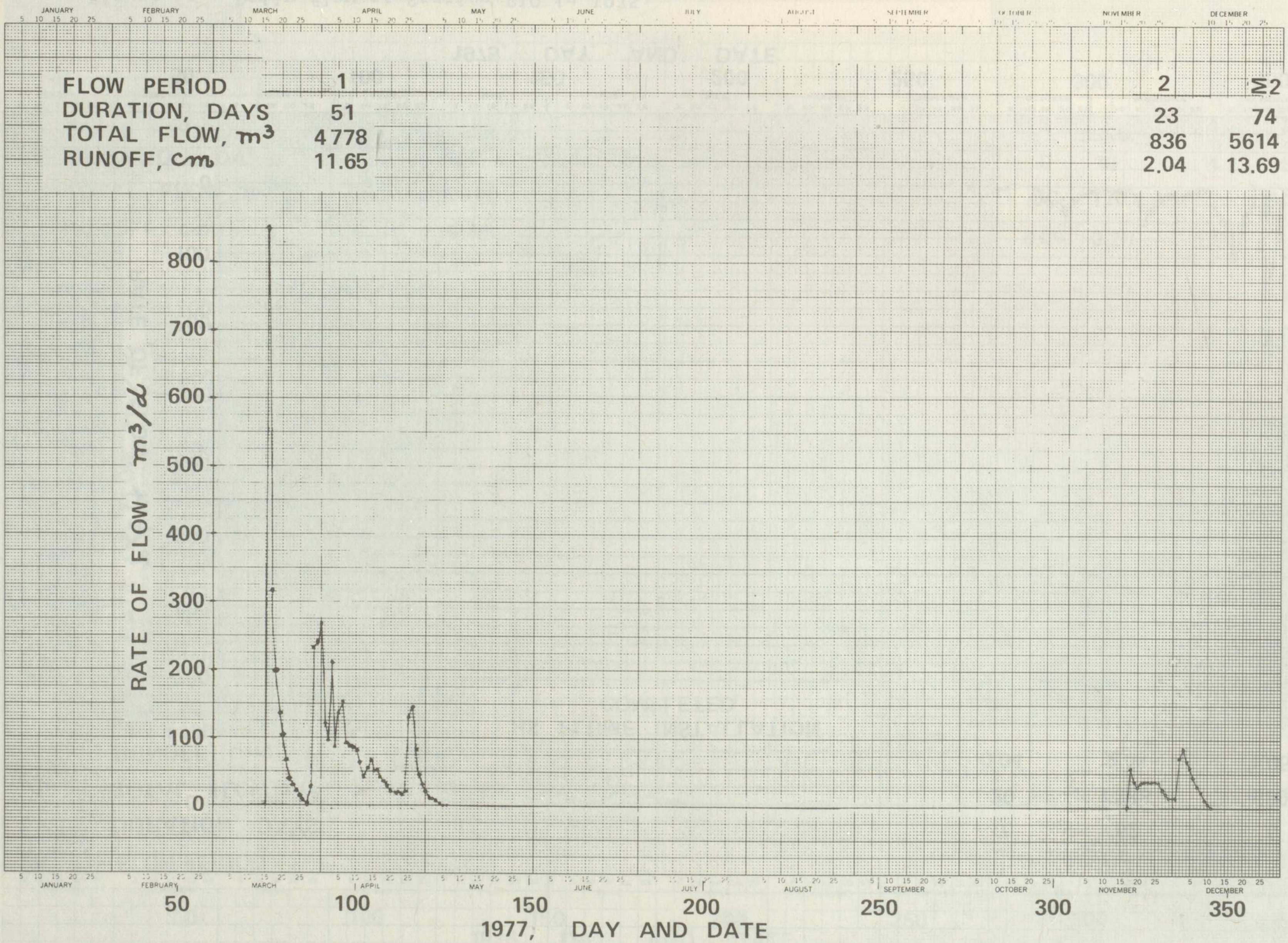

Figure 5c. Daily flow at Station 15 in 1977.

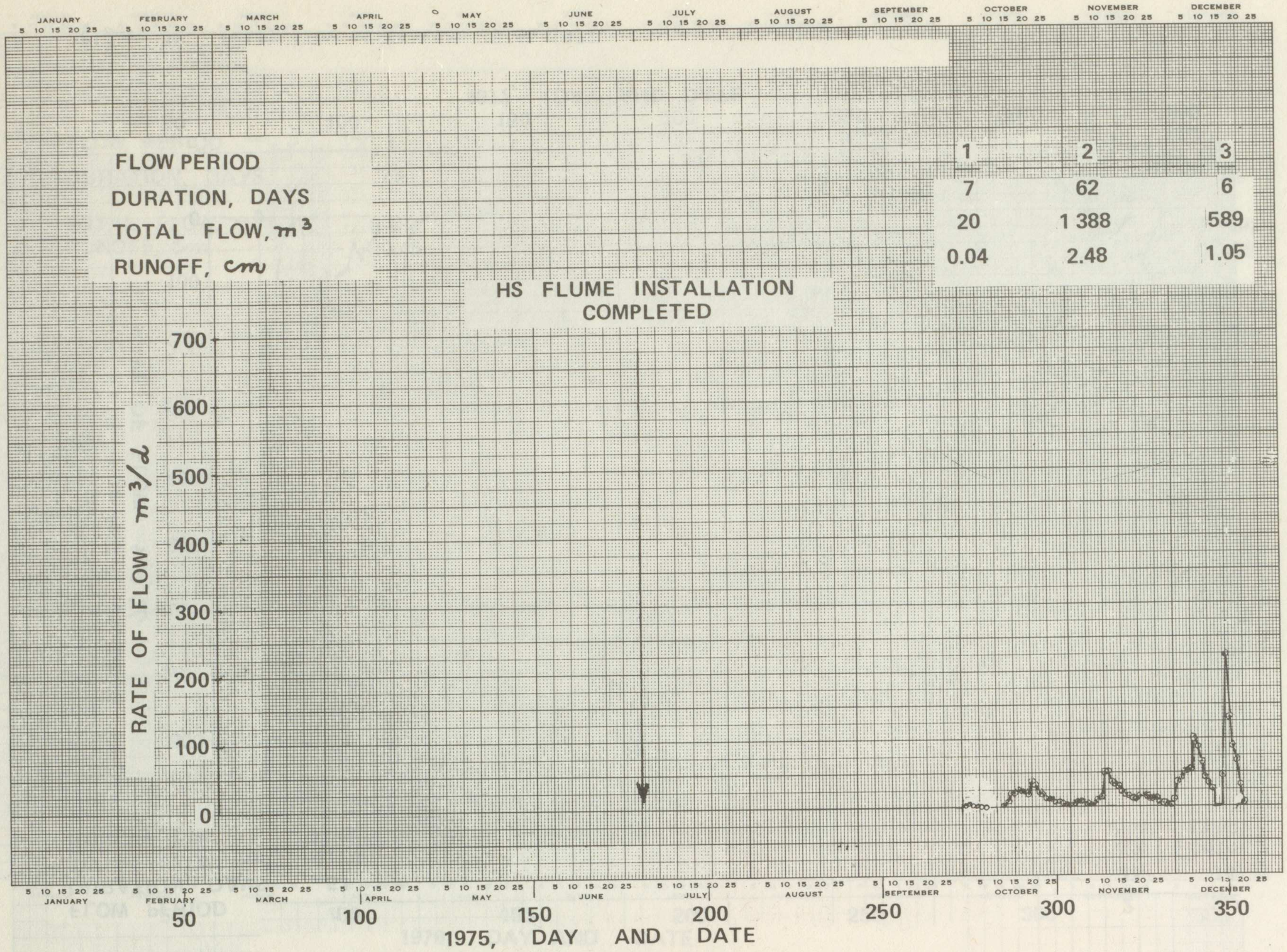

Figure 6a. Daily flow at Station F10 in 1975.

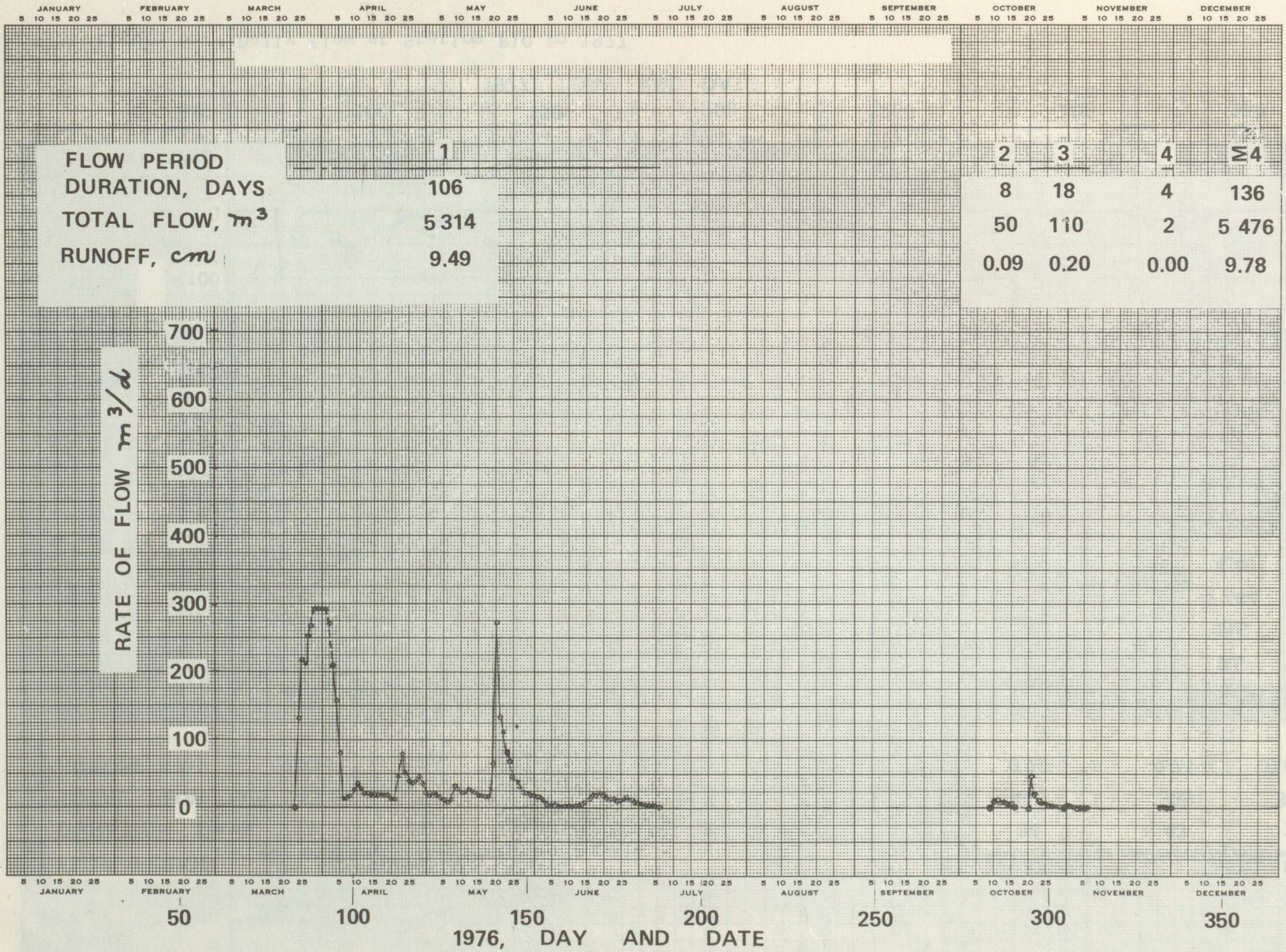

Figure 6b. Daily flow at Station F10 in 1976.

Dr. Tennant and Mr. Toxopeus at the National Capital Region Laboratories of the Environmental Protection Service. Their results are reported in the next section.

Surface water:

Flows: Most of the annual flow occurred in the initial few weeks of spring. Considerable variation in the flow rate was sometimes observed between the morning and afternoon flows during the high flow periods. A typical flow hydrograph is shown in Figure 7 for Station 6 in 1976.

Stream water quality: Results on the physical and chemical quality of stream water from April 1975 to August 1977 are given in Appendix Table A6. Results of the bacteriological quality in 1975 are given in Appendix Table A7. This Table includes data from two Stations, 5 and 9, which are located in the essentially non-manured area drained by the Baker Creek (Figure 2).

Land use practice: Most of the cropped area in the land drained by Black Rapids Creek and its tributary is normally under a 3 to 5 year rotation of corn and mixed legume-grass, with some fields in small grain. Table 2 shows the land use practice during the three-year experimental period.

Nutrient applications: Fertilizer and manure applications in the drainage area during the experimental period are given in Appendix Table A8. Typical fertilizer applications appropriate for the crop were made each year except for some fields under corn which received manure applications only. The volume of manure incorporated into land was 16,800 m^3 in 1975, 21,300 m^3 in 1976 and 22,200 m^3 in 1977. The average dry matter content of the manure was 8.5 percent. Of the total volume of manure incorporated, about 65% originated from dairy cattle, 30% from sheep and 5% or less from poultry. No manure was incorporated into the land drained by Station 3 during the experimental period.

Pollutant and nutrient transport to streams: Flows at stream stations and concentrations of various parameters were used to determine total transport of pollutants and nutrients at each station. For a given day, the total input at the inlet stations and the total output at the outlet stations were used to determine the net transport of pollutants to the drainage water. Since all the data for all the stations were not available on some days, estimated values based on partially available data were sometimes used. Values for total input and total output for the days without any sample collection and flow measurement were calculated by interpolation from graphs for daily total inputs and outputs. Total transports in the inlet and outlet water of the drainage area, and the net contribution to drainage water from the cropping activity are shown in Table A9.

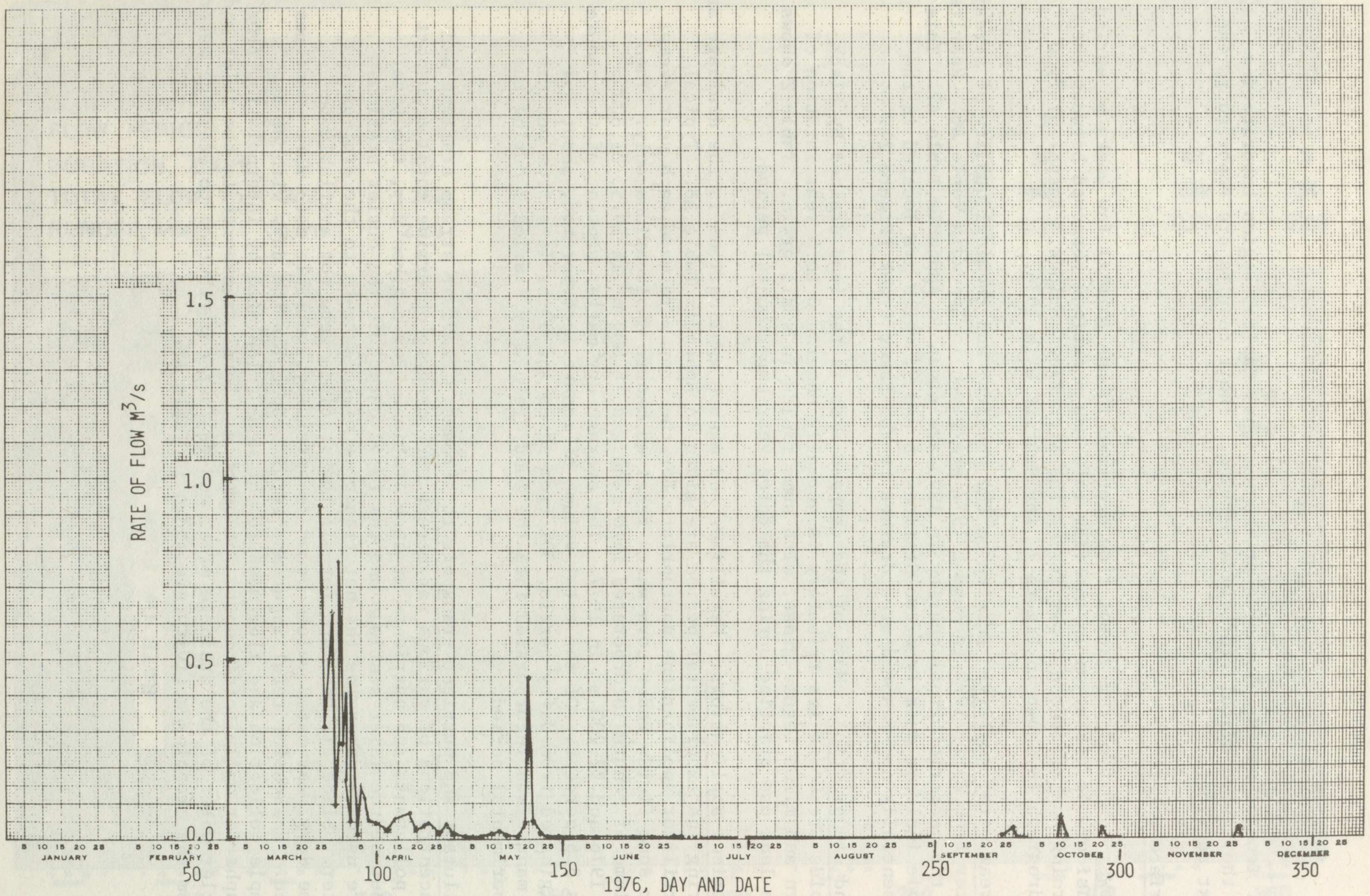

Figure 7. Daily flow at Station 6 in 1976.

TABLE 2

PERCENT OF THE 569 HA CULTIVATED AREA UNDER DIFFERENT CROP TYPES AT THE SURFACE WATER STUDY SITE

Year	Corn	Legumes	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

DATA INTERPRETATION AND CONCLUSIONS

Subsurface water:

Flows: An examination of Figures 4 and 5 indicates that the number of flow periods per year and the duration of each flow period are not comparable in the two fields with the same soil type and tile drainage system. Comparison with Figure 6 shows that the tile drainage per unit area is less in the sandy field, Station F10, compared to the clay fields, as would be expected.

An analysis of tile flow data is presented in Tables 3a, b, and c. Tile flow data for the year 1976 in Table 3a shows that more than 90% of the annual tile flow occurred during the spring runoff. Tile drainage runoff as a fraction of the total annual precipitation was only about one-fifth and one-tenth respectively for the fine-textured soil and the coarse-textured soil. Data for the small clay field for 1975, Figure 5a, showed that while more than 90% of the annual tile flow occurred in winter and spring runoff, the tile drainage runoff as a fraction of the total annual precipitation was about two-fifths (402 mm runoff, 990 mm annual precipitation).

Peak flows recorded on the same date at the three fields are compared in Table 3b. The small clay field (Station 15) had 0.8 to 2.2 times the runoff per unit area than that recorded for the large clay field (Station F4) On five out of six such occasions, however, the runoff from the small clay field exceeded the runoff from the large clay field. The small clay field (Station 15) had runoffs 2.0 to 4.9 times the runoff from the sandy field (Station F10). On average, the small clay field (Station 15) had 1.4 times the runoff from the large clay field (Station F4) and 3.3 times the runoff from the sandy field (Station F10).

Runoff caused by rainfall-induced peak flow events lasting for a few days are compared for the three fields in Table 3c. The small clay field had 1.1 to 1.8 times the runoff per unit area compared to the large clay field and 2.1 to 3.8 times the runoff compared to the sandy field. On average, the small clay field (Station 15) had runoff values that were 1.2 times the large clay field (Station F4) and 2.6 times the sandy field (Station F10).

Water quality: Examination of data in Table A1 reveals that the values for most parameters were comparable in all fields including the non-manured, chemically-fertilized field (Station 13) except that tile water from the coarse-textured soil field (Station F10) had considerably higher values for specific conductivity, total solids, nitrate nitrogen and potassium but lower

TABLE 3a

SUMMARY OF TILE FLOW DATA, 1976

ARI Greenbelt Farm, Ottawa

Station and drainage area, ha	Flow period number	Dates of flow 1976	No. of days of flow	Runoff cm	Runoff % Annual flow	Runoff % Annual precipitation[a]
F4	1	3/25: 7/ 1	99	12.47[b]	93.5[b]	13.3[b]
27.5 ha clay loam	2	10/ 9:10/18	10	0.32	2.4	0.3
	3	10/20:11/ 7	19	0.52	3.9	0.5
	4	11/27:11/30	4	0.02	0.2	0.0
	Total		132	13.33[b]	100.0[b]	14.2[b]
15	1	3/19: 5/30	73	20.45	100.0	21.8
4.1 ha clay loam	Total		73	20.45	100.0	21.8
F10	1	3/23: 7/ 6	106	9.49	97.0	10.1
5.6 ha sandy loam	2	10/ 9:10/16	8	0.09	0.9	0.1
	3	10/20:11/ 6	18	0.20	2.0	0.2
	4	11/27:11/30	4	0.00	0.0	0.0
	Total		136	9.78	100.0	10.5

[a]Annual precipitation - Jan. 1 to Dec. 31: 935 mm.

[b]Excludes runoff which could not be estimated during period of flooding.

TABLE 3b

COMPARISON OF SINGLE-DAY PEAK FLOWS IN TILE-DRAINED FIELDS

ARI Greenbelt Farm, Ottawa

Year	Date of peak flow	F4 (27.5 ha, clay loam)	15 (4.1 ha, clay loam)	F10 (5.6 ha, sandy loam)	15/F4	15/F10	F4/F10
		Tile stations (drainage areas) runoff, cm			Runoff ratios		
1975	Dec. 15	1.10	0.90	0.40	0.82	2.25	2.75
1976	Apr. 23	0.24	0.52	0.14	2.17	3.71	1.71
	May 8	0.13	0.21	0.055	1.62	3.82	2.36
	May 20	1.28	1.49	0.49	1.16	3.04	2.61
	Oct. 11	0.092	-	0.020	-	-	4.60
	Oct. 21	0.22	-	0.088	-	-	2.50
1977	Apr. 14	0.14	0.16	0.081	1.14	1.98	1.73
	Apr. 26	0.20	0.35	0.071	1.75	4.93	2.82

TABLE 3c

COMPARISON OF "PEAK" FLOW EVENTS IN TILE-DRAINED FIELDS

ARI Greenbelt Farm, Ottawa

Year	Peak flow event dates (inclusive)	Tile stations (drainage areas) F4 (27.5 ha, clay loam)	15 (4.1 ha, clay loam)	F10 (5.6 ha, sandy loam)	Runoff ratios 15/F4	15/F10	F4/F10
		runoff, cm					
1975	Dec.14 to 20	2.14	2.27	1.05	1.06	2.16	2.04
1976	Apr.21 to 30	1.53	1.68	0.73	1.10	2.30	2.10
	May 6 to 18	0.97	1.12	0.46	1.15	2.43	2.11
	May 19 to 30	4.48	5.04	1.63	1.13	3.09	2.75
	Oct. 9 to 17	0.32	-	0.09	-	-	3.56
	Oct.20 to 30	0.51	-	0.18	-	-	2.83
1977	Apr.12 to 17	0.61	0.77	0.36	1.26	2.14	1.69
	Apr.24 to May 1	0.69	1.21	0.32	1.75	3.78	2.16

values for total Kjeldahl nitrogen. As the manured fields were given the same cropping treatment in 1975, 1976 and 1977, the observed difference has to be attributed to the history of nutrient applications on these fields prior to the start of the experiment and to the type of soil. Figures 8a, b and c show the annual application rates of nitrogen, phosphorus and potassium respectively in the four experimental fields from 1971 to 1977 inclusive, and the 1975-1977 annual mean concentrations of these elements in the tile drainage water. The sandy field drained by Station F10 had a history of high manure application rates prior to the start of the experiment. This field has been an experimental "disposal" field for manure. The higher values for the parameters mentioned above for Station F10 are undoubtedly attributable to excessively high applications of manure in this field. Phosphorus concentrations do not appear to be affected by manure application rates. Low concentrations of total Kjeldahl nitrogen in water at Station F10 would be due to sandy soil which tends to be more aerobic compared to clay soils and hence more subject to mineralization.

Although standards and objectives do not exist for tile drainage water quality, it is desirable that tile water draining agricultural fields should not be excessively polluted. Appendix Table A10 lists the Canadian objectives and standards for public water supplies for the parameters of concern that were also studied in this work. Results in Tables A1 and A2 indicate that with one exception, manure application rates of about 500 kg N/ha/yr split between spring and fall applications for three successive years on corn fields, did not lead to excessive or unacceptable deterioration of physical or chemical quality of tile drainage water. The exception is nitrate nitrogen, the high concentration of which was undoubtedly related to the prior history of high manure application rates. This may be observed in Figure 8a. In the case of Station F4, the mean nitrate nitrogen concentration increased from 1.6 mg/l in 1975 to 3.6 mg/l in 1976 and to 5.1 mg/l in 1977. The mean concentration after three years was well below the permissible limit. Continued manure applications at comparable rates would eventually lead to concentrations in excess of this limit. It may be noted that the permissible limit is based on nitrogen concentration in nitrate plus nitrite. However nitrite nitrogen concentration in surface and ground waters is normally much below 0.1 mg/l and seldom exceeds 1 mg/l even in sewage-treatment-plant effluents[4], and therefore, nitrite nitrogen has not been considered in this study. Concentrations of nitrate nitrogen exceeding 10 mg/l at Station 15 could be explained by the prior (1973 and 1974) high manure application rates of 720 kg N/ha/yr (Figure 8a), and by the low removal of nitrogen by the winter rye and sorghum sudan crops planted in those years (Table 1). However, it should also be noted that the annual mean concentrations of nitrate nitrogen in tile water from the chemically fertilized field (Station 13), with considerably lower rates of nitrogen application (Figure 8a), are comparable to nitrate nitrogen concentrations in water at Station 15.

Bacteriological quality results for tile drainage water, shown in Table A3, indicated very low geometric mean and median values for all test parameters, at both the fine- and coarse-textured soil fields, which easily meet recreational water quality objectives. Also, the fecal coliform and fecal streptococci counts in water from manured fields were quite comparable to the counts in water from the non-manured, chemically fertilized field

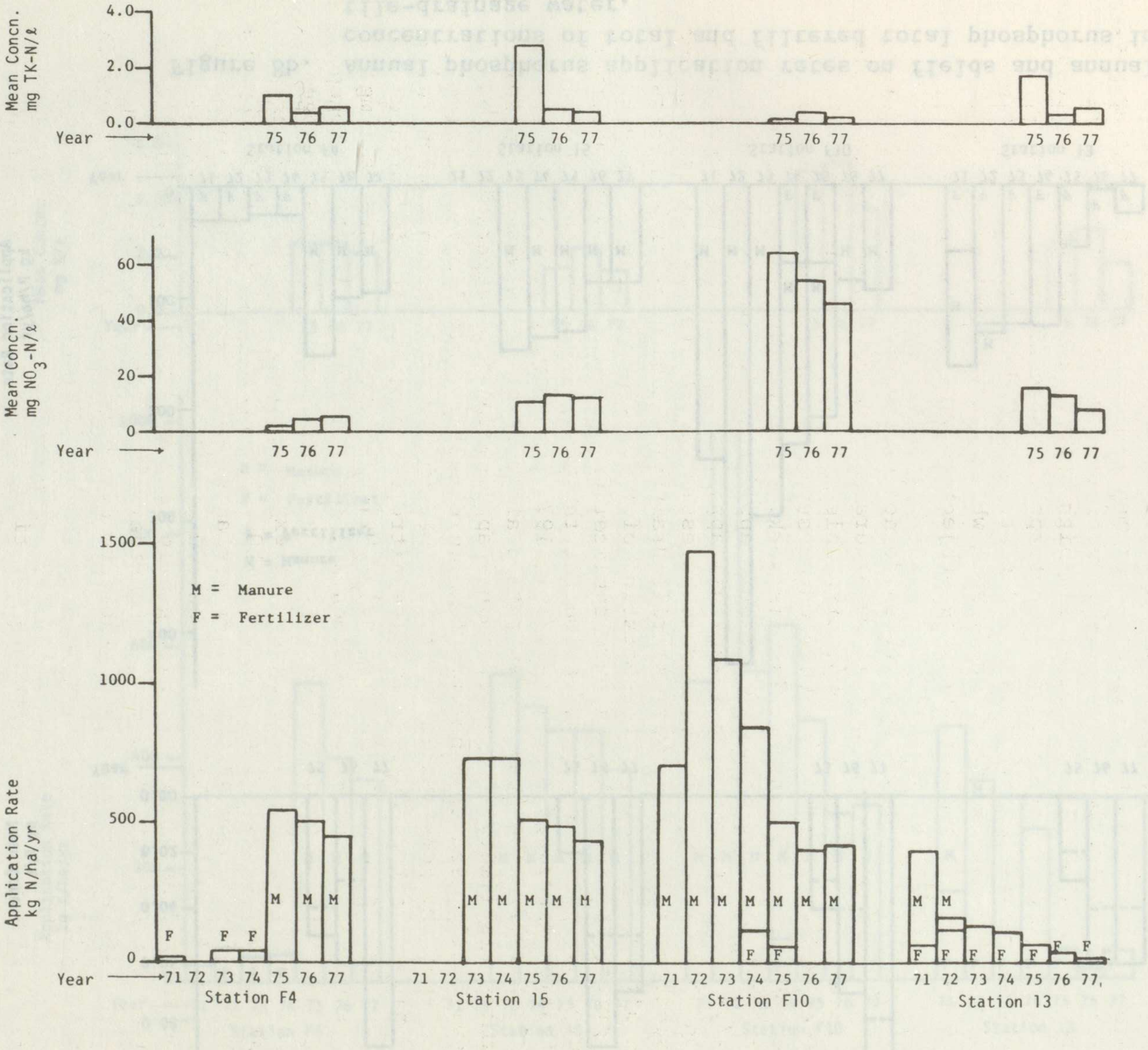

Figure 8a. Annual nitrogen application rates on fields and annual mean concentrations of nitrate and total Kjeldahl nitrogen in tile-drainage water.

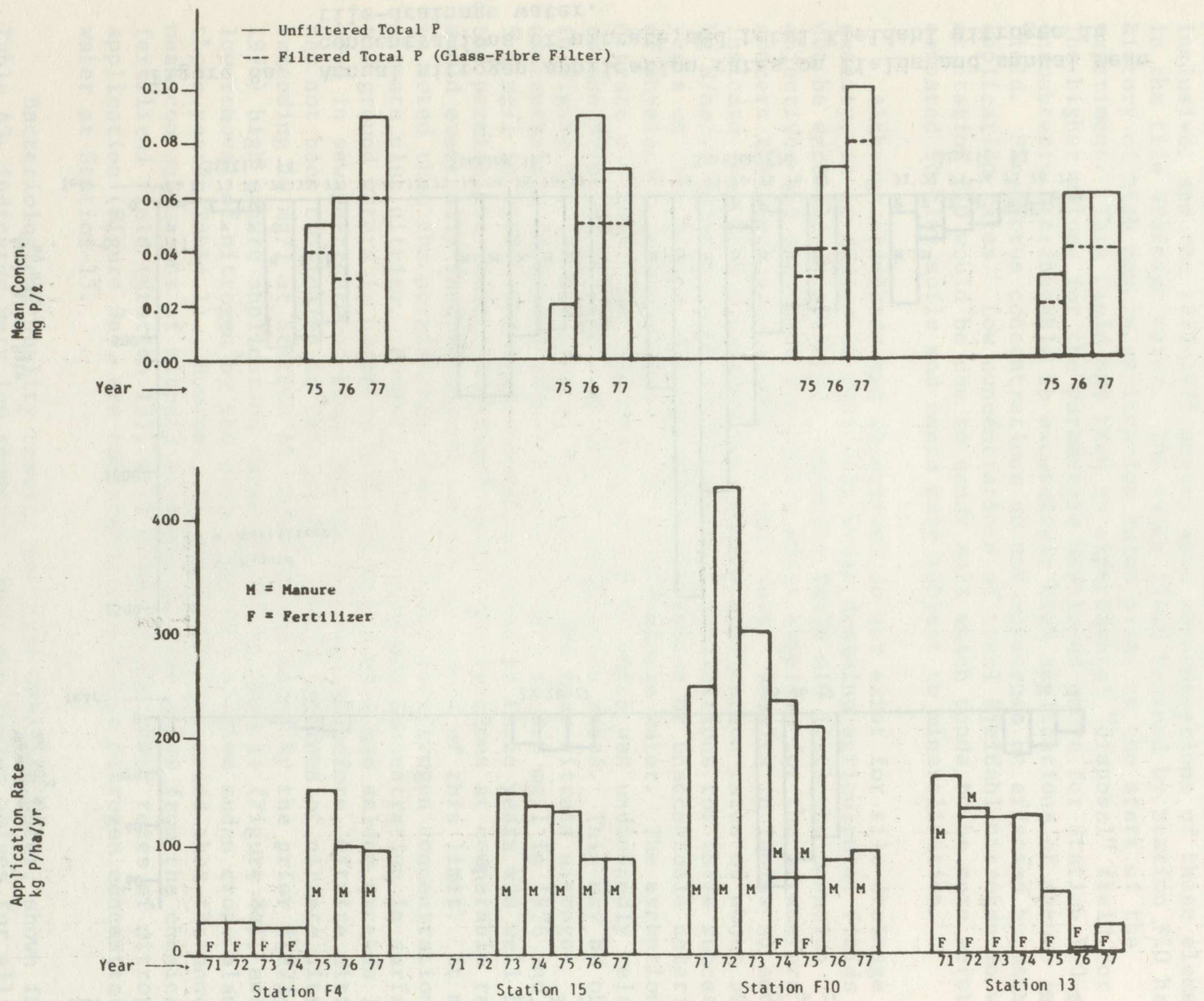

Figure 8b. Annual phosphorus application rates on fields and annual mean concentrations of total and filtered total phosphorus in tile-drainage water.

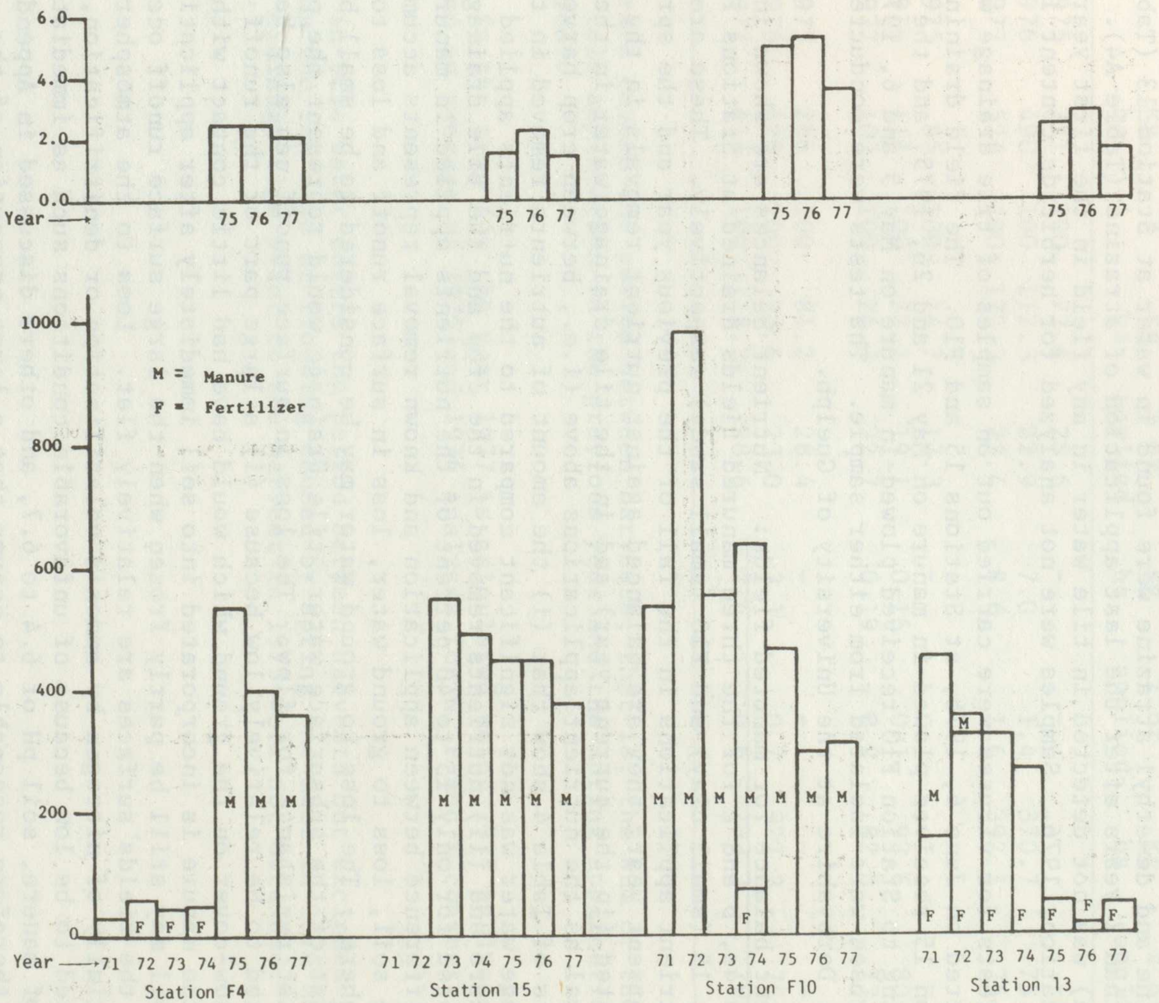

Figure 8c. Annual potassium application rates on fields and annual mean concentrations of potassium in tile-drainage water.

(Station 13). Increased bacterial concentrations were observed at all stations following heavy rainfall events.

Concentrations of atrazine and de-ethyl atrazine were found to be generally low in the tile drainage water (Table A5). Concentrations were higher in the sandy field, Station F10, to which atrazine was applied every year from 1972 to 1976 inclusive, compared to concentrations at the other two manured fields to which atrazine was applied in 1975 and 1976 only. Atrazine and de-ethyl atrazine were found in water at Station 13 (Table A5) more than 2 years after the last application of atrazine (Table A4). Butylate (Sutan) was not detected in tile water in any field in the first year of application, 1976. Samples were not analyzed for herbicide content in 1977.

Tests for viruses were carried out on samples of tile drainage water collected on June 6, 1975, at Stations 15 and F10. The field draining to Station 15 received plowed-in manure on May 21 and 26, 1975, and the field draining to Station F10 received plowed-in manure on May 5 and 6, 1975. No viruses were isolated from either sample. The tests were conducted by Dr. Derbyshire at the University of Guelph.

Nutrient balance for manured fields: Nutrient balances are shown in Tables 4a, b and c for the three manured fields drained at Stations F4 (large clay), 15 (small clay) and F10 (small sandy) respectively. These are based on nutrient applications in the fall of the previous year and the spring of the current year; they are balanced against nutrient removals in the crop harvested (in the current year) and in the tile drainage water in the same interval as the nutrient applications above (i.e., between crop harvests). Results of Table 4 show that (i) the amount of nutrients removed in tile drainage water was not significant compared to the nutrients applied in manure and (ii) nutrients removed in the crop and the tile drainage water accounted for only 15 to 40 percent of the nutrients applied in manure. The difference between application and known removal represents accumulation in the soil, loss to ground water, loss in surface runoff and loss to the atmosphere. The loss to ground water may be considered to be small because for most of the subsurface water, tile drainage would represent the path of least resistance for flow. The loss in surface runoff can also be expected to be relatively low because (i) a large part of the runoff is from the snow-cover on the ground which would have had little contact with soil; (ii) the manure is incorporated into soil immediately after application and the soil may still be partly frozen when the large surface runoff occurs; (iii) the fields' surfaces are relatively flat. Loss to the atmosphere, essentially of nitrogen by ammonia volatilization or denitrification, is expected to be low because of unfavorable conditions such as immediate plow-down of manure, soil pH of 6.4 to 6.7, and others discussed in Appendix IV. It is therefore reasonable to assume that a large proportion of the nutrients applied in manure remained in the soil. Over a period of time, accumulation of nutrients would lead to increased concentrations in tile drainage water due to leaching of soluble and mobile nutrients. This was observed in the case of tile drainage water from Station F10 as discussed earlier.

Results of Table 4 show that nutrient transports to tile drainage water were not comparable in the three fields although they were of the same

TABLE 4a

NUTRIENT BALANCE FOR MANURED FIELD DRAINED AT STATION F4

ARI Greenbelt Farm, Ottawa

Drainage area: 27.5 ha, clay loam soil

Nutrient element	Year	Application rate[a]		Removal rate in crop[b]		Removal rate in tile water[c]		Unaccounted by difference	
		kg/ha	%	kg/ha	% of applied	kg/ha	% of applied	kg/ha	% of applied
Nitrogen	1975	271	100	77.4	28.6	-	-	-	-
	1976	490	100	112.3	22.9	7.0	1.4	370.7	75.7
	1977	523	100	122.3	23.4	8.6	1.6	392.1	75.0
Phosphorus	1975	85	100	14.7	17.3	-	-	-	-
	1976	116	100	22.2	19.1	0.16	0.1	93.6	80.7
	1977	107	100	24.3	22.7	0.19	0.2	82.5	77.1
Potassium	1975	286	100	81.2	28.4	-	-	-	-
	1976	429	100	98.6	23.0	3.1	0.7	327.3	76.3
	1977	414	100	118.3	28.6	2.4	0.6	293.3	70.8

[a] Application rate covers the period between harvests, that is, the sum of the post-harvest fall application in the previous year and the spring application in the current year.

[b] Removal rate in the crop for the year 1977 is calculated using 1977 analyses for dry matter and an average of 1975 and 1976 analyses for N, P and K content in dry matter.

[c] Removal rate in tile water covers the period between harvests but excludes possible removal during the few days of flooding caused by spring snowmelt in 1976 and 1977. Data on tile drainage flow prior to the harvest in 1975 were not obtained.

TABLE 4b

NUTRIENT BALANCE FOR MANURED FIELD DRAINED AT STATION 15

ARI Greenbelt Farm, Ottawa

Drainage area: 4.1 ha, clay loam soil

Nutrient element	Year	Application rate[a] kg/ha	Application rate[a] %	Removal rate in crop[b] kg/ha	Removal rate in crop[b] % of applied	Removal rate in tile water[c] kg/ha	Removal rate in tile water[c] % of applied	Unaccounted by difference kg/ha	Unaccounted by difference % of applied
Nitrogen	1975	625	100	121.4	19.4	53.2	8.5	450.4	72.1
	1976	530	100	105.6	19.9	34.4	6.5	390.0	73.6
	1977	478	100	114.8	24.0	15.0	3.1	348.2	72.8
Phosphorus	1975	135	100	19.7	14.6	0.08	0.1	115.2	85.3
	1976	126	100	18.6	14.8	0.37	0.3	107.0	84.9
	1977	92	100	19.3	21.0	0.13	0.1	72.6	78.9
Potassium	1975	486	100	120.5	24.8	6.4	1.3	359.1	73.9
	1976	440	100	87.1	19.8	4.5	1.0	348.4	79.2
	1977	455	100	104.2	22.9	1.9	0.4	348.9	76.7

[a] Application rate covers the period between harvests, that is, the sum of the post-harvest fall application in the previous year and the spring application in the current year.

[b] Removal rate in the crop for the year 1977 is calculated using 1977 analyses for dry matter and an average of 1975 and 1976 analyses for N, P and K content in dry matter.

[c] Removal rate in tile water covers the period between harvests but excludes possible removal during the few days of flooding caused by spring snowmelt in 1976.

TABLE 4c

NUTRIENT BALANCE FOR MANURED FIELD DRAINED AT STATION F10

ARI Greenbelt Farm, Ottawa

Drainage area: 5.6 ha, sandy loam soil.

Nutrition element	Year	Application rate[a] kg/ha	Application rate[a] %	Removal rate in crop[b] kg/ha	Removal rate in crop[b] % of applied	Removal rate in tile water[c] kg/ha	Removal rate in tile water[c] % of applied	Unaccounted by difference kg/ha	Unaccounted by difference % of applied
Nitrogen	1975	732	100	139.4	19.0	-	-	-	-
	1976	448	100	134.4	30.0	36.4	8.1	277.2	61.9
	1977	446	100	136.5	30.6	15.9	3.6	293.6	65.8
Phosphorus	1975	255	100	23.9	9.4	-	-	-	-
	1976	106	100	25.1	23.7	0.08	0.1	80.8	76.2
	1977	102	100	24.4	23.9	0.06	0.1	77.5	76.0
Potassium	1975	585	100	131.5	22.5	-	-	-	-
	1976	391	100	145.6	37.2	4.4	1.1	241.0	61.6
	1977	333	100	138.5	41.6	1.2	0.4	193.3	58.0

[a] Application rate covers the period between harvests, that is, the sum of the post-harvest fall application in the previous year and the spring application in the current year. In 1975, 50 kg/ha of N and 70 kg/ha of P (as chemical fertilizer) were inadvertently applied with the planter.

[b] Removal rate in the crop for the year 1977 is calculated using 1977 analyses for dry matter and an average of 1975 and 1976 analyses for N, P and K content in dry matter.

[c] Removal rate in tile water covers the period between harvests but excludes possible removal during the few days of flooding caused by spring snowmelt in 1976 and 1977. Data on tile drainage flow prior to the harvest in 1975 were not obtained.

order of magnitude. This would be due to the variations in flows and differences in prior history of nutrient application rates.

Herbicide removal: Table 5 shows the herbicide applications in the fields and removal in tile drainage water. The results demonstrate that an insignificant amount of atrazine was lost to the tile drainage water compared to the amounts applied.

Bacteriological examination of manure and soil: The results of the bacteriological examination of manure applied to the fields and the soil from the same fields have been reported by Toxopeus et al.[5] These tests were carried out in 1975 only.

Spring-applied winter-stored manure, derived from storage tanks had fecal coliform MF counts ranging from 1,200 to 52,000 per gram with a median value close to 10,000 per gram in the 22 samples examined. These numbers are considerably lower than for fresh feces. Fifty-five samples from fall-applied trench manure (consisting of a mixture of recently stored manure and relatively fresh excrement) had a fecal coliform MF count ranging from 34,000 to 3,100,000 with a central tendency near 1,000,000 per gram. The bacterial counts for the other four test parameters also showed a wide variation. Tank-stored liquid manure was characterized by low fecal coliform:fecal streptococcus ratios. Tank manure applied to the large clay field (Station F4) in the spring had a geometric mean FC:FS ratio of only 0.5. Combined trench and tank manure ratios for fall-applied manure on the same field had a geometric mean of 1.2, and individual samples had ratios as high as 8.2 Fall-applied trench manure at the small clay field (Station 15) had a geometric mean FC:FS ratios of 1.95 with a maximum ratio of 4.4 These inconsistencies in the bacterial content of liquid manure made it virtually impossible to derive any precise estimate of mean bacterial application to soil, particularly on a large field-scale study.

Soil samples at three depth levels were tested for each of the five test parameters and after manure plowdown in the fields in spring and fall in order to get information on soil bacterial content and its relationship to contribution of bacteria in manure to subsurface waters. A total of 302 soil samples were collected from the three fields at upper, middle and lower levels which were respectively 5 to 10, 15 to 30 and 25 to 45 cm below the soil surface.

The data for the two study periods, for each of the three soil depths, and for each of the five test parameters, were subjected to linear regression analysis; counts for each parameter were entered as log numbers for y, with time in days as x, in the general equation $y = mx + b$. The slope values (m) and the y values (in counts per gram) for each parameter at 0-day and 100-day times were calculated from the best-fit lines. Minor and major changes in the slope values were used to determine bacteriologically significant changes. The analysis indicated that total coliform numbers tended to increase probably because of in situ multiplication in response to nutrients added with manure. Conversely, fecal coliform and fecal streptococcus numbers tended to decrease; end-point counts tended to be below detectable levels. This observation demonstrates the unsuitability of total coliforms as pollution-index tracer organisms. Standard Plate Counts tended to remain static or to increase slightly during the soil study periods. Particularly during the

TABLE 5

HERBICIDE APPLICATION ON FIELDS AND REMOVAL IN TILE DRAINAGE WATER

A.R.I. Greenbelt Farm, Ottawa.

Field Station	Atrazine[a] application Date	Amount, g	Herbicide removal in tile water Period, Dates	Atrazine, g	de-ethyl atrazine, g
F4	10-6-75	38,600	1-7-75 to 31-5-76	2.09	b
clay loam			3-76 to 31-5-76		5.38
	1-6-76	30,900	1-6-76 to 31-12-76	0.19	0.38
15	10-6-75	5,730	10-6-75 to 1-6-76	0.88	b
clay loam			3-76 to 1-6-76		1.68
	2-6-76	4,580	2-6-76 to 31-12-76	0.0	0.0
F10	28-5-75	7,820	1-7-75 to 1-6-76	3.08	b
sandy			3-76 to 1-6-76		6.30
loam	2-6-76	6,260	2-6-76 to 31-12-76	0.20	0.32

a - technical grade, minimum 94% pure atrazine.

b - tile drainage water was not analyzed for de-ethyl atrazine in 1975.

summer, the slope data indicated a significant die-off of fecal coliforms and fecal streptococci which could not be verified in subsurface water because of lack of flow. In general, bacterial counts tended to be lower in soil samples collected during the summer period, probably because of the application of relatively low-count long-stored tank manure in spring. There was also a trend to lower bacterial numbers (all parameters) with increasing sample depth (in soil).

Surface water:

Physical and chemical quality: Results given in Table A6 show that the mean and median values of parameters in the water leaving the drainage area at Stations 2 and 3 were well within the standards and objectives for raw surface water supplies listed in Table A10. The mean and median values for the water leaving the watershed were generally either comparable to or a little above the mean and median values for the water entering the watershed at the inlet Stations 6, 7, 8 and DOT. For all stations, increased scatter in values for all parameters was observed during the snowmelt runoff period.

Drainage water at Station 3 was from an area which was subjected to normal cropping operation, and to which no manure was applied since 1974, whereas water at Station 2 was from an area which received substantial manure applications in addition to normal recommended fertilizer applications for the crops planted. Dissolved oxygen values indicated that contribution of readily biodegradable material from manuring activity was not great. Slight increase in the specific conductivity of the water leaving the drainage area indicated some contribution of dissolved ionic material to the drainage water. Results for total, suspended and volatile suspended solids (total, nonfiltrable and volatile nonfiltrable residue) again indicated some contribution from the cropping activity. On the average, suspended solids constituted about 10 percent or less of the total solids at all stream stations, and about 40 percent of this suspended material was volatile. Concentrations of nitrate nitrogen were found to have the greatest relative increase over the inlet water concentrations compared to other chemical quality parameters. Filtered total phosphorus constituted about half the total phosphorus in the raw water samples at all the stations. Increased nutrient concentrations indicated some contribution from cropping activity, but again, the contribution was not excessive.

Bacteriological quality: Examination of stream water samples by Mr. H.R. Toxpeus and Dr. A. D. Tennant of Environment Canada showed (Table A7) that bacterial densities were comparable for water draining from heavily manured land (Station 2) and essentially non-manured land (Stations 3 and 5) within the Animal Research Institute Farm. This led to the conclusion that fecal indicator bacteria concentrations in drainage streams were not influenced by the manuring activity. The observed fecal indicator bacteria concentrations in stream water were attributed to the native and transient animal and bird population at the Farm. Low geometric mean and median values for fecal coliforms:fecal streptococci ratios indicated that the observed fecal bacteria were essentially from non-human sources. As in the case of tile drainage water, major increases in bacterial numbers were observed in water samples collected after significant rainfall events.

The reasonably good physical, chemical and bacteriological quality of the stream drainage water from the intensively manured and cropped 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 storage of manure during wet weather and winter, rotation of fields for manure applications, and manure applications away from stream banks.

Pollutant and nutrient transport to streams: The values given in Table A9 indicate that losses of upto 1000, 400, 24, 1 and 16 kg/ha/yr can be reached for total solids, suspended solids, nitrogen, phosphorus and potassium respectively, as calculated for 1976. Loss estimates for 1977 upto the end of August are considerably lower than the estimates for 1976 for the same period. It appears that flow pattern during heavy spring flows, which is dependent on ambient temperature and precipitation, influences pollutant and nutrient contributions to surface streams. The spring of 1976 was characterized by a rapid thaw resulting in very heavy flows and flooding. The spring of 1977 was characterized by a thaw followed by freeze-up, so that there were fewer days with very heavy flows. The results of Table A9 show that nutrient and pollutant losses to stream drainage water can be substantially different from year to year, and this appears to be influenced by conditions of flow.

The percentage of applied nutrients lost to stream water in the drainage area is shown in Table 6. The loss of applied phosphorus is quite low, but upto one-sixth of the nitrogen and potassium in the fertilizer and manure applied to the area could be lost to drainage water. The actual numbers shown in Table 6 could be slightly different when more refined calculations on loss to stream water are completed in the future but the conclusion would remain the same.

Calculation of annual transport as a product of the annual mean concentration and the annual total flow did not always give values close to those shown in Table A9 (e.g. suspended solids and total Kjeldahl in 1976). This is caused by the influence of very heavy flows for very few days on total transports. Caution is therefore advisable in the use of annual mean values to calculate annual total loadings.

TABLE 6

LOSS OF APPLIED NUTRIENTS TO SURFACE WATER IN THE BLACK RAPIDS CREEK DRAINAGE AREA

ARI Greenbelt Farm, Ottawa

Description		Year	Nutrient N	P	K
Application rate	kg/ha	1975	134	67	130
Loss to surface streams [a]	kg/ha		18.6	0.1	3.6
% of applied nutrient lost to surface water			13.9	0.2	2.8
Application rate	kg/ha	1976	154	42	116
Loss to surface streams	kg/ha		24.2	0.8	16.2
% of applied nutrient lost to surface water			15.7	1.9	14.0
Application rate	kg/ha	1977	128	46	120
Loss to surface streams [b]	kg/ha		8.2	0.6	6.6
% of applied nutrient lost to surface water			6.4	1.3	5.5

[a] After April 22, 1975

[b] Upto August 31, 1977

RELATIONSHIP OF RESULTS TO PLUARG OBJECTIVES

The effect of land incorporation of large quantities of manure on the quality of surface and subsurface drainage water in a large cropping operation has been established under certain conditions of management practices and study-site details. Annual unit area loadings to subsurface water from manured fields and to surface drainage water from a manured and fertilized cropping operation have been obtained. Conditions under which pollutant contributions to streams can increase have been discussed.

REFERENCES

1. International Reference Group on Pollution of the Great Lakes from Land Use Activities, "Detailed Study Plan to Assess Great Lakes Pollution from Land Use Activities", March 1974.

2. American Public Health Association, Washington, D.C., Standard Methods for the Examination of Water and Wastewater, 13th Edition, 1971.

3. U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D.C., Methods for Chemical Analysis of Water and Wastes, 1974.

4. Sawyer, C.N. and McCarty, P.L., Chemistry for Sanitary Engineers, McGraw Hill, 1967, p.429.

5. Toxopeus, H.R., Bastien, J.A.P., Beauchamp, M., Vandewint, J., and Tennant, A.D., "Bacteriological Data Summary, 1975, Pollutant Transport to Subsurface and Surface Waters in an Integrated Farm Operation, Animal Research Institute, Canada Department of Agriculture", December, 1975.

APPENDIX I

DESCRIPTION OF SOILS IN THE DRAINAGE AREA

Information on soils in the drainage area of this study was available from the Soil Research Institute (now the Land Resource Research Institute), Agriculture Canada and the Geography Division, Survey and Mapping Branch, Department of Energy, Mines and Resources, Ottawa. This information, published in 1976, is summarized below. Additional information on soil associations, engineering test data, cross-sectional diagrams and water table levels in the region are available from the above sources.

Figure A1 shows a soil map of the area. The dominant soil associations are Dalhousie, Manotick and Uplands. Details of these and others are as follows:

1. CASTOR: Medium to slightly acid, moderately coarse to medium-textured, marine and estuarine veneer (25 to 100 cm) overlying neutral, moderately fine to fine-textured marine material.

2. CHATEAUGUAY: Slightly acid to neutral, medium to moderately fine-textured modified marine veneer (25 to 100 cm) overlying mildly alkaline, moderately coarse-textured, stony glacial till.

3. DALHOUSIE: Neutral, fine-textured modified marine materials, interbedded with layers of silty sediments within 2 m of the surface.
   Parent material texture - silty clay, clay
   depth - > 2 m
   reaction- neutral, pH 6.6 - 7.3
   Surface texture - clay loam, loam
   Land form - level marine
   Surface expression - level to gently sloping; slopes 0-2%
   Soil drainage - poor
   Soil taxonomic components - Orthic Humic Gleysol (Brandon Series)

4. ERODED CHANNEL: Erroded gullies, steep valley walls and narrow creekbeds.

5. MANOTICK: Strongly acid, coarse-textured marine and estuarine veneer (25 to 100 cm) overlying neutral, moderately fine to fine-textured marine clay.

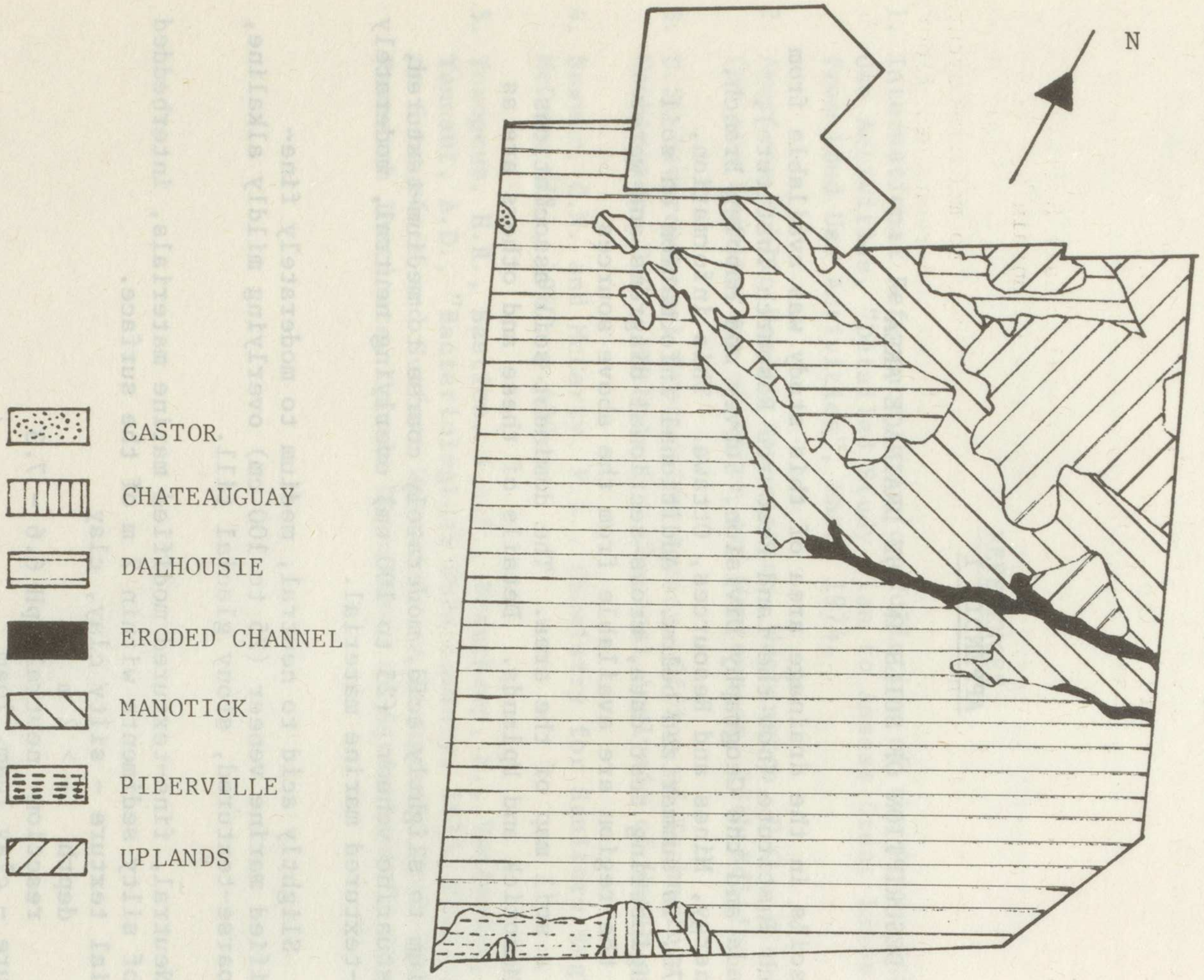

Figure A1. Soil map of the drainage area of Black Rapids Creek, within the Greenbelt Farm, Animal Research Institute, Ottawa.

Parent material texture - fine sand, loamy fine sand
depth - 25 to 100 cm to marine clay
reaction- strongly acid, pH 5.1 - 5.5
Surface texture - fine sandy loam, loamy fine sand
Land form - level marine and fluvial veneer over level marine
Surface expression - level to very gently sloping; slopes 0-2%
- very gently sloping to gently undulating; slopes 1-3%
Soil drainage - imperfect to poor
Soil taxonomic components - Orthic Humic Gleysol (Allendale Series)
- Gleyed Sombric Brunisol (Mountain Series)

6. PIPERVILLE: Slightly acid to neutral, moderately coarse to medium-textured marine and estuarine materials. Fluvium in abandoned river channel floors and terraces.

7. UPLANDS: Very strongly to strongly acid, coarse-textured (medium to fine sand), marine and estuarine materials. Fluvium in abandoned river channel floors and terraces.
Parent material texture - sand
depth - > 2 cm
reaction- very strong to strongly acid, pH 4.6 - 5.5
Surface texture - loamy sand, sandy loam
Land form - Undulating eolian, level to undulating marine and fluvial blanket
Surface expression - level to undulating; slopes 0-5%
Soil drainage - excessive to imperfect
Soil taxonomic components - Orthic Sombric Brunisol (Carlsbad Series), Gleyed Sombric Brunisol (Ramsayville Series), Orthic Humic Gleysol (St. Samuel Series)

APPENDIX II

ANALYTICAL METHODOLOGY

Field determinations:

Temperature: Determined with a mercury in glass thermometer.

pH: Determined using a Radiometer Model PHM29 portable pH meter with a Radiometer Combination Electrode.

Dissolved oxygen: Determined in situ with a YSI Model 51A portable dissolved oxygen meter.

Laboratory determinations:

Specific conductivity: Determined using a YSI Model 33 portable conductivity meter. Readings were adjusted to 25^{o}C. Specific conductivity measurements were made in the field in 1975.

Total solids: Determined by the method for Total Residue at 103-105^{o}C in Standard Methods (13th Ed.), p. 288.

Suspended solids: Determined by the method for Nonfiltrable Residue at 103-105^{o}C in Standard Methods (13th Ed.), p. 291. Sample was filtered through Reeve Angel 934AH glass fibre filter paper.

Volatile suspended solids: Determined as the difference between suspended solids above and fixed solids determined by the method for Fixed Residue in Standard Methods (13th Ed.), p. 292.

Nitrogen, ammonia: Determined using Orion Model 95-10 ammonia electrode according to U.S. E.P.A. Manual of Methods for Chemical Analysis of Water and Wastes (1974) and Orion Instruction Manual for ammonia electrode.

Nitrogen, total Kjeldahl: Determined using Orion ammonia electrode after manual digestion of sample according to Standard Methods (13th Ed.), p. 244.

Nitrogen, nitrate: Determined using Orion Model 93-07 nitrate specific ion electrode according to Standard Methods (14th Ed.), p. 422, and Orion Instruction Manual for nitrate electrode.

Total phosphorus: Determined by manual digestion of sample using persulfate followed by spectrophotometric determination in 1975 and 1976 (Beckman 25) or automated determination in 1977 (Technicon Autoanalyser II) after ascorbic acid reduction, according to the procedures described in U.S. E.P.A. Manual (1974), pp. 249-264.

Total phosphorus, filtered: Determined by the method used for total phosphorus, after filtration of the sample through a Reeve Angel 934AH glass fibre filter paper. Sample filtration was carried out in the laboratory on the day of collection or the following day.

Potassium: Determined using a Varian Techtron Model 1200 Atomic Absorption Spectrophotometer. U.S. E.P.A. Manual (1974), p. 143.

Bacteria: Determined according to Standard Methods, 13th Ed. (1971) and 14th Ed. (1976).

APPENDIX III

TABLES

TABLE A1

SUMMARY OF TILE DRAINAGE WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Temperature ^{o}C	F4	119	7.5	4.0	6.5	1.0	25.0
	15	119	5.3	3.0	5.0	0.0	15.0
	F10	121	7.0	4.2	6.5	0.5	16.5
	13	124	6.0	3.6	6.0	0.0	16.3
pH	F4	118	7.1	0.2	7.1	6.3	7.8
	15	118	7.1	0.3	7.0	6.4	8.0
	F10	115	7.0	0.2	7.0	6.3	7.7
	13	120	7.1	0.2	7.0	6.7	8.1
Specific conductivity micromhos per cm. @ $25^{o}C$	F4	123	552	106	577	292	738
	15	107	421	120	412	145	726
	F10	126	759	189	820	259	1016
	13	130	569	108	574	129	798
Total solids mg/1	F4	75	346	85	353	46	532
	15	71	284	96	278	40	611
	F10	86	527	158	551	190	788
	13	104	368	81	370	56	684
Suspended solids	F4	75	9	11	5	0	51
	15	72	10	9	7	0	33
	F10	86	11	18	6	0	136
	13	98	10	16	6	0	142
Volatile suspended solids mg/1	F4	75	4	5	2	0	24
	15	72	4	5	2	0	22
	F10	86	5	7	2	0	33
	13	97	4	8	2	0	74

TABLE A1 cont'd

SUMMARY OF TILE DRAINAGE WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Nitrate nitrogen mg/l	F4	100	3.6	2.6	3.0	0.2	20.5
	15	93	12.2	6.4	11.3	1.3	45.0
	F10	111	52.2	18.8	57.4	8.8	84.0
	13	117	11.2	3.8	11.3	0.6	24.5
Total Kjeldahl nitrogen mg/l	F4	124	0.64	1.54	0.24	0.0	15.5
	15	99[a]	1.21	3.34	0.48	0.0	22.5
	F10	123	0.27	0.69	<0.05	0.0	5.50
	13	133[b]	0.66	1.93	0.29	0.0	20.0
Ammonia nitrogen mg/l	F4	120	0.08	0.11	<0.05	<0.02	0.90
	15	100	0.09	0.17	<0.05	<0.02	1.48
	F10	124	0.07	0.11	<0.05	<0.02	0.94
	13	135	0.10	0.20	<0.05	0.02	1.10
Total phosphorus mg/l	F4	122	0.06	0.08	0.04	0.00	0.49
	15	99	0.07	0.10	0.02	0.00	0.65
	F10	120	0.08	0.13	0.04	0.00	0.87
	13	134	0.05	0.08	0.02	0.00	0.38
Filtered total phosphorus mg/l	F4	120	0.04	0.05	0.03	0.00	0.29
	15	95	0.05	0.06	0.02	0.00	0.30
	F10	116	0.05	0.08	0.03	0.00	0.55
	13	125	0.04	0.06	0.01	0.00	0.30
Potassium mg/l	F4	123	2.4	0.5	2.4	1.7	6.0
	15	102	1.8	0.7	1.7	1.0	4.5
	F10	124	4.8	1.5	4.7	1.3	9.2
	13	137	2.4	0.9	2.3	0.9	8.1

TABLE A1 cont'd

SUMMARY OF TILE DRAINAGE WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Filt. tot. P / Tot. P %	F4	119	62.2	38.7	75.0	0	100
	15	95	62.7	38.8	75.5	0	100
	F10	114	62.8	36.3	70.8	0	100
	13	125	53.9	40.6	69.7	0	100
Susp. solids / Tot. solids %	F4	71	3.1	3.2	1.8	0	12.7
	15	70	4.5	7.5	2.3	0	55.0
	F10	83	2.0	2.9	1.0	0	22.2
	13	97	3.9	9.1	1.5	0	62.7
Vol. susp. solids / Susp. solids %	F4	74	43.5	33.2	33.3	0	100
	15	72	36.1	27.4	33.3	0	100
	F10	86	44.6	35.8	40.0	0	100
	13	96	42.0	32.4	40.0	0	100

[a] Excludes one high value of 80 mg/l on May 22, 1975.

[b] Excludes one high value of 68 mg/l on April 6, 1975.

TABLE A2

YEARLY VARIATION OF SOME TILE WATER QUALITY PARAMETERS

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	Year	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Specific conductivity micromhos per cm. @ 25°C	F4	75	40	537	69	545	408	681
		76	55	581	107	594	292	738
		77	28	525	131	520	308	714
	15	75	26	404	111	360	285	620
		76	41	440	123	480	183	726
		77	40	411	123	422	145	682
	F10	75	31	859	96	859	520	1016
		76	58	789	181	857	259	968
		77	37	632	194	710	322	861
	13	75	19	569	63	550	486	710
		76	67	592	112	578	196	798
		77	44	536	110	581	129	669
Total[a] solids mg/l	F4	75	-	-	-	-	-	-
		76	47	345	92	363	46	518
		77	28	348	75	331	221	532
	15	75	-	-	-	-	-	-
		76	31	270	128	277	26	611
		77	40	296	72	278	125	485
	F10	75	-	-	-	-	-	-
		76	49	570	153	615	190	788
		77	37	470	150	500	199	700
	13	75	-	-	-	-	-	-
		76	56	380	93	375	56	684
		77	44	355	62	363	190	481

TABLE A2 cont'd

YEARLY VARIATION OF SOME TILE WATER QUALITY PARAMETERS

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	Year	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Nitrate nitrogen mg/l	F4	75	17	<1.6	0.4	<1.4	<1.4	2.5
		76	56	3.6	2.9	2.7	1.4	20.5
		77	27	5.0	1.7	5.0	0.86	9.6
	15	75	18	10.4	3.8	8.8	6.2	23.1
		76	37	13.0	7.8	11.8	1.3	45.0
		77	38	12.4	5.8	11.0	3.2	29.0
	F10	75	17	63.5	17.7	63.5	21.7	84.0
		76	57	53.7	15.6	58.0	13.6	76.0
		77	37	44.7	20.9	52.0	8.8	72.0
	13	75	12	15.2	3.2	14.0	11.9	24.5
		76	63	12.7	2.8	12.0	3.2	19.0
		77	42	7.7	2.5	8.1	0.60	13.0
Total Kjeldahl nitrogen mg/l	F4	75	41	1.0	2.5	0.0	0.0	15.5
		76	57	0.42	0.44	0.30	<0.01	2.37
		77	26	0.59	0.52	0.50	<0.05	2.1
	15	75	24[b]	2.7	5.0	1.1	0.0	22.5
		76	37	1.06	3.52	0.30	<0.01	21.5
		77	38	0.43	0.51	0.16	<0.05	1.8
	F10	75	29	0.1	0.3	0.0	0.0	1.3
		76	58	0.36	0.90	<0.01	<0.01	5.50
		77	36	0.23	0.44	<0.05	<0.05	2.4
	13	75	26[c]	1.7	4.2	0.0	0.0	20.0
		76	66	0.34	0.30	0.28	<0.01	1.39
		77	41	0.49	0.57	0.38	<0.05	2.8

TABLE A2 cont'd

YEARLY VARIATION OF SOME TILE WATER QUALITY PARAMETERS

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	Year	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Total phosphorus mg/l	F4	75	39	0.05	0.08	0.04	0.00	0.49
		76	56	0.06	0.06	0.04	0.00	0.32
		77	27	0.09	0.10	0.030	0.01	0.46
	15	75	23	0.02	0.03	0.02	0.00	0.15
		76	36	0.09	0.14	0.03	0.00	0.65
		77	40	0.07	0.08	0.03	0.01	0.35
	F10	75	28	0.04	0.04	0.03	0.00	0.18
		76	55	0.07	0.13	0.04	0.00	0.87
		77	37	0.10	0.16	0.04	0.01	0.65
	13	75	28	0.03	0.05	0.02	0.00	0.23
		76	64	0.06	0.08	0.02	0.00	0.36
		77	42	0.06	0.09	0.02	0.01	0.38
Potassium mg/l	F4	75	40	2.5	0.7	2.3	1.9	6.0
		76	56	2.5	0.3	2.5	1.9	3.3
		77	27	2.1	0.4	2.0	1.7	3.3
	15	75	24	1.6	0.3	1.4	1.2	2.4
		76	38	2.3	0.8	2.0	1.6	4.5
		77	40	1.5	0.3	1.5	1.0	2.3
	F10	75	29	5.0	1.0	4.9	3.6	8.2
		76	58	5.4	1.2	5.0	2.6	8.4
		77	35	3.6	1.5	3.2	1.3	9.2
	13	75	28	2.5	1.2	2.3	1.3	8.1
		76	65	2.9	0.6	3.0	2.0	5.5
		77	44	1.7	0.4	1.7	0.9	3.8

[a] Solids determinations were not made on tile drainage water samples in 1975.

[b] Excludes one high value of 80 mg/l on May 22.

[c] Excludes one high value of 68 mg/l on April 6.

TABLE A3

SUMMARY OF TILE DRAINAGE WATER BACTERIOLOGICAL QUALITY DATA

ARI Greenbelt Farm, Ottawa

Parameter	Station	Year	No. of samples	Geom. mean	Median	Min.	Max.
Total coliforms MF count per 100 ml	F4	75	33	320	460	<2	480,000
		76	35	54	32	<2	26,000
		77	19	19	10	<2	560
	15	75	29	750	1000	4	23,000
		76	14	31	18	<2	20,000
		77	20	35	42	<2	2,800
	F10	75	21	590	720	50	8,700
		76	31	80	52	<2	40,000
		77	22	67	84	<2	6,500
	13	75	35	81	130	<2	4,400
		76	36	15	9	<2	4,200
		77	27	14	6	<2	4,200
	F4,15,F10	75,76,77	224	115	120	<2	480,000
	13	75,76,77	98	29	22	<2	4,400
Fecal coliforms MF count per 100 ml	F4	75	33	23	12	<2	28,000
		76	35	7	<2	<2	5,500
		77	19	5	<2	<2	42
	15	75	29	34	19	<2	2,600
		76	14	6	<2	<2	6,700
		77	20	3	<2	<2	16
	F10	75	21	9	6	<2	170
		76	31	9	4	<2	7,000
		77	22	7	<2	<2	340
	13	75	35	2	<2	<2	68
		76	36	3	<2	<2	44
		77	27	2	<2	<2	12
	F4,15,F10	75,76,77	224	9	4	<2	28,000
	13	75,76,77	98	3	<2	<2	68

TABLE A3 cont'd

SUMMARY OF TILE DRAINAGE WATER BACTERIOLOGICAL QUALITY DATA

ARI Greenbelt Farm, Ottawa

Parameter	Station	Year	No. of samples	Geom. mean	Median	Min.	Max.
Fecal streptococci MF count per 100 ml	F4	75	33	22	12	<2	19,000
		76	35	12	6	<2	8,300
		77	19	13	<2	<2	132
	15	75	29	69	49	<2	2,600
		76	14	8	<2	<2	8,300
		77	20	11	4	<2	240
	F10	75	21	11	12	<2	260
		76	31	8	<2	<2	10,000
		77	22	10	4	<2	520
	13	75	35	4	<2	<2	370
		76	36	6	<2	<2	540
		77	27	4	<2	<2	260
	F4,15,F10	75,76,77	224	14	8	<2	19,000
	13	75,76,77	98	5	<2	<2	540
FC:FS ratio	F4	75	33	1.05	1.11	0.02	3.60
		76	35	0.56	0.56	0.03	5.00
		77	19	0.50	1.00	0.14	1.00
	15	75	29	0.49	0.69	0.10	1.13
		76	14	0.81	1.00	0.17	1.00
		77	20	0.24	0.50	0.02	1.00
	F10	75	21	0.81	0.91	0.12	2.50
		76	31	1.08	1.00	0.30	4.00
		77	22	0.73	1.00	0.02	5.00
	13	75	35	0.63	1.00	0.03	2.00
		76	36	0.49	1.00	0.04	1.00
		77	27	0.60	1.00	0.04	2.00
	F4,15,F10	75,76,77	224	0.66	1.00	0.02	5.00
	13	75,76,77	98	0.56	1.00	0.03	2.00

TABLE A3 cont'd

SUMMARY OF TILE DRAINAGE WATER BACTERIOLOGICAL QUALITY DATA

ARI Greenbelt Farm, Ottawa

Parameter	Station	Year	No. of samples	Geom. mean	Median	Min.	Max.
Standard Plate Counts at 20°C per ml	F4	75	33	2,700	1,200	110	1,000,000
		76	35	4,200	5,200	6	2,700,000
		77	19	10,000	8,500	210	440,000
	15	75	29	3,900	2,300	280	69,000
		76	14	1,700	980	140	800,000
		77	20	13,000	11,000	62	450,000
	F10	75	21	960	1,300	110	11,000
		76	31	3,600	3,300	42	3,000,000
		77	22	21,000	38,000	260	900,000
	13	75	35	810	1,000	22	47,000
		76	36	530	460	4	610,000
		77	27	4,500	2,600	140	540,000
	F4,15,F10	75,76,77	224	4,400	3,000	6	3,000,000
	13	75,76,77	98	1,200	1,000	4	610,000
Standard Plate Counts at 35°C per ml	F4	75	33	460	400	30	84,000
		76	35	490	360	16	700,000
		77	19	520	320	39	19,000
	15	75	29	520	500	21	9,200
		76	14	220	65	26	360,000
		77	20	610	800	42	13,000
	F10	75	21	220	260	42	1,300
		76	31	350	530	2	200,000
		77	22	980	1,100	52	40,000
	13	75	35	100	86	12	9,800
		76	36	46	29	3	12,000
		77	27	150	100	9	6,800
	F4,15,F10	75,76,77	224	460	400	2	700,000
	13	75,76,77	98	90	66	3	12,000

TABLE A4

HERBICIDE APPLICATION HISTORY FOR TILE-DRAINED FIELDS

ARI Greenbelt Farm, Ottawa

Description	Field Station F4	15	F10	13
Area drained, ha	27.5	4.1	5.6	132
Soil Type	Clay loam	Clay loam	sand to sandy loam	clay loam
Drainage class	poor	poor	rapid to imperfect	poor
Nutrient source (up to 1977)	manure 3 years	manure 5 years	manure >7 years	chemical fertilizer 5 years
Crop (up to 1977)	Silage corn 3 years	Silage corn 3 years	Silage corn 3 years	1975: corn, alfalfa 1976; 1977: barley, alfalfa
Herbicide - date, type and rate of application (atrazine: technical grade, minimum 94% pure atrazine)	1974, none;	1974, none;	1974, June, atrazine 1.4 kg/ha;	1974, June, Lasso 4.2 ℓ/ha on 62 ha, atrazine 1.4 kg/ha on 70 ha;
	1975, June 10, atrazine, 1.4 kg/ha;	1975, June 10, atrazine, 1.4 kg/ha;	1975, May 28, atrazine, 1.4 kg/ha;	1975, May 2, 4-DB 1.4 ℓ/ha on 62 ha;
	1976, June 1, atrazine, 1.12 kg/ha; plus Sutan 4.2 ℓ/ha;	1976, June 2, atrazine 1.12 kg/ha plus Sutan 4.2 ℓ/ha;	1976, June 2, atrazine 1.12 kg/ha plus Sutan 4.2 ℓ/ha;	1976, May 2,4-DB 1.4 ℓ/ha on 70 ha;
	1977, none	1977, none	1977, none	1977, May, 2,4-DB 0.8 ℓ/ha on 70 ha

TABLE A5

HERBICIDE CONTENT OF TILE DRAINAGE WATER

ARI Greenbelt Farm, Ottawa

tr = trace; ND = not detected

Field station	Sampling date	Herbicide concentration, ppb atrazine	de-ethyl atrazine	Sutan
F4	July 25, 1975	0.2		
	Oct. 18	tr		
	20	tr		
	Dec. 4	ND		
	May 3, 1976	0.1	0.2	ND
	19	0.1	0.2	ND
	June 3	tr	0.1	ND
	6	0.1	0.2	ND
	10	0.2	0.2	ND
	14	0.1	0.2	ND
	17	0.2	0.3	ND
	22	0.1	0.1	ND
	Oct. 10	0.3	0.4	ND
	13	tr	tr	ND
	Nov. 27	tr	0.1	
15	June 6, 1975	ND		
	Nov. 12	0.2		
	Dec. 9	tr		
	May 3, 1976	0.1	0.2	ND
	12	0.1	0.2	ND

Note: Large gaps in sampling dates are due to lack of flow in tiles.

TABLE A5 cont'd

HERBICIDE CONTENT OF TILE DRAINAGE WATER

ARI Greenbelt Farm, Ottawa

tr = trace; ND = not detected

Field station	Sampling date	Herbicide concentration, ppb atrazine	de-ethyl atrazine	Sutan
F10	June 6, 1975	0.9		
	Oct. 1	1.1		
	20	0.4		
	Dec. 4	0.5		
	May 3, 1976	0.5	1.5	ND
	12	0.3	0.7	ND
	June 3	0.2	0.5	ND
	6	0.3	0.7	ND
	10	1.6	1.3	ND
	14	0.3	0.7	ND
	17	1.4	0.9	ND
	22	0.3	0.7	ND
	Oct. 10, 1976	0.3	0.8	ND
	13	0.3	0.7	ND
	Nov. 27	0.3	0.7	
13	July 25, 1975	0.2[a]		
	Dec. 9	0.4		
	May 3, 1976	0.4	1.4	ND
	June 10	0.4	0.8	ND
	14	0.3	0.8	ND
	17	0.3	0.6	ND
	22	0.2	0.5	ND
	July 8	0.2	0.5	
	Oct. 10	0.3	0.7	ND
	13	0.3	0.5	ND
	Nov. 1	0.2	0.4	ND
	27	0.3	0.5	

[a]This sample was also tested for 2,4-DB. None was detected.

TABLE A6

SUMMARY OF STREAM WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Temperature °C	2	203	9.1	6.8	7.0	0.0	25.0
	3	179	8.1	5.4	6.8	0.0	23.8
	6	172	9.4	7.1	8.0	0.0	31.0
	7	89	5.2	5.0	4.0	0.0	30.0
	8	127	7.4	5.8	6.0	0.0	29.0
	DOT	27	2.4	2.1	2.0	0.0	9.0
pH	2	194	7.3	0.6	7.2	6.7	8.8
	3	171	7.3	0.4	7.2	6.6	8.6
	6	168	7.3	0.4	7.3	6.0	8.3
	7	85	7.1	0.3	7.0	6.7	8.1
	8	121	7.2	0.4	7.2	6.7	8.2
	DOT	24	7.2	0.2	7.3	6.8	7.6
Dissolved oxygen mg/l	2	163	10.8	2.3	11.0	4.7	14.3
	3	142	11.2	1.9	11.2	4.6	14.5
	6	146	11.2	2.1	11.2	5.0	14.8
	7	85	12.0	1.9	12.5	6.0	14.8
	8	117	10.6	2.8	11.2	4.5	14.7
	DOT	27	12.3	1.7	13.2	7.9	14.0
Specific conductivity micromhos per cm @ 25°C	2	176	459	135	488	109	708
	3	151	511	163	545	92	1054
	6	159	453	129	494	120	841
	7	85	383	147	434	45	580
	8	115	382	150	454	43	570
	DOT	27	332	154	290	173	711

TABLE A6 cont'd

SUMMARY OF STREAM WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Total solids mg/l	2	153	335	114	334	52	937
	3	134	374	153	369	93	1272
	6	141	303	136	306	46	1520
	7	79	262	86	266	39	466
	8	93	257	80	270	1	404
	DOT	22	231	102	238	28	424
Suspended solids mg/l	2	151	33	79	14	0	757
	3	132	20	24	11	0	131
	6	138	15	19	8	0	115
	7	80	16	32	9	0	274
	8	97	15	22	8	0	138
	DOT	23	11	16	9	0	76
Volatile suspended solids mg/l	2	142	8	11	6	0	87
	3	124	9	13	4	0	82
	6	132	6	9	3	0	67
	7	80	7	14	4	0	115
	8	94	7	12	3	0	80
	DOT	23	8	17	3	0	79
Nitrate nitrogen mg/l	2	150	5.0	3.9	4.2	<0.1	18.2
	3	130	8.1	4.5	8.5	0.3	20.3
	6	139	1.8	3.0	1.1	<0.1	20.3
	7	83	0.8	2.3	0.14	<0.1	20.6
	8	96	0.7	0.9	0.1	<0.1	6.2
	DOT	25	2.6	6.4	1.2	0.3	32.9

TABLE A6 cont'd

SUMMARY OF STREAM WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Total Kjeldahl nitrogen mg/l	2	156	1.4	1.9	0.95	0.0	12.0
	3	134	1.3	3.3	0.72	0.0	34.0
	6	138	0.76	0.97	0.48	0.0	6.0
	7	81	0.53	0.90	0.35	0.0	8.0
	8	94	0.77	0.98	0.53	0.0	6.4
	DOT	23	1.95	3.12	0.99	<0.1	14.4
Ammonia nitrogen mg/l	2	150	0.21	0.38	<0.1	<0.02	3.30
	3	130	0.13	0.18	0.08	<0.02	1.30
	6	139	0.10	0.30	0.06	<0.02	2.80
	7	82	0.07	0.09	0.05	<0.02	0.68
	8	96	0.09	0.12	<0.05	<0.02	0.72
	DOT	23	0.40	0.50	0.18	0.04	1.80
Total phosphorus mg/l	2	152	0.14	0.18	0.09	0.00	0.89
	3	135	0.09	0.12	0.04	0.00	0.53
	6	139	0.08	0.09	0.05	0.00	0.44
	7	78	0.05	0.08	0.03	0.00	0.47
	8	95	0.06	0.09	0.04	0.00	0.61
	DOT	22	0.18	0.17	0.13	0.03	0.77
Filtered total phosphorus mg/l	2	108	0.09	0.12	0.04	0.00	0.79
	3	90	0.05	0.07	0.02	0.00	0.38
	6	107	0.06	0.06	0.04	0.00	0.24
	7	74	0.03	0.05	0.02	0.00	0.32
	8	75	0.05	0.11	0.02	0.00	0.86
	DOT	22	0.12	0.12	0.09	0.01	0.49

TABLE A6 cont'd

SUMMARY OF STREAM WATER PHYSICAL AND CHEMICAL QUALITY DATA (1975-77)

ARI Greenbelt Farm, Ottawa

Parameter	Sampling station	No. of samples	Mean	Std. Dev.	Median	Min.	Max.
Potassium mg/l	2	158	4.2	2.4	3.6	1.4	18.4
	3	138	2.9	1.6	2.7	1.0	9.0
	6	145	2.5	0.8	2.4	1.2	6.2
	7	83	2.3	0.9	2.3	0.9	6.1
	8	97	2.4	0.8	2.3	1.1	4.8
	DOT	25	4.1	1.5	3.8	1.6	7.6
Filt. tot. P / Tot. P %	2	103	52.0	32.0	50.0	0	100
	3	90	48.7	34.9	44.8	0	100
	6	100	55.0	36.8	63.5	0	100
	7	76	53.0	34.1	53.6	0	100
	8	73	58.5	33.7	66.0	0	100
	DOT	21	66.0	24.6	64.0	12.0	100
Suspended solids / Total solids %	2	146	10.0	15.3	4.2	0	94.0
	3	131	6.8	10.8	2.5	0	65.5
	6	133	5.9	8.7	2.9	0	71.4
	7	79	7.6	12.7	3.7	0	88.1
	8	93	6.9	13.0	3.4	0	83.8
	DOT	22	5.8	11.4	2.5	0	54.3
Vol. susp. solids / Susp. solids %	2	141	44.4	30.0	38.4	0	100
	3	123	42.9	31.0	36.3	0	100
	6	131	39.9	31.1	37.5	0	100
	7	80	41.6	30.0	35.3	0	100
	8	94	42.2	29.4	33.3	0	100
	DOT	23	42.7	31.8	33.3	0	100

TABLE A7

SUMMARY OF SURFACE STREAM WATER BACTERIOLOGICAL QUALITY DATA FOR 1975

ARI Greenbelt Farm, Ottawa

Parameter	Station	No. of samples	Geom. Mean	Median	Min.	Max.
Total coliforms MF count per 100 ml	2	41	2,200	2,100	30	280,000
	3	22	2,200	2,700	50	24,000
	5	40	1,100	1,700	20	60,000
	6	11	890	1,200	58	13,000
	7	4	250	110	26	15,000
	8	7	190	44	34	14,000
	9	14	670	1,100	40	15,000
Fecal coliforms MF count per 100 ml	2	41	170	120	<2	24,000
	3	22	140	160	10	1,200
	5	40	120	190	2	4,300
	6	11	35	78	<2	760
	7	4	10	5	<2	330
	8	7	8	4	<2	230
	9	14	75	110	<2	4,400
Fecal streptococci MF count per 100 ml	2	41	260	290	4	82,000
	3	22	130	180	<2	4,400
	5	40	210	250	2	15,000
	6	11	140	98	14	3,500
	7	4	64	37	4	3,200
	8	7	46	42	4	1,800
	9	14	180	130	12	9,000
FC:FS ratio	2	41	0.65	0.60	0.06	5.8
	3	22	1.10	0.53	0.06	450.0
	5	40	0.57	0.50	0.08	13.7
	6	11	0.26	0.21	0.07	2.7
	7	4	0.16	0.08	0.06	0.5
	8	7	0.18	0.19	0.04	0.5
	9	14	0.41	0.49	0.02	4.6

TABLE A7 cont'd

SUMMARY OF SURFACE STREAM WATER BACTERIOLOGICAL QUALITY DATA FOR 1975

ARI Greenbelt Farm, Ottawa

Parameter	Station	No. of samples	Geom. Mean	Median	Min.	Max.
Standard Plate Counts at 20°C per ml	2	40	7,300	7,100	1,100	91,000
	3	22	4,600	5,300	560	95,000
	5	40	4,000	4,000	410	77,000
	6	11	2,500	2,000	800	24,000
	7	4	2,300	1,500	1,300	6,200
	8	7	2,200	2,300	700	5,700
	9	14	4,500	3,100	1,200	40,000
Standard Plate Counts at 35°C per ml	2	40	2,000	2,300	110	68,000
	3	22	880	580	82	36,000
	5	40	1,100	1,100	62	9,200
	6	11	650	660	91	5,100
	7	4	260	120	90	6,700
	8	7	450	490	86	2,800
	9	14	1,000	1,000	88	16,000

TABLE A8

NUTRIENT APPLICATION RATES IN BLACK RAPIDS CREEK DRAINAGE AREA

ARI Greenbelt Farm, Ottawa

Nutrient source	Year	Area[a] ha	Nutrient applied, kg/ha N	P	K
Fertilizer	1975	522	52	45	57
Manure		100	524	165	476
Total		594	134	67	130
Fertilizer	1976	486	58	19	36
Manure		141	449	110	367
Total		594	154	42	116
Fertilizer	1977	487	32	22	41
Manure		106	573	159	484
Total		594	128	46	120

[a] Total area refers to watershed area of 594 ha which includes 25 ha of roads and drainage ditches and 569 ha of cultivated fields. Some fields that were chemically fertilized earlier in the year were later plowed with manure.

TABLE A9

NUTRIENT AND POLLUTANT TRANSPORT TO SURFACE WATER OF BLACK RAPIDS CREEK

ARI Greenbelt Farm, Ottawa

Parameter	Year[a]	Inlet total kg	Outlet total kg	Difference kg	Contribution rate kg/ha
Total solids	1975	128,840	340,485	211,645	356.0
	1976	130,082	757,586	627,504	1,056.0
	1977	108,702	290,191	181,489	306.0
Suspended solids	1975	8,279	36,381	28,102	47.0
	1976	12,368	245,025	232,657	392.0
	1977	4,063	33,569	29,506	50.0
Nitrogen-total Kjeldahl	1975	617	4,385	3,768	6.3
	1976	1,925	11,422	9,497	16.0
	1977	999	2,525	1,526	2.6
Nitrogen-nitrate	1975	606	7,896	7,290	12.3
	1976	695	5,596	4,901	8.3
	1977	607	3,950	3,343	5.6
Nitrogen-total Kjeldahl + nitrate	1975	1,223	12,313	11,058	18.6
	1976	2,620	17,018	14,398	24.2
	1977	1,606	6,475	4,869	8.2
Phosphorus-total unfiltered	1975	18	100	82	0.1
	1976	91	568	477	0.8
	1977	107	471	364	0.6
Potassium	1975	1,028	3,190	2,162	3.6
	1976	1,973	11,568	9,595	16.2
	1977	1,743	5,647	3,904	6.6

[a] Data for 1975 is after April 22; excludes snowmelt runoff.

Data for 1977 is upto August 31; excludes fall runoff.

TABLE A10

OBJECTIVES AND STANDARDS FOR PUBLIC WATER SUPPLIES[a]

Parameter	Objective or desirable criteria	Acceptable criteria	(Max.) Permissible limit	Source
Temperature			$85^{\circ}F$	2
pH		6.5 to 8.3		1
Dissolved oxygen mg/l	Near saturation		>4 (monthly mean) >3 (individual sample)	2
Total dissolved solids mg/l	<500	1,000		1
Nitrate + nitrite as N mg/l	<10.0	<10.0	10.0	1
Ammonia-N	0.01	0.5		1
Phosphates as PO_4 (Inorganic)	<0.2	0.2		1
(as P)	(<0.07)	(0.07)		1
Total coliforms MPN or MFC	<100 per 100 ml	<1000 per 100 ml	<5000 per 100 ml	2,3
Fecal coliforms MPN or MFC	< 10 per 100 ml	< 100 per 100 ml	<1000 per 100 ml	2,3

[a]The quoted sources should be consulted for additional details.

Sources:

1. Guidelines for Water Quality Objectives and Standards, Dept. of Environment, Inland Waters Directorate, Ottawa, Ontario. Technical Bulletin 67, 1972.

2. Guidelines and Criteria for Water Quality Management in Ontario, Ontario Ministry of the Environment, Toronto, Ontario.

3. Canadian Drinking Water Standards and Objectives - 1968, Dept. of National Health and Welfare, Ottawa, Ontario. 1969.

APPENDIX IV

NITROGEN LOSSES FROM MANURED FIELDS BY DENITRIFICATION

It is the opinion of the authors that under the conditions of the experiment, a large proportion of the unaccounted-for nitrogen in the manure incorporated into the ground (Tables 4a, 4b and 4c) remained in the soil compared to that lost by denitrification and other mechanisms. While the conditions that would lead to lower losses of nitrogen by ammonia volatilization and removal in ground and surface water are obvious, conditions that would lead to lower losses by denitrification are not so obvious. This discussion is limited to the latter.

There is considerable evidence, both direct and indirect, that denitrification occurs in the upper layers of soil (1-9). Commonly, unaccounted-for N in nitrogen balances (soil-plant-water) is attributed to possible loss by denitrification. On the other hand, some investigators have reported that loss of nitrogen by denitrification is not significant (10, 12, 14), especially in well-drained soils (5, 7, 13) and when nitrogen application rates are not excessive (11). A review of literature shows that results reported by different investigators are sometimes contradictory, and that very little is known about the rate (kg/ha/day) of loss of nitrogen by denitrification, particularly when manure is plowed into soil.

Conditions that are considered to inhibit denitrification are low temperatures (usually below 10 C), low pH, aerated or oxygen-rich atmosphere, low moisture content, lack of nitrified nitrogen, lack of readily available carbon, lack of denitrifying microbial population, and presence of uniform soils with rapid to moderate permeabilities.

In this study, low soil temperatures, particularly during periods of high soil moisture content, and good drainage (all fields were tile-drained) are expected to have kept denitrification losses of N to be relatively low. Manure nitrogen was applied at rates of about 250 kg N/ha in spring (May) and in fall (October). Only about 40 to 50% of nitrogen in the applied manure was in the ammonium form and nitrates were virtually absent. In the clay soil, about half of the NH_4^+-N would be fixed on application and released slowly. In the vicinity of the experimental fields, soil temperatures near the surface and 50 cm below were observed to be 10 C or less between about October 15 and May 15 (Figure A2 gives a typical temperature profile). Therefore, nitrification and denitrification of a large part of the fall-applied manure nitrogen would occur in late spring of the following year,

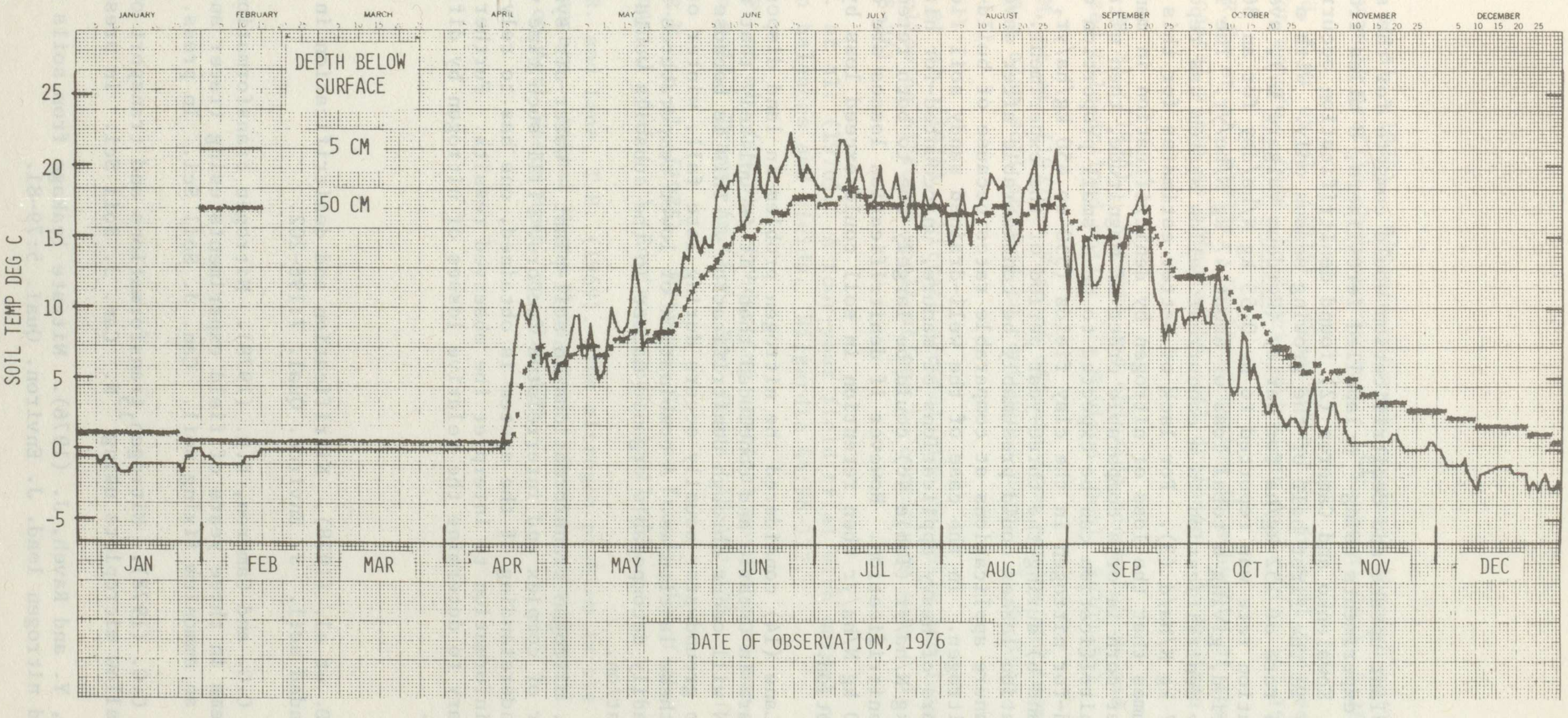

Figure A2. Soil temperatures at 5 and 50 cm below the surface at "Merivale, C.D.A." weather station. Greenbelt Farm, Animal Research Institute, Ottawa, Ontario.

when both plant uptake and denitrification would compete for the soil NO_3^--N. In experiments using ^{15}N labelled fertilizers, 8 miles from the study site, Kowalenko and Cameron (2) found denitrification occurring essentially in the first half of the growing season only. With a fertilizer application rate of 152 kg/ha for barley (Hordeum vulgare L.), average denitrification rate was reported to be 0.55 kg N/ha/day for an 86-day growing period, giving a total loss of about 47 kg N/ha/yr. The loss of nitrogen by denitrification in a concurrent fallow system was reported to average 0.7 kg N/ha/d (3). For lack of better estimates for this study, if one assumes that the loss of nitrogen by denitrification in manured fields under corn is of a comparable order of magnitude, then nitrogen loss by denitrification can be expected to be a small proportion of the unaccounted-for nitrogen in the clay fields (350 to 450 kg/ha/yr, Tables 4a and b) during the three-year period of the experiment. Denitrification losses could presumably be considerable after several years of manure applications at comparable rates because of build-up of residual nitrogen. In the case of the well-drained sandy soil field with several years of heavy applications of manure, unaccounted-for nitrogen of about 280 kg N/ha/yr (Table 4c) could be largely due to both retention in soil and denitrification. However if denitrification losses are of the order of 50 kg N/ha/yr then retention in soil could exceed loss by denitrification.

Webber and Lane (14) considered the nitrogen problem in land disposal of liquid manure in Ontario and concluded that "it is unlikely that significant losses of N will occur through denitrification". This is because movement of NO_3^--N to groundwater usually occurs during late fall, winter or early spring in these lattitudes. A combination of lower temperatures and a lack of readily decomposable organic matter in the subsoils would inhibit denitrification.

Admittedly, nitrogen transformations in soil-plant - water-air systems depend on a number of complex and interrelated factors. Till such time when a complete understanding of the system is obtained, one has to rely on available information to interpret the observed results. Further studies are necessary to determine the relative losses of nitrogen by different mechanisms.

References:

1. Guenzi, W.D. et al. (1978). Nitrification and denitrification in cattle manure-amended soil. J. Environ. Qual. 7:196-202.

2. Kowalenko, C.G. and Cameron, D.R. (1978). Nitrogen transformations in soil-plant systems in three years of field experiments using tracer and non-tracer methods on an ammonium fixing soil. Can. J. Soil Sci. In press.

3. Kowalenko, C.G. (1978). Nitrogen transformations and transport over 17 months in field fallow microplots using ^{15}N. Can. J. Soil Sci. In press.

4. Avnimelech, Y. and Raveh, J. (1976). Nitrate leakage from soils differing in texture and nitrogen load. J. Environ. Qual. 5:79-81.

5. Devitt, D. et al. (1976). Nitrate-nitrogen movement through soil as affected by soil profile characteristics. J. Environ. Qual. 5:283-288.

6. Wallingford, G.W. et al. (1975). Denitrification in soil treated with beef-feedlot manure. Comm. Soil Sci. and Plant Anal. 6(2):147-161.

7. Gambrell, R.P. et al. (1975). Denitrification in subsoils of the North Carolina coastal plain as affected by soil drainage. J. Environ. Qual. 4:311-316.

8. Gast, W.W. et al. (1974). Nitrate and chloride accumulation and distribution in fertilized tile-drained soils. J. Environ. Qual. 3:209-213.

9. Kimble, J.M. et al. (1972). Fate of nitrate from manure and inorganic nitrogen in a clay soil cropped to continuous corn. J. Environ. Qual. 1: 413-415.

10. Gast, R.G. et al. (1978). Nitrate accumulation in soils and loss in tile drainage following nitrogen applications to continuous corn. J. Environ. Qual. 7:258-261.

11. Pratt, P.F. et al. (1976). A four-year field trial with animal manures. I. Nitrogen balances and yields. Hilgardia 44:98-112.

12. Walter, M.F. et al. (1975). Predicting vertical movement of manurial nitrogen in soil. Trans. Am. Soc. Agr. Engrs. 18:100-105.

13. Gambrell, R.P. et al. (1975). Nitrogen losses from soils of the North Carolina coastal plain. J. Environ. Qual. 4:317-323.

14. Webber, L.R. and Lane, T.H. (1969). The nitrogen problem in the land disposal of liquid manure. Animal Waste Management. Proceedings Cornell Univ. Conference on Agr. Waste Mgmt. pp. 124-129.

INTERNATIONAL JOINT COMMISSION
GREAT LAKES REGIONAL OFFICE
100 Ouellette Avenue
Windsor, Ontario N9A 6T3