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Nitrogen Loadings from Agricultural Activities in the Great Lakes Basin: Integration Report on Nitrogen, Agricultural Watershed Studies, Task C, Canadian Section, Activity 1

International Reference Group on Great Lakes Pollution from Land Use Activities

Canada. Department of Agriculture. Soil Research Institute

G. H. Neilsen

J. L. Culley

D. R. Cameron

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INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES

**INTERNATIONAL
JOINT
COMMISSION**

NITROGEN LOADINGS FROM AGRICULTURAL ACTIVITIES IN THE GREAT LAKES BASIN

NITROGEN LOADINGS FROM AGRICULTURAL ACTIVITIES IN THE GREAT LAKES BASIN

INTEGRATION REPORT ON NITROGEN AGRICULTURAL WATERSHED STUDIES

Task C (Canadian Section) - Activity 1
International Reference Group on Great Lakes
Pollution from Land Use Activities
International Joint Commission

G.H. Neilsen, J.L. Culley and D.R. Cameron

Soil Research Institute
Agriculture Canada
Ottawa, Ontario

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DISCLAIMER

The study discussed in this document was carried out as part of the efforts of the International Reference Group on Great Lakes Pollution From Land Use Activities (PLUARG), an organization of the International Joint Commission (IJC), established under the Canada - U.S. Great Lakes Water Quality agreement of 1972. Funding for this study was provided through Agriculture Canada.

Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

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SUMMARY

This N integration report was carried out as part of the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG, Task C). The purpose of this report was to interpret research information obtained from the agricultural studies pertinent to the parameter N and to identify remedial measures where significant N problems existed.

The major sources of information included a number of problem oriented detailed studies by individual researchers with varying emphasis on N, and considerable land use and N water quality data available for 11 intensively surveyed agricultural watersheds in southern Ontario.

Major conclusions with respect to N derived from the detailed projects suggested:

1. A statistically significant positive relationship occurred between watershed fertilizer plus manure inputs and stream N concentration.

2. High unit area N inputs associated with rural precipitation exceeded stream N loadings in watersheds with extensive areas of hay and pasture.

3. Fertilization, mineralization and septic tank seepage were identified as sources of stream N in a sandy intensively cropped watershed.

4. Soil organic N was identified as a large source of N in watersheds. It was suggested that increased cultivation could have accelerated mineralization and increased stream N content. Increased availability of leachable N occurred when mineralized N exceeded plant uptake and denitrification. Denitrification was reduced in cold soils while mineralization varied directly with volumetric soil moisture content and temperature. Thus, mineralization could contribute significantly to leachable N during warm, moist soil conditions.

5. Detailed field plot studies in sandy and clay soils indicated considerable N, much produced as a result of mineralization, was available for leaching and denitrification under tobacco, corn, winter wheat, potatoes, and green beans but not soybeans.

6. Although agricultural cropping contributed to elevated groundwater N concentrations, particularly beneath coarse textured soils, denitrification of groundwater N combined with spatial variability of groundwater NO_3-N concentrations prevented development of adequate, large scale, deterministic N transport models.

7. In-stream denitrification was likely under low flow conditions.

8. In one watershed study, drifting organic matter was enriched in N but comprised a negligible fraction of annual stream N loadings.

9. In a watershed with high livestock density, N contamination of runoff from livestock activities were associated with inadequate disposal of manure in the near stream area, particularly where N transport directly

to streams was facilitated. Winter manure spreading and barnyard drains connected to field drainage lines were two examples.

10. Groundwater monitoring near an unpaved feedlot suggested considerable N movement to shallow groundwater and denitrification of groundwater N in fine textured and relatively impermeable soils.

11. Large annual applications of liquid manure followed by plowdown on flat, fine textured fields may not impair stream water quality to unacceptable levels. Surface stream drainage water concentrations of N, P and K increased slightly over the 3 year experimental period implying that such large annual applications may not be advisable on an indefinite basis.

12. Most studies identified the fall, winter and spring periods as having highest stream N concentrations and loadings.

Detailed analysis of the 11 Pluarg pilot watersheds suggested:

1. Watershed flow weighted mean NO_3:NH_4 concentration ratios ranged from 4 to 70 indicating most soluble N was lost as NO_3-N.

2. The 10 mg/l NO_3-N drinking water standard was exceeded (as frequently as 8% of the time) on watersheds with more than 20% corn.

3. Increased stream NO_3-N concentration occurred from watersheds with more tile drainage, corn production and higher unit area fertilizer N inputs. Frequently, these watersheds also contained extensive areas of soils with high organic N contents.

4. Corn was the dominant N fertilized crop with from 40-90% of watershed N applied to corn.

5. Higher stream Kjeldahl N concentrations were associated with watersheds with larger areas of impermeable soils.

6. Kjeldahl N stream loadings averaged 30% of total N loadings.

7. For 1975-77, monthly runoff volumes and N loadings had similar annual patterns with large runoff volumes and loadings occurring from December to March.

8. For 3 watersheds, modelling the N cycle suggested N fertilization was essential to maintain optimum growth, mineralized N could be an important component of leachable N particularly after plant growth had ceased, and plant uptake comprised the largest N output from all watersheds.

9. Best fit statistical relationships between field N inputs and watershed N outputs predicted total N stream loadings of 26 kg/ha/yr from corn and potatoes, 3.6 kg/ha/yr from cereals, beans, vegetables and tobacco, 0.1 kg/ha from hay and unimproved pasture and 0.0 kg/ha from unimproved land.

10. Predicted total N loadings from (9) compared well to N loadings measured in sectors of the Grand and Saugeen but overpredicted loadings in sectors with extensive non agricultural land.

11. 83% and 94% of stream total N loadings in the Grand and Saugeen were predicted to occur from rural land which comprised 97 and 99% respectively of total watershed area.

12. Using 1971 census tract land use data, extrapolation of the statistical models identified watersheds with high row crop and livestock densities as areas of high potential N loss to the lower Great Lakes.

Remedial measures to avoid increased N water quality problems should involve minimizing N loss from livestock and field cropping activities.

The following should be considered for livestock activities:

1. adequate winter manure storage,
2. roofed solid manure storage areas,
3. consideration of local hydrology in location of manure storage areas and feedlots,
4. prevention of direct entry of manure effluent to streams,
5. restriction of manure application within stream floodplains or during the winter,
6. quick ploughdown of freshly applied manure,

and

7. prevention of direct cattle access to streams.

for cropping activities:

1. elimination of fertilization above rates established locally for maximum yield,
2. elimination of fall fertilization,
3. increased use of split application and banding of N on corn,
4. development of a soil test for N,
5. use of winter cover crops where practical,
6. increased use of green manuring and incorportion of legumes in farm crop rotations,
7. early seeding of cereal crops,
8. development of crop varieties requiring reduced N fertilization,

and

9. to reduce Kjeldahl N field losses, increased use of classical soil erosion conservation techniques such as conservation tillage, contour planting and ploughing, grassed waterways, etc.

In general, many management methods currently exist to reduce N loss but require increased education through extension, occassional modification for Canadian conditions and further study to assess economic impact and acceptability by the individual farm operator.

1. INTRODUCTION

Article VI of the Great Lakes Water Quality Agreement, 1972, requested that the International Joint Commission inquire into and report on "pollution of the boundary waters of the Great Lakes System from agricultural, forestry and other land use activities, in accordance with the terms of reference attached to this agreement". The International Joint Commission (IJC) established the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG) to plan and implement the requested study.

The PLUARG study program consisted of four major tasks as outlined in the Reference Group's February 1974 "Detailed Study Plan to assess Great Lakes Pollution from Land Use Activities".

> *"Task A is devoted to the collection and assessment of management and research information and, in its later stages to the critical analysis of implications of potential recommendations. Task B is first the preparation of a land-use inventory, largely from existing data, and, second, the analysis of trends in land-use patterns and practices. Task C is the detailed survey of selected watersheds to determine the sources of pollutants, their relative significance and the assessment of the degree of transmission of pollutants to boundary waters. Task D is devoted to obtaining supplementary information on the inputs of materials to the boundary waters, their effect on water quality and their significance in these waters in the future and under alternative management schemes."*

Task C was described as, "Intensive studies of a small number of representative watersheds, as selected and conducted to permit some extrapolation of data to the entire Great Lakes Basin, and to relate contamination of water quality, which may be found at river mouths on the Great Lakes to specific land uses and practices".

Activity 1 (Canada) of Task C called for "Pilot Agricultural Watershed Surveys". The objective of this activity was "to obtain data on the inputs of pollutants into the Great Lakes Drainage System which have their origins in the complex land use activities known as agriculture".

The Agricultural Watershed Studies consisted of the monitoring of 11 small (20-70 km^2) agricultural basins selected to represent major agricultural regions in southern Ontario, and included a number of detailed studies in six of these. Descriptions of these studies may be found in the Detailed Study Plan, Agricultural Watershed Studies, Task C Activity 1, Canada, October 1975. During the final phase of the program, individuals were identified as "integrators" responsible for compiling information related to main parameter group (i.e. phosphorus, nitrogen, sediments, heavy metals and pesticides) and for livestock sources.

The N integration report has involved three major objectives:

1. an assessment and summary of the information generated in the detailed studies pertinent to the problems involved in reducing N losses to the Great Lakes,

2. a detailed analysis of the N data for the intensively monitored agricultural watersheds identified in Activity 1, and

3. a comparison of the results obtained with other PLUARG and literature studies in order to identify remedial measures where significant problems existed.

To achieve these aims, the report has been constructed as follows:

Section 1 has included background information and report objectives and structure;

Section 2 is concerned with a general introduction to the physical and chemical processes controlling N loss from agricultural watersheds with a summary of other similar work as reported in the literature;

Section 3 describes the locations and land use, soils, flow and water sampling characteristics of the major watersheds discussed in this report;

Section 4 summarizes important conclusions involving N as found in the detailed process related studies;

Section 5 is concerned with stream N loadings in the intensively monitored small agricultural watersheds;

Section 6 discusses N loadings from sectors of the major Grand and Saugeen river systems;

Section 7 develops models of the seasonal variation of N storage within agricultural watersheds and of watershed N losses.

Based upon these models, extrapolations of agriculture's contribution to N addition in the Great Lakes are made in Section 8.

Section 9 considers remedial measures to reduce N runoff from agricultural land.

2. LITERATURE REVIEW

Conserving N in agricultural watersheds is important both from an environmental and an economic viewpoint. The environmental impact of high N runoff on excessive growth of algae, phyto and zooplankton has been a major concern in the late 1960's and early 1970's (Viets, 1975; CDA Task Force[1]). Further, since energy for N fertilizer is one of the largest items of the energy budget for crop production by modern methods (Pimentel et al., 1973), large losses of N in runoff are likely to be viewed as increasingly extravagant as energy costs rise.

Understanding N behavior in agricultural watersheds requires knowledge of the physical processes affecting N transport and the chemical processes affecting N transformations - all at the watershed scale. Watershed stream runoff at any time is comprised of varying proportions of surface (overland), inter and groundwater flow (Fig. 2-1). This flow can contain soluble organic N, NH_4-N, NO_3-N* or N associated with sediment as exchangeable NH_4-N or organic-N. The extremely dynamic and complex N cycle (Fig. 2-2) is complicated at the watershed scale by soil variability. Further, the major watershed sources and sinks illustrated in Fig. 2-2 - particularly those associated with biological processes such as mineralization, N_2 fixation and denitrification - have proven extremely difficult to quantify in the field (Cameron et al., 1977).

In response to water quality concerns, a number of monitoring studies have been reported in the recent literature involving N loadings from agricultural land. Table 2-1 summarizes some of these recent studies in a form which will allow direct reference to similar information generated as a result of the watershed studies conducted in Ontario. The reference list has been generally restricted to watershed rather than tile drainage or small plot N loss information, although it was apparent that a considerable range in area (from just above 1 hectare to 33 000 hectares) existed in the studies. Measured unit area stream loadings fell within the 0.2 to 37.1 kg total N/ha range with the bulk of loadings not exceeding 20 kg total N/ha. This can be compared to unit area precipitation N loadings which have been estimated to range between 2 and 20 kg N/ha (Allison, 1966). Seven of these 15 studies indicated major stream loadings in the spring or at other periods of peak runoff. Nevertheless, Burwell et al. (1976), described a study in Iowa in which 84-95% of annual soluble N loadings occurred during periods of subsurface flow. A number of agricultural practices which have been linked to elevated N loadings included loss of N from winter spreading of manure (Taylor et al., 1971) or livestock feeding areas (Burwell et al., 1974), loss of N residual from cropping activities (Kilmer et al., 1974), especially from corn cropping (Webber and Elrick, 1967) on impermeable soils (Neilsen and Mackenzie, 1977). Domestic sewage from rural septic tanks (Johnson et al., 1976) was another potential N source and a number of studies (Olness et al., 1975; Kissel et al., 1976) have indicated sizeable amounts of N loss with sediment. In general, it was frequently pointed out that N loadings were small when compared to precipitation and fertilizer-N inputs. Nevertheless, varying degrees of reduction in water quality were also noted. There was no information on the extent to which N would be transported from these small agricultural watersheds to receiving bodies of water.

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[1] CDA Task Force for Implementation of Great Lakes Water Quality Program Section II.

* In this report NO_3-N also includes any NO_2-N.

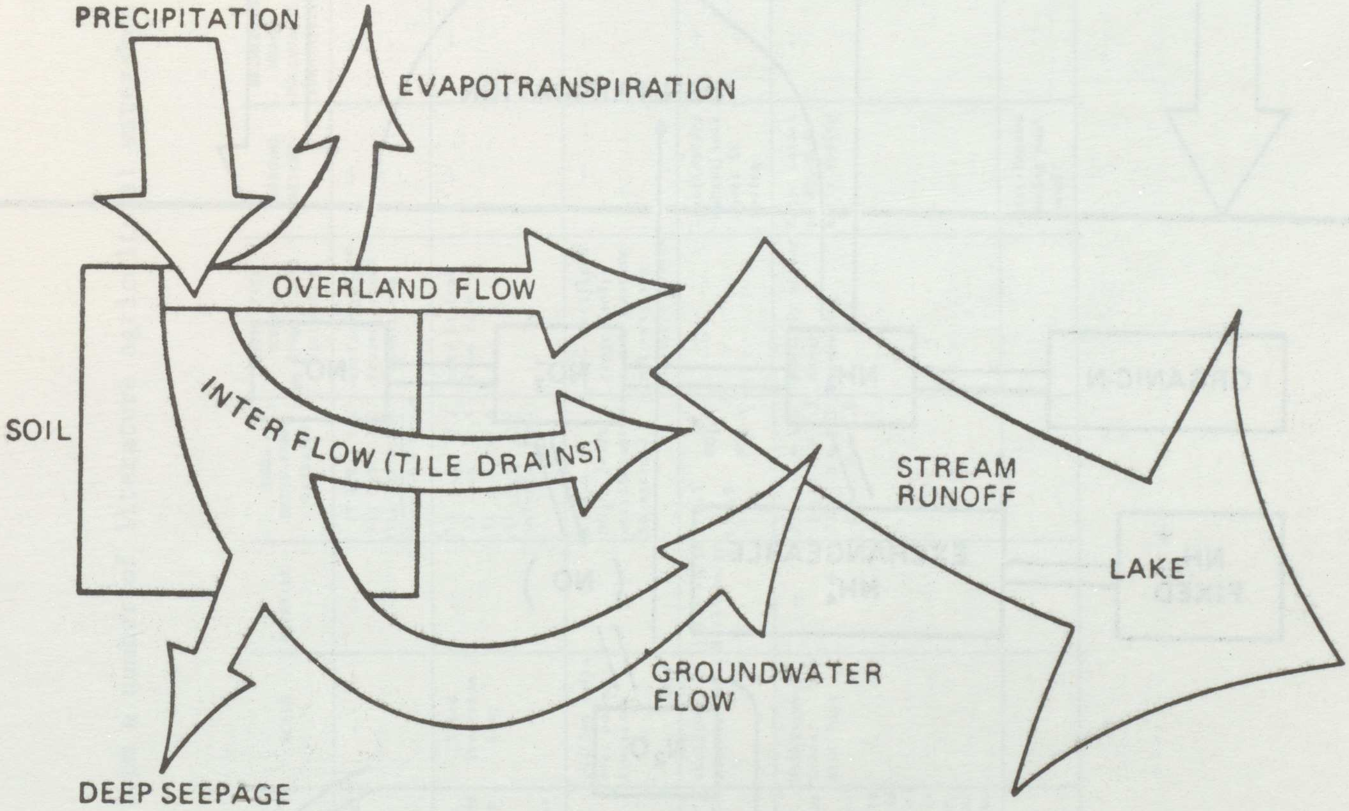

Fig. 2-1. Schematic of hydrologic cycle illustrating major watershed runoff routes.

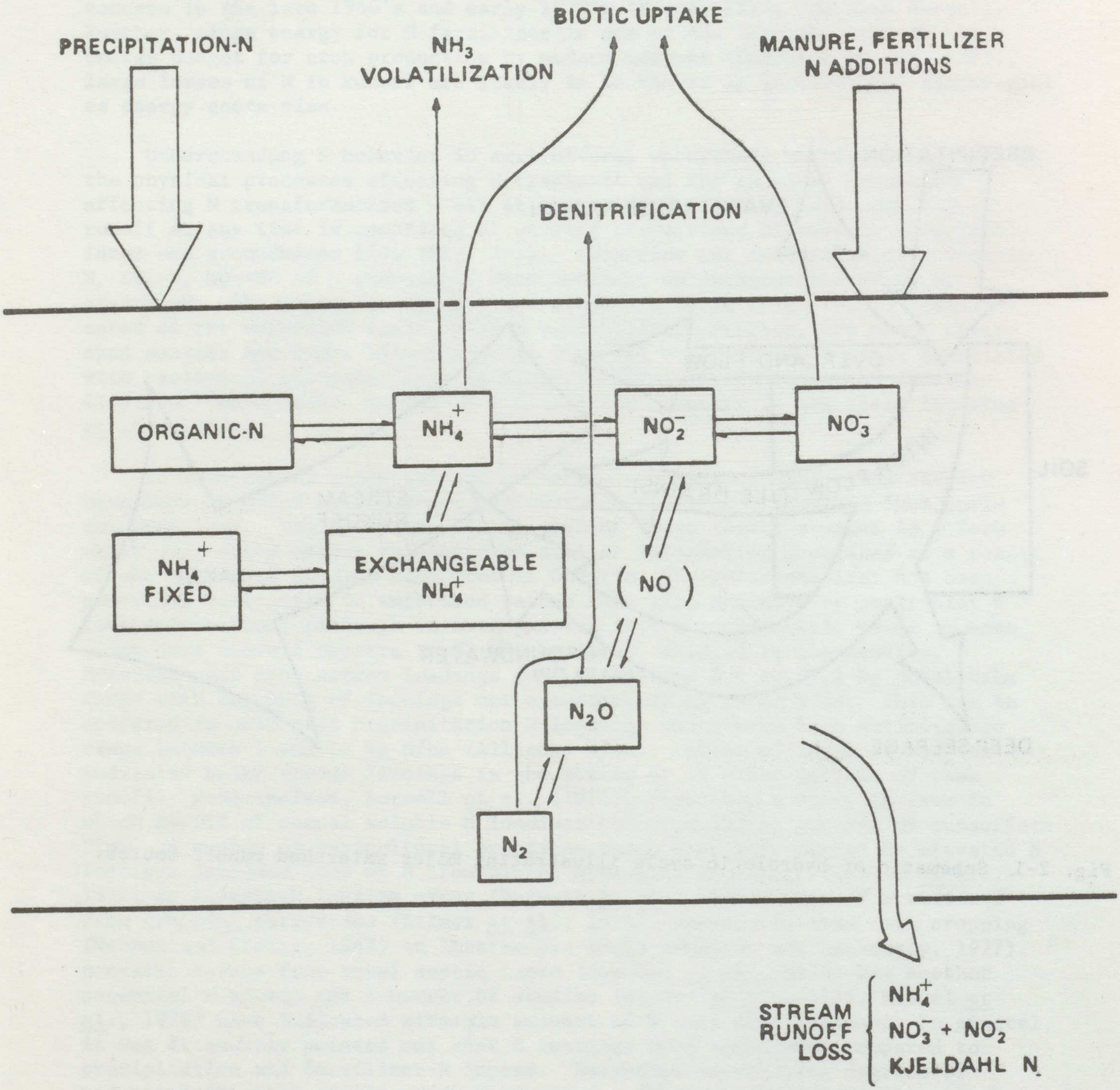

Fig. 2-2 · Major chemical pathways involved in N cycle.

Table 2-1. Summary of results from a number of literature agricultural watershed N studies.

REFERENCE	GEOGRAPHICAL REGION	WATERSHED AREA	LAND USE	SOILS	RAINFALL	LOSS RATES-FORMS kg/ha/yr	IDENTIFIED SOURCES (PRACTICES) YIELDING N	SEASONAL PATTERN	DEGREE TO WHICH POLLUTANTS TRANSMITTED	COMMENT
Sawyer 1947	Madison, Wisc.	--	agricultural	- -	--	I) 4.9 + 1.8 II) 5.5 + 2.0 III) 7.2 + 2.0 Inorg.N + Org.N	-surface runoff -frozen ground conditions	--	--	
Webber & Elrick 1967	Woodslee, Ont.	--	1) Bluegrass sod 2) Cont. corn 3) Corn Rot. 4) Alfalfa (2nd year)	Tiled Brookston Clay	--	1) 0.2 0.2 2) 5.6 11.9 3) 4.6 11.6 4) 4.9 5.7 Unfert. Fert. +N+	-note highest from corn	--	--	tile drainage measurements supplied by J.W. Ayelsworth C.D.A. Research Stn., Woodslee
Campbell & Webber 1969	Canal Lake, S.W. Ontario	13,620 ha	rangeland	shallow soils over porous limestone		I) -0.4 NO_3-N (≈90% attributable to agric.)	-non-fertilized range land, summer pasture not very signific. N source	--	--	
Bormann, Likens & Eaton 1969	Hubbard Brook, New Hamp.	13.23 ha	hardwood forest	shallow, coarser soils	I) 125 cm/yr II) 133 cm/yr	I) 6.5 NO_3-N I) 5.9 NO_3-N	--	-particulate matter, bulk moves in spring	--	
Taylor, Edwards & Simpson, 1971	Coshocton, Ohio	1) 17.6 ha 2) 123.0 "	1) Woodland (Pine & Locust trees 2) Farmland ≈½ area is permanent pasture. The rest = rotation of corn, winter wheat, grass clover meadow	Muskingum - Keene silt loam	--	1) NO_3-N = 1.0 Total N = 2.5 2) NO_3-N = 4.3 Total N = 6.0	-possibly winter manure spreading	Major Losses of NO_3-N in early spring	--	3 year study
Bouldin, Reid & Lathwell 1971								-most losses during peak runoff		

Table 2-1. (cont'd.)

REFERENCE	GEOGRAPHICAL REGION	WATERSHED AREA	LAND USE	SOILS	RAINFALL	LOSS RATES-FORMS kg/ha/yr	IDENTIFIED SOURCES (PRACTICES) YIELDING N	SEASONAL PATTERN	DEGREE TO WHICH POLLUTANTS TRANSMITTED	COMMENT
Schuman, Burwell, Piest and Spomer 1973	Treynor, Iowa	1) 30.0 ha 2) 33.6 " 3) 43.0 " 4) 60.8 "	1. Corn 2. Corn 3. Bromegrass 4. Corn Conservation Practice 1 Contour 2 Contour 3 Rotation Grazing 4 Terraces	Marshall, Monona, Ida, Napier silt loams. (loess soils) N fertilizer applied 1 448 kg/ha 2 168 kg/ha 3 168 kg/ha 4 448 kg/ha	1969-71 Averages 1 77.8 cm 2 77.4 3 75.5 4 75.7	Total N* 1. 39.64 2. 25.05 3. 2.36 4. 3.04 *most of this N was lost with eroded sediment	surface (storm) runoff important especially for sediment N	soluble -N and sediment -N show a definite decrease through the cropping season.	--	
Muir, Seim and Olson 1973	-Nebraska	-statewide survey	-varied	--	--	--	human and livestock densities more important than agricultural land loss.			
Burwell, Schuman, Piest, Spomer and McCalla. 1974	Southwestern Iowa	1. 157.5 ha 2. 33.6 ha	1. 60% corn + soybean 40% pasture 2. continuous contour corn since 1964	silt loams (loess)	≈69 cm/yr	1) 6.11 total N (4.29) associated with the sediment. 2) 36.34 total N (33.24) associated with the sediment.	-livestock feeding areas greatly increased NH_4-N and Kjeldahl -N content of the sediment	--	--	- 2-year study
Kilmer, Gillian, Lutz, Joyce, and Eklund. 1974.	Western N. Carolina	1. 1.89 ha 2. 1.48 ha	-fertilized grassland 1. 28 kg N/ha /yr fert. 2. 112 kg N/ha/yr fert.	-Hapludults seldom exceeding 1 m in thickness	109 cm	1) 3.28 (70% as NO_3-N) 2) 12.08 (85% as NO_3-N)	≈winter N loss probably residual from cropping activities	-losses high during winter and spring months		- 4-year study
Olness, Smith, Rhoades and Menzel. 1975	-Central Oklahoma	11 watersheds ranging in area from 5 - 17 ha	both cropland and rangeland watersheds	-cropland watersheds on alluvial soils and rangeland watersheds on residual upland soils	-96-102 cm cropland -105-111 cm rangeland	total from 2-15 kg N/ha with lower losses from rangeland	-N losses primarily organic or sediment adsorbed forms from cropland	--	--	- 1-year study surface runoff 4-10 fold greater than previous years

Table 2-1. (cont'd.)

REFERENCE	GEOGRAPHICAL REGION	WATERSHED AREA	LAND USE	SOILS	RAINFALL	LOSS RATES-FORMS kg/ha/yr	IDENTIFIED SOURCES (PRACTICES) YIELDING N	SEASONAL PATTERN	DEGREE TO WHICH POLLUTANTS TRANSMITTED	COMMENT
Burwell, Schuman, Saxton and Heinemann. 1976	Iowa	4 watersheds ranging in area from 30-60 ha	3 in corn, 1 in bromegrass pasture	-deep loess	- 72.4 cm/yr	Total soluble N ranged from 8.1-37.1	-subsurface NO_3 accounted for from 84-95% of annual soluble N loss. -terraces reduce sediment but not soluble N losses.	--	--	- 5-year study
Kissel, Richardson & Burnett. 1976	Texas	duplicate 4 ha watersheds	rotation of grain sorghum, cotton and oats	-swelling Houston Black clay		NO_3-N loss 3.2 sediment N 5.0	small and insignificant amount of N lost to surface waters as a result of fertilization	--	--	- 5-year study
Neilsen and Mackenzie. 1977	-Southeastern Ont. and Southwestern Quebec	-7 ranging in area from about 2,000 - 25,000 ha	-range typical of dairy area with corn, small grains and hay and pasture	-primarily soils developed on Champlain Sea sediments	--	soluble N from 1.1-22.8 sediment N from 0.9-7.9	-higher N losses from watersheds with more corn and relatively impermeable soils	Most of annual soluble and sediment N lost from March - May		- 1-year study
Johnson, Bouldin, Goyette & Hedges. 1976.	New York State	33,000 ha (various subwatersheds of major watersheds)	-34% forest -40% agric. land (dairying main agric. activity)	-thin acid tills at higher elevation to complex mixture of glacial outwash, lacustrine & alluvial deposits along streams	85-100 cm	Loss rates vary from 1.2-11.6	-likely land in corn production & domestic sewage major sources of NO_3-N	-concentration fit sine curve with max. values from Dec. to March	--	2-3 years

3. WATERSHED LOCATIONS, DESCRIPTIONS, AND SAMPLING

3.1 Agricultural Watersheds

Eleven predominantly agricultural watersheds were sampled, flow monitored and the water samples chemically analysed by the Ontario Ministry of the Environment (Water Resources and Laboratories Branch). Section 5 will be concerned with an analysis of this data. In addition, a number of more detailed process related studies were carried out in 6 of these watersheds, (AG-01, AG-03, AG-04, AG-05, AG-10 and AG-13). These studies with particular significance to stream N loadings will be summarized in section 4.

3.1.1 Location

The agricultural watersheds, ranged in area from about 2000 to 7500 hectares, and were located in south central and southwestern Ontario (Fig. 3-1). The watersheds eventually drained into either Lake Ontario (AG-07, AG-10, AG-11), Lake Erie (AG-01, AG-02, AG-04, AG-05, AG-13) or Lake Huron (AG-03, AG-06, AG-14).

3.1.2 Watershed characteristics

Considerable information was accumulated concerning the characteristics of the surveyed watersheds (Frank *et al*., 1977; Coote 1977). The information as used in this report has been summarized in Table 3-1).

The watersheds were selected to represent the range of agricultural land uses and kinds of soil in the Great Lakes drainage basin. For example, proportion of watershed area in corn ranged from 9.5% of AG-14 to 42.3% of AG-05. Significant amounts of soybeans (AG-13, 37.4%), tobacco (AG-02, 22.2%), and vegetables (AG-13, 27.8%) were located in some watersheds. Livestock densities ranged from low (0.01 animal units/hectare) to high (0.77 animal units/hectare) in AG-13 and AG-10 respectively. As a consequence of these variations in agricultural activity, fertilizer N additions ranged from 8.1 (AG-14) to 67.0 (AG-13) kg N/watershed hectare. A similar variation existed for manure N loads which were as low as 1.1 (AG-13) and as high as 48.1 (AG-10) kg manure N/watershed hectare. The variation in soil was illustrated by the % sand in surface soil (as estimated by the soil survey) which ranged from 10% for relatively impermeable watersheds AG-03 and AG-10 to 80% for AG-02. As a consequence of soil and drainage differences, estimated tile drainage was virtually nonexistent for some Watersheds (AG-02, AG-07 and AG-10) and almost 100% for others (AG-05, AG-13).

3.1.3 Sampling and flow characteristics

Water samples were collected at the flow monitoring stations located at the outlets of each watershed a variable number of times during the 1974-April 01, 1977 sampling period discussed for this report. The number of samples varied according to the watershed as illustrated for NO_3-N (Table 3-2). Watersheds AG-01, AG-03, AG-04, AG-05, AG-10 and AG-13 were most intensively sampled and the fewest samples (31) were collected from watershed AG-11. For most watersheds (7 of 11 watersheds), 1976 represented the year of most intensive sampling. Consequently, this year was used in order to assess the nature of sampling for the watersheds. Appendix 3-1 contains comparisons of

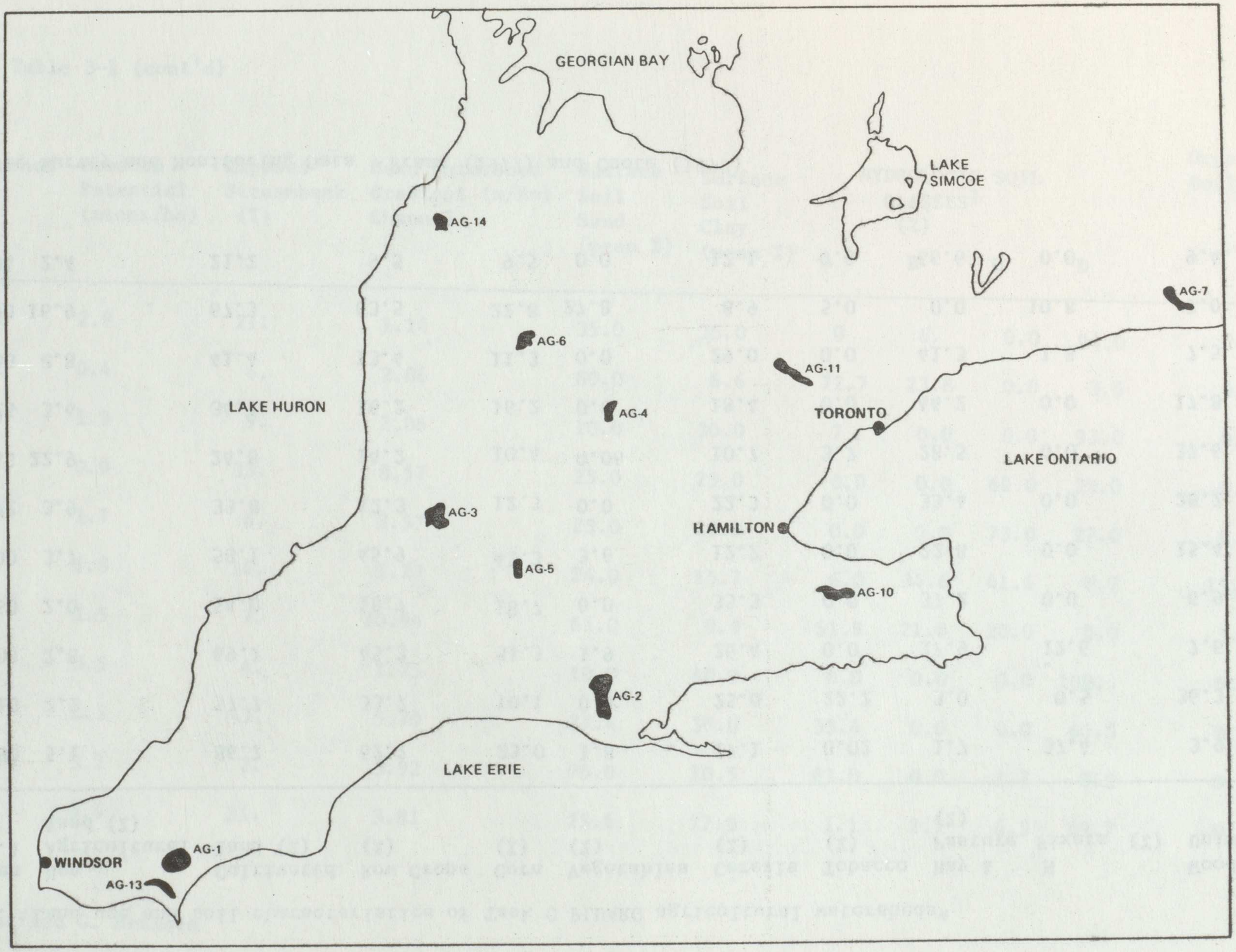

Fig. 3-1. Location of Task "C" Agricultural Watersheds

Table 3-1. Land use and soil characteristics of Task C PLUARG agricultural watersheds*

Watershed	Area (ha.)	Non Agricultural land (%)	Cultivated land (%)	Row Crops (%)	Corn (%)	Vegetables (%)	Cereals (%)	Tobacco (%)	Hay & Pasture (%)	N Fixers (%)	Woodland & Unimproved (%)
AG-01	5080	5.1	86.7	62.2	23.0	1.8	27.1	0.02	1.7	37.4	3.9
AG-02	7913	2.1	57.7	33.7	10.1	0.8	25.0	22.2	3.0	0.5	36.3
AG-03	6200	2.8	69.7	45.3	31.3	1.9	26.4	0.0	17.9	12.6	7.6
AG-04	1860	2.0	54.0	18.7	18.7	0.0	35.3	0.0	37.2	0.0	6.9
AG-05	3000	3.7	58.1	45.9	42.3	3.6	12.2	0.0	22.8	0.0	15.4
AG-06	5472	3.9	33.8	12.3	12.3	0.0	22.3	0.0	33.4	0.0	28.2
AG-07	5645	22.9	24.8	14.2	10.4	0.06	10.7	3.7	28.5	0.0	37.6
AG-10	3025	3.4	34.1	16.2	16.2	0.0	18.4	0.0	44.2	0.0	17.8
AG-11	2383	8.8	41.4	13.4	11.3	0.0	29.0	0.0	41.3	1.8	7.5
AG-13	1990	16.9	67.3	63.5	22.8	27.8	8.9	5.0	0.0	10.8	7.0
AG-14	4504	2.4	21.2	9.5	9.5	0.0	12.1	0.0	66.6	0.0	9.4

*Source Land Use Survey and Monitoring Data Frank (1977) and Coote (1977)

Table 3-1 (cont'd)

Watershed	Erosion Potential (mtons/ha)	Exposed Streambank (%)	Mean Watershed Gradient (m/Km) Channel	Surface Soil Sand (mean %)	Surface Soil Clay (mean %)	HYDROLOGIC SOIL CLASSES[1] (%)				Organic Soils (%)
						A	B	C	D	
AG-01	2.9	21.	1.14	35.0	35.0	0	6.	0.0	94.0	0.0
AG-02	0.4	6.	2.86	80.0	6.6	72.7	23.8	0.0	3.8	0.2
AG-03	1.9	9.	2.86	10.0	30.0	7	0.0	0.0	93.0	0.0
AG-04	0.9	33.	8.57	25.0	25.0	0.0	0.0	69.0	25.0	0.0
AG-05	1.7	6.	8.57	25.0	20.0	0.0	0.0	73.0	27.0	0.0
AG-06	1.8	14.	1.27	24.0	15.7	6.0	34.6	41.6	0.7	15.9
AG-07	2.5	7.	10.96	61.0	9.9	51.8	21.8	20.0	0.0	3.8
AG-10	0.5	4.	1.25	10.0	40.0	0.0	0.0	0.0	100.	0.0
AG-11	1.3	43.	5.70	27.4	30.0	33.4	0.0	0.0	66.5	0.0
AG-13	3.2	7.	3.92	75.0	10.5	83.0	0.0	1.7	0.0	0.0
AG-14	0.6	21.	3.81	25.6	27.5	1.1	2.7	6.5	89.7	0.0

[1] Classified G. Neilsen

Table 3-1 (cont'd)

Watershed	SOIL POLLUTION GROUPS					Livestock Density (animal units/ha)	Fertilizer N (kg/watershed) ha	Manure N (kg/watershed ha)	Housing Density (houses/ Km^2	Tile Drainage (% of watershed)
	Group 1	Group 2	Group 3	Group 4	Group 5					
AG-01	8.0	0.0	0.0	5.0	87.0	.08	58.4	3.7	.04	80.0
AG-02	0.0	0.0	96.0	0.0	4.0	.04	27.9	1.5	.03	2.0
AG-03	57.0	9.0	0.0	1.0	33.0	.48	35.3	35.2	.03	50.0
AG-04	76.0	1.0	0.0	1.0	22.0	.75	12.3	45.5	.04	20.0
AG-05	11.0	35.0	2.0	24.0	28.0	.61	45.6	43.7	.01	98.0
AG-06	52.	1.	47.	0.0	0.0	.51	11.3	42.0	.03	25.0
AG-07	26.	0.	74.	0.0	0.0	.28	15.5	17.1	.03	5.0
AG-10	66.0	0.0	0.0	0.0	34.0	.77	13.6	48.1	.05	0.0
AG-11	79.7	0.0	20.3	0.0	0.0	.32	12.0	23.9	.08	15.0
AG-13	11.0	26.0	36.0	3.0	24.0	.01	67.0	1.1	.17	99.0
AG-14	81.3	0.0	1.1	2.7	14.9	.55	8.1	28.9	.01	13.0

1976 sample and discharge duration curves which allow assessments to be made concerning whether flow was sampled in proportion to its occurrence (Fig. A.3.1 - Fig. A.3.11). These figures should be referred to concerning the statements which follow.

1976 sampling was biased to higher flows for watersheds AG-01; AG-04 and AG-06 but biased to low flows for watersheds AG-02 and AG-07. Flow and sample duration curves were similar for AG-03, AG-05 and AG-10 which were sampled near or above 300 times in 1976. Watershed AG-13 and AG-14 had irregular sampling while AG-11 had poor sample distribution.

Additional information concerning flow and sample characteristics in these watersheds has been summarized in Table 3-3. For example, the extent of sampling of the peak 20 flows is recorded. For every watershed, peak runoff flows occurred during the spring melt and runoff in either February or March. High flows occasionally occurred in April and November in some watersheds. AG-05 was the only watershed which had some of the top 10 annual flows occurring during the growing season months of July and August.

With the exception of watershed AG-07, annual runoff during both 1975 and 1976 was above long term normals (Table 3-4). The precipitation data for these watersheds (Table 3-5) indicated a dry October-November period in both 1975 and 1976 which was more than compensated for by precipitation during the rest of the year.

3.1.4 Chemical analyses

The N measured in the runoff samples from these watersheds included total kjeldahl N (TKN) on the bulk water samples and dissolved NO_3+NO_2-N and NH_4^+-N on water filtered through a 0.45 µ membrane. To determine TKN the bulk water sample was digested with concentrated H_2SO_4 in the presence of $K_2S_2O_8$. The resultant NH_4^+ was then determined colorimetrically on an autoanalyzer with alkali phenol, potassium, sodium tartrate and sodium hypochlorite (Berthelot method). For dissolved ammonia, the Berthelot reaction was again used with the color developed from the reaction of alkali phenol, potassium, sodium tartrate and sodium hypochlorite with ammonia detected on the autoanalyzer. The NO_3+NO_2-N was determined after filtration through a 0.45 µ membrane filter and reduction by Cd. The resulting NO_2-N was colorimetrically determined after reaction with sulphanilic acid and 1-napthylamine. It can therefore be seen that it was not possible to distinguish the relative proportions of NO_3 and NO_2-N. However, since NO_2-N runoff concentrations were likely quite low (Patni and Hore, Project 22), the NO_3+NO_2-N value will be henceforth referred to as NO_3-N. The sum of dissolved NO_3+NH_4-N was considered dissolved N (DN) while TKN plus soluble NO_3-N was considered total N (TN).

3.2 The Grand and Saugeen Rivers

In addition to and coincident with water sampling carried out in the agricultural watersheds, monitoring was undertaken by the Ontario Ministry of the Environment at various sites in the Grand and Saugeen River systems. These sample sites were located so that the outputs of the various sectors as defined in the location map (Fig. 3-2) could be determined. The whole Grand watershed represents about 700 000 hectares of land draining into Lake Erie whereas the approximately 400 000 hectares of the Saugeen system drain into

Table 3-2. Number of NO_3N measurements made each year (1974-1977) for each agricultural watershed.

	Number of Samples/Year			
WATERSHED	1974	1975	1976	1977*
AG-01	16	73	261	45
AG-02	--	41	34	6
AG-03	--	77	321	107
AG-04	--	50	298	19
AG-05	--	74	365	80
AG-06	--	72	59	17
AG-07	--	44	33	5
AG-10	--	123	294	39
AG-11	--	18	10	3
AG-13	--	79	141	86
AG-14	--	49	64	24

*samples as collected until April 01, 1977

Table 3-3. 1976 Sampling distribution with respect to flow characteristics of the 11 detailed agricultural watersheds:

WATERSHED		FLOW (q) CHARACTERISTICS $^*q_{10}$			THOSE OF LARGEST 20 FLOWS SAMPLED 1976	MONTHS OF LARGEST 10 ANNUAL FLOWS	NUMBER 1976 SAMPLES (NO_3-N)	GENERAL COMMENT CONCERNING SAMPLE DISTRIBUTION
		q_{10}	q_{50}	q_{90}				
		- - - cfs - - -						
AG-01	mean daily flow (qd)	28.	0.3	- -	2,5,9,11, 14,15	Feb. (6) Mar. (4)	261	- bias to higher flows
	flows on sample days (qs)	41.	0.8	- -	18 - 20			
AG-02	qd	98.	32.	21.	9	Feb. (7) Mar. (3)	34	- bias to low flows
	qs	56.	26.	21.				
AG-03	qd	100.	8.4	2.6	2-7, 9-11, 15 - 18	Feb. (5)Apr.(1) Mar.(3)Nov.(1)	321	- close to actual flow distribution
	qs	120	8.4	2.2				
AG-04	qd	24.	1.3	.12	1-12,14-17, 19	Mar.(8)Nov.(1) Apr.(1)	298	- bias to high flows
	qs	50.	3.6	.27				
AG-05	qd	42.	62.	1.2	1-2,4-6,9-13, 15-18	Feb.(2)May(1)Aug(2) Mar.(4)July(1)		- close to actual flow distribution
	qs	37.	59.	1.2			365	
AG-06	qd	72.	18.	10.	7-8, 10-12, 16,18	Mar.(10)	59	- bias to high flows
	qs	110.	28.	10.				
AG-07	qd	50.	17.5	12	none	Feb.(2)Mar(7) Apr(1)	33	- bias to low flows
	qs	30.	15.5	11.				
AG-10	qd	30.	0.84	.19	1-2,8,13 15-16,20	Feb.(6)Mar.(3) Apr.(1)	294	- slight bias to high flows
	qs	35.	1.4	.14				
AG-11	qd	12.	- -	- -	none	Feb.(6) Mar.(4)	10	- poor
	qs	12.	2	0.1				
AG-13	qd	14.	0.76	0.11	3-4,10,12 15,17	Jan.(1)Feb.(6) Mar.(3)	141	- bias to higher flows in low flow range
	qs	16.	2.2	0.2				
AG-14	qd	70.	1.9	- -	1-5,9-10, 14.	Mar.(9) Nov.(1)	64	- greater number of samples in mid and low flow range
	qs	64.	1.6	- -				

$^*q_{10}$, q_{50} and q_{90} represent the flows which were exceeded 10, 50 and 90% of the time.

Table 3-4. 1975 and 1976 annual runoff, long term (1952-1961) average annual runoff and per cent of precipitation occurring as stream runoff during an October 1st, 1975 to September 30th, 1976 water year for the 11 monitored agricultural watersheds.

WATERSHED	ANNUAL RUNOFF		LONG TERM (1952-1961)	PRECIPITATION as
	1975	1976	ANNUAL RUNOFF*	% RUNOFF FOR
	- - - - - - - -	cm	- - - - - - - -	(Oct.1/75-Sept.30/76)
AG-01	32	25	14	36
AG-02	43	53	28	52
AG-03	--	55	30	65
AG-04	44	41	33	47
AG-05	--	51	36	48
AG-06	--	58	47	70
AG-07	41	41	42	47
AG-10	--	42	29	58
AG-11	--	30	20	--
AG-13	37	33	14	47
AG-14	--	58	37	66

*based upon "Estimating Runoff in Southern Ontario" A. Coulson (1967)

Table 3- 5. Deviation* of monthly precipitation as measured in the 11 agricultural watersheds by M. Sanderson from long-term precipitation sites near each watershed, June 1975 - December 1976.

	1975							1976													
WATERSHED	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	June 1975 to Dec. 1976
AG-01	+55.4	-49.2	+141.1	- 2.9	-28.4	-11.0	+12.2	- 9.4	+12.4	+ 52.0	-11.5	-22.0	+ 8.4	+ 8.8	-55.6	+26.8	- 2.4	-45.0	-47.8	+ 31.9
AG-03	+13.0	-15.8	+ 83.2	- 5.4	-64.5	-28.4	-35.7	-38.0	-21.7	+ 17.8	+ 5.5	-15.3	- 4.9	+ 61.2	-18.8	+ 5.6	-26.5	-35.4	-67.7	-191.8
AG-04	+40.9	+ 6.7	+102.5	- 2.2	-35.2	-16.5	+ 3.3	+20.7	+ 5.8	+ 70.4	+12.4	-12.6	+38.9	+ 1.7	-41.5	+31.8	-14.2	-52.5	-36.7	+123.7
AG-05	+24.4	-14.5	+ 93.3	-14.3	-51.9	-12.6	+ 6.1	- 9.0	-11.4	+ 59.7	- 0.9	- 2.4	-31.6	+129.5	+78.3	+20.7	+ 2.1	-20.6	-42.9	+ 70.1
AG-06	+ 9.3	- 8.1	+142.6	+11.3	-21.4	-22.4	+ 2.7	- 0.5	- 1.7	+ 51.6	+ 5.0	+ 1.9	+11.3	+ 19.6	-20.4	+24.3	-14.4	-48.4	-44.3	+ 98.0
AG-07	+24.2	-14.6	- 28.0	+23.3	-40.8	- 7.9	+ 1.9	+ 4.6	- 9.4	+ 58.1	- 1.0	+ 5.7	+37.2	- 19.6	-34.0	- 5.7	-12.8	-51.9	-55.1	-125.8
AG-10	+39.6	- 1.4	+100.0	+ 2.9	-11 0	- 0.7	+10.1	-11.5	- 4.7	+ 66.9	+13.2	+22.9	+38.6	- 6.4	-49.0	+ 5.9	- 7.0	-48.7	-23.9	+135.8
AG-11	+ 4.1	-35.9	+ 5.5	-19.0	-30.9	-19.8	- 1.7	-15.1	+12.6	+ 37.0	-11.9	+ 6.8	+13.1	+ 33.1	-44.5	+ 8.0	- 7.9	-59.8	-32.7	-159.0
AG-13	+20.4	-38.2	+162.1	+ 5.8	-29.4	-19.0	+ 9.2	- 0.6	+28.4	+116.0	-19.5	-27.0	+ 9.4	+ 7.8	-53.9	+32.8	- 3.4	-31.0	-44.8	+125.1
AG-14	+22.8	-17.5	+119.6	- 5.3	-45.7	- 4.3	-32.4	+23.2	-13.3	+ 46.8	-37.3	-10.3	+81.8	+ 5.5	-47.4	+24.7	- 1.7	- 0.3	-50.4	+ 50.5

* deviations from long term averages (mm)

Lake Huron. Section 6 will be concerned with a detailed analysis of these major river systems with respect to stream N loadings.

3.2.1 Sector characteristics

The various sectors of the Grand and Saugeen range in area from about 24 000 to 193 000 hectares. They thus represent much larger tracts of land with more heterogeneous land use conditions than the agricultural watersheds. For example, within the Middle Grand sector were located the major urban centres of Guelph, Kitchener and most of Cambridge. Brantford and Paris were located in the Brantford sector. The Saugeen basin represented a more rural area but nevertheless contained nine small rural communities including Walkerton, Hanover, Chesley etc. Consequently, not all the N lost in runoff represented inputs from agricultural activities. Industrial and municipal N sources exist. Although considerably more information describing the Grand and Saugeen sectors can be found in the Ontario Ministry of Environment study reports, sector characteristics as used in the analysis of N loss from the Grand and Saugeen have been summarized in Table 3-6. It was evident from these characteristics that the intensity of agricultural land use was less in the sectors compared to the agricultural watersheds. For example, proportion of corn plus potatoes did not exceed 28% total area (Caledonia, Grand River). No estimated fertilizer rate exceeded the 31.1 kg/watershed hectare in the Caledonia sector. The heterogeneous mixture of soils within the Grand and Saugeen is probably reflected by the restricted range of surface mean clay contents (15.3-28.2% in the Grand and 16.0-19.3% in the Saugeen).

3.2.2 Sampling, flow characteristics and chemical analyses

Gauging stations on the Grand and Saugeen allowed the calculation of continuous discharge for the monitored sites. Event oriented surface samples were collected by the 'equal transit rate method' (Guy and Norman, 1970) and N was analysed by the Laboratories Branch of the Ontario Ministry of the Environment using methods previously described for the agricultural watersheds.

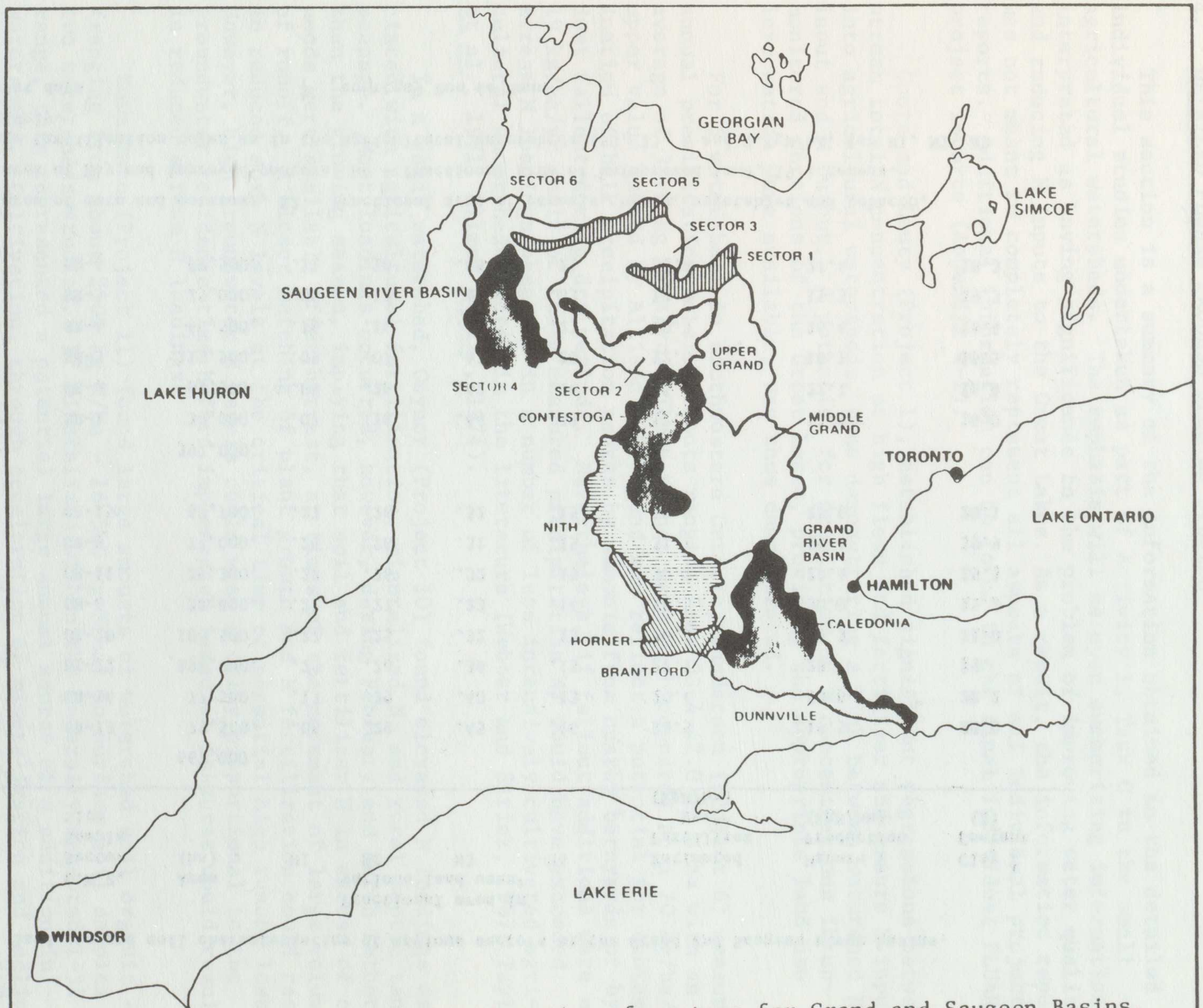

Fig. 3-2 Location of sectors for Grand and Saugeen Basins.

Table 3-6. **Area, land use and soil characteristics of various sectors at the Grand and Saugeen river basins.**

Sector	O.M.E. Sector Sample Site	Area (ha)	Fractional area in various land uses* N1	N2	N3	N4	Estimated Fertilizer Use** (kgN/ha)	Manure † Production (kgN/ha)	Clay ‡ Content (%)
The Grand River		667,000.							
Upper Grand River	GR-13	79,500.	.08	.29	.45	.16	16.5	19.5	20.0
Conestoga River	GR-14	77,500.	.13	.29	.40	.13	20.4	40.8	28.2
Middle Grand River	UL-22	194,000.	.23	.26	.36	.15	27.1	28.	19.
Nith River	GR-20	103,500.	.27	.25	.32	.13	30.3	35.3	21.0
Horner Creek	GR-6	38,400.	.22	.27	.23	.14	26.5	30.0	15.3
Brantford	GR-11	29,300.	.27	.26	.32	.15	30.2	27.4	19.3
Caledonia	GR-5	77,000.	.28	.26	.31	.15	31.1	26.4	19.9
Dunnville	GR-15	63,700.	.27	.26	.32	.15	30.4	25.6	20.1
The Saugeen River		397,000.							
Upper Saugeen	SR-1	39,000.	.07	.16	.44	.33	12.4	13.9	16.0
South Saugeen	SR-2	61,500.	.08	.26	.42	.24	15.6	22.7	16.9
Central Saugeen	SR-3	115,500.	.09	.07	.43	.28	12.0	18.1	16.5
Teeswater	SR-4	66,500.	.16	.16	.46	.23	20.3	26.4	16.4
North Saugeen	SR-5	25,000.	.05	.12	.49	.33	10.2	15.3	19.3
Lower Saugeen	SR-6	89,500.	.11	.18	.45	.25	16.4	27.4	18.3

*N1 - fractional area of corn and potatoes, N2 - fractional area of cereals, beans, vegetables and tobacco, N3 - fractional area of hay and improved pasture, N4 - fractional area of unimproved land, 1971 census.

** assuming average fertilization roles as in the agricultural watersheds (80, 25, 6 and 0.KgN/ha, for N1, N2, N3 and N4 respectively.

† 1971 census tract data

‡ courtesy Ron de Haan

4. DETAILED PLUARG PROCESS-RELATED STUDIES

This section is a summary of the information obtained in the detailed individual studies undertaken as part of Activity 1, Task C in the small agricultural watersheds. The emphasis will be upon summarizing information interpreted as having significance to the problem of improving water quality and reducing N inputs to the Great Lakes. As a result, the information reported was not meant to completely represent all aspects of all individual project reports. Additional information can be found in the final individual PLUARG project reports (Appendix 4-1).

Coote and Leuty (Project 1), established significant regressions between stream total N concentration at high flows and fertilizer and manure N inputs into agricultural watersheds, thus demonstrating a link between watershed N input and N output. A potential for prediction of N concentrations in unmonitored portions of the Great Lakes, providing the appropriate land use information were available, was thus demonstrated.

For 6 watersheds in southwestern Ontario, Sanderson (Project 6) measured annual precipitation total N inputs ranging from 33.4-42.0 kg N/ha with an average of 38.0 kg N/ha/yr. These values were high compared to a 20 kg/ha/yr upper value quoted by Allison (1966) and may reflect a potential for contamination of bulk precipitation gauges by ammonia from nearby barnyards or by dust fallout during dry periods. Nevertheless, if fallout additions were only 19 kg/ha/yr (half of those measured precipitation N) would have exceeded stream N loadings observed in a number of less intensively cultivated agricultural watersheds quoted in the literature (Webber and Elrick, 1967; Taylor _et al_., 1971; Kilmer _et al_., 1974).

In a sandy watershed, Gaynor (Project 10) found elevated N loadings associated with agricultural fertilization, mineralized N, and rural septic tank seepage. Most loadings occurred, however, during February and March rather than the growing season, implying that soil and fertilizer N in excess of crop needs were available after harvest, at times of the movement of large volumes of runoff. A closer matching of plant growth and N fertilization could result in reduced soil N levels at the critical time of potential high runoff loss. However, high groundwater N levels could mean a delay proportional to the groundwater residence time before implemented remedial measures would result in reduced stream N loadings.

Kowalenko (Project 11) found large amounts of watershed soil organic -N (ranging from about 2500 kg N/ha - 16 500 kg N/ha) in surface soil samples in two watersheds studied. If mineralized within the generally accepted 1-3% range, this represented a potential large annual source of N addition in watersheds. Cultivation, through acceleration of mineralization and decline in soil organic matter content, may have released significant amounts of N to groundwater or streams in the past. Since mineralization remains relatively constant compared to seasonal variations of plant uptake and denitrification, excess mineralized N could be available for leaching at certain times of the year. As a consequence of this, and the generally higher natural organic N content of finer textured soils, it was suggested that an objective soil N test would be useful to better match crop needs with N supply and promote efficient N fertilization. Given that the C/N ratios of organic residues influence whether net mineralization or immobilization of N occur, management of organic residues may hold promise for reducing the apparent excess of soil N at the end of the growing season prior to the leaching of watershed soils by the large volumes of water associated with late winter and spring runoff. Denitrification, which seemed quite temperature sensitive, does not appear to hold potential in reducing NO_3-N in soil water during the cool, wet seasons.

Field plot studies conducted by Cameron et al. (Project 13) within a sandy and clay watershed revealed that, with the possible exception of soybeans, N in excess of crop needs was available for leaching. Net mineralization of N from added organic residues was considered an important N addition to soil. In the sandy watershed AG-13, net mineralization was calculated to account for the addition of approximately 30 to 80 kg N/ha/year, but fertilization on potatoes and burley tobacco added another 165 and 210 kg/ha, respectively. Average estimated N losses (calculated by a balance method) on the sandy watershed were near zero for the soybean fields, 33 for the burley tobacco and 133 kg/ha/year for the potato fields.

Net mineralization rates in the clay watershed AG-01 were estimated to range from 80 to 180 kg N/ha/year, while average fertilization rates were 65 and about 160 kg N/ha on winter wheat and corn, respectively. Average annual N losses (including leaching and denitrification) were very consistent, ranging from 61 to 81 kg N/ha/year. Cameron et al., (1977) suggested that 50% of the excess N in these watershed soils was probably lost by denitrification leaving the remainder to be lost by deep drainage or interflow, via tile drains. Miller (1975) has shown substantial tile drain losses of NO_3-N (as high as 56 kg/ha/year) on similar southern Ontario soils.

Suction lysimeters installed at 90 and 150 cm on the plot areas gave some evidence of deep NO_3-N movement during the rainy spring period. However, most of the movement of NO_3-N took place in fall and winter. A simulation model was developed based on the monitored plot data from Cameron et al., (Project 13), the N-transformation data from Kowalenko (Project 11) and the physical data from Topp (Project 12). This model showed that major NO_3-N losses on the tobacco plot took place in the fall. A model developed by W. Findlay demonstrated the importance of the winter period for deep percolation of NO_3-N in the mild wet winter climate of southern Ontario.

From one intensively monitored sandy Ontario watershed with a high potential for groundwater contamination, (Gillham et al., Project 14) groundwater N was estimated to contribute 10 to 20 kg N/ha/yr to stream N loadings. (Measured NO_3-N loadings during 1976 from this watershed were about 21 kg/ha). Although agricultural activity was definitely contributing to elevated NO_3-N concentrations in groundwater, as evidenced by a general trend for elevated N concentration in the shallow groundwater in cultivated areas, the exact contribution of agriculture to groundwater and stream N could not be assessed since highest groundwater N concentrations did not necessarily occur in areas of highest fertilizer N application rate. This implies that a simple reduction in N fertilization may not reduce N to stream courses.

There was also strong evidence for denitrification of deeper groundwater N in these coarse textured soils since lower NO_3-N concentrations, decreased redox potential and low dissolved oxygen contents and methane production occurred in deep piezometers. The nonconservation of N mass in groundwater flow, combined with the spatial variability of NO_3-N concentrations created extreme difficulties in developing deterministic models for large scale systems to predict NO_3-N transport or discharge to streams.

In the coarse textured soils, tritium analyses suggested a 7-15 year travel time for discharge of groundwater N to the main stream course. It is quite possible that current agricultural practices were not being reflected in present groundwater drainage. In addition, the extent of denitrification of this groundwater N would remain unknown. For example, groundwater N delivery in this watershed was estimated to be 10-20 Kg N/ha while N storage was approximately 91 kg N/ha. Since groundwater travel times in finer textured soils would likely be orders of magnitude slower, waterways through areas of coarse textured overburden were judged to be more susceptible to pollution from contaminated groundwater. In addition, reconnaissance groundwater surveys in other watersheds indicated that higher NO_3-N concentrations occurred more frequently in coarse than fine textured material.

Since most NO_3-N losses to groundwater occur in the fall and spring, it was suggested that fall cover crops could reduce N available for leaching at this critical time.

Although denitrification of sediment NO_3-N and nitrification of sediment NH_4-N occurred in aerated columns overlying sediment collected from Ontario streams (Robinson and Kaushik, Project 19-A), variability in measurement of discharge and problems in accounting for all N additions within a stream channel prevented definitive field confirmation of N gains or losses from sediment to the stream. Consideration of literature values suggested one might conservatively assume loss rates of about 0.2 g of N/m^2/day for Ontario streams (2 kg/day/ha of stream channel).

In one watershed (Hynes, Project 19-B), measurements of drifting solid organic matter showed that although the material was enriched in N (1-8% dry weight), most loss was concentrated during spring melt and runoff, but comprised a negligible fraction of annual stream N loadings.

Detailed nutrient monitoring by BEAK consultants (Hodd, Project 20) in a high livestock density watershed showed high unit area N loadings to the stream from beef, dairy and swine livestock operations (ranging from 35-300 kg/ha). This compared well to loadings (ranging from 26-169 kg) from agricultural cropping areas in the same watershed. N loadings were about 50 times the magnitude of P loadings and occurred primarily (85%) as NO_3-N. Most of annual N loadings occurred during the winter and spring.

It was suggested that N loadings from livestock activities could be decreased by separation of sewage and land drainage systems and prevention of direct access of cattle to surface water, especially at times of high volume flow in the winter and spring. A need for careful disposal of manure in the near stream area was identified. This was likely to be especially important for watersheds which have relatively impermeable clay soils. Thus, adequate waste containment where land slopes towards the stream, avoidance of winter manure spreading in the stream flood plain and diversion of ditches draining livestock areas from direct entry to stream channels was recommended.

Groundwater monitoring in a coarse textured till near an unpaved feedlot (Hore and Coote, Project 21) suggested a considerable movement of N into groundwater. Evidence was presented to suggest mineralization of organic -N, nitrification of NH_4-N and denitrification within the shallow groundwater zone which was influenced by the feedlot. This implied a chemical complexity in the transport of groundwater N and non-conservation of N mass in groundwater transport. Variability between feedlots would lead to imprecision in estimating the impact of feedlots and manure storages on N loadings to the Great Lakes. Rates of denitrification relative to availability of NO_3-N may vary according to soil physical characteristics such as texture and permeability.

In a study of subsurface and surface runoff from an integrated farm operation at the Greenbelt Farm of the Animal Research Institute (Patni and Hore, Project 22), it was concluded that most of annual flow occurred during a few days of heavy spring runoff. Consequently, this time period had an overriding influence on annual N loadings. Stream N loadings were higher from fields with previous high manure application rates. Evidence suggested higher stream N loadings from the drained coarse textured soils. It was concluded that N from plowdown of large applications of liquid manure (500 kg N/ha/yr, split into spring and fall applications) for up to 3 consecutive years on fine-textured soils did not impair stream water quality.

5. AGRICULTURAL WATERSHED STUDIES

5.1 Stream N Concentrations

5.1.1 Total Kjeldahl-N

From 1974-1977, watershed flow weighted TKN averages ranged from a minimum of 0.64 mg/L at AG-06 and AG-02 to a maximum of 2.37 mg/L at AG-01 (Table 5.1). AG-06 and AG-01 also had minimum and maximum average suspended sediment concentrations respectively. This suggested a close association of TKN and sediment. The TKN measurement included soluble and exchangeable NH_4-N and soluble and particulate organic N. Exchangeable NH_4-N and particulate organic N would be directly associated with sediment.

5.1.2 NH_4-N

Soluble NH_4-N was almost always the lowest value of the 3 measured N parameters. Flow weighted averages ranged from 0.03 mg/L at AG-06 to 0.60 mg/L at AG-13. Watershed AG-13 had the maximum rural housing density (Table 3-1) suggesting that the higher NH_4-N concentrations might reflect contamination of stream runoff by septic tank seepage. The 3.00 mg/L NH_4-N value, considered toxic to fish (OWRC, 1970) was exceeded once during the course of the study in two of the watersheds (AG-01 and AG-05).

5.1.3 NO_3-N

Average NO_3-N concentrations ranged from 0.57 mg/L at AG-07 to 5.62 mg/L at AG-01. It appeared that agricultural activities significantly influenced stream N concentrations since AG-07 with maximum area of unimproved and woodland represented low intensity agriculture. In contrast, watershed AG-01 was second only to AG-13 in row crops and unit area fertilizer N input (Table 3-1) and could therefore be considered typical of intense agricultural activity. The relatively impermeable soils of AG-01 may result in more favorable conditions for N runoff in comparison to the sandy soils of AG-13. NO_3-N was the predominant form of runoff N since mean NO_3-N concentration exceeded NH_4-N values by from 4 to 70 times for the 11 agricultural watersheds (Table 5-1). More detailed examination of NO_3-N concentration distributions indicated that the 10 mg/L NO_3-N drinking water standard (OWRC, 1970) was exceeded as frequently as 8% of the samples in 6 of the 11 monitored watersheds (Table 5-2).

Watersheds with samples exceeding the NO_3-N drinking water standard had more intensive agricultural activity with corn hectarages exceeding 20% of total watershed area (with the exception of AG-10, 16.2% corn). 5 of these 6 watersheds had concentrations between 5 and 10 mg/L from 16.2% of the time (AG-01) to 46.8% of the time (AG-03). Thus, there is the possibility that intensification of agricultural activities (higher N fertilizer rates, greater corn hectarages) could result in more NO_3-N concentrations exceeding the drinking water standards if attention is not paid to minimizing N loss to drainage waters. Biggar and Corey (1969) suggested that a critical readily-available N concentration above 0.3 mg/L was associated with acceleration of eutrophication and this may be a useful threshold although Viets (1975) cautioned that recent literature refrains from setting limits on the concentration of N

Table 5-1. Flow weighted means, range and number of samples for total Kjeldahl N, NO_3-N, soluble NH_4-N and suspended sediment as measured for the 11 agricultural watersheds over 1974 - April 1977 sample period.

	NO_3-N			Dissolved Ammonia			Total Kjeldahl N			Suspended Solids		
Watershed	Samples	Mean	Range	Samples	Mean	Range	Samples	Mean	Range	Samples	Mean	Range
		- - mg/L - -			- - mg/L - -			- - - mg/L - -			- - mg/L - -	
AG-01	395	5.62	(.01-32.80)	384	0.43	(.00-3.50)	413	2.37	(.20-8.70)	374	244.8	(6 -4667)
AG-03	506	5.50	(.39-20.40)	510	0.14	(.00-1.25)	517	0.96	(.24-2.70)	467	22.5	(1 -391)
AG-05	519	4.33	(.24-11.30)	519	0.24	(.00-3.70)	521	1.48	(.03-9.20)	492	55.3	(0.5-1794)
AG-13	306	4.30	(.05-16.00)	301	0.60	(.00-2.95)	318	2.28	(.10-5-75)	277	84.1	(0.25-1225)
AG-04	367	3.75	(.02-13.00)	368	0.28	(.00-2.40)	348	1.51	(.40-6.10)	314	172.4	(2 -3588)
AG-11	31	3.34	(.00-4.35)	31	0.41	(.00-2.24)	32	1.34	(.16-3.90)	31	32.6	(1.7-460)
AG-10	456	2.13	(.00-15.80)	454	0.52	(.00-2.90)	466	2.34	(.05-5.40)	451	64.2	(2 -644)
AG-06	148	2.08	(.11-3.60)	150	0.03	(.00-.08)	150	0.64	(24-1.28)	142	9.8	(1 -192)
AG-02	84	1.05	(.18-6.63)	83	0.04	(.00-.13)	87	0.64	(.17-1.70)	84	47.4	(0.5-695)
AG-14	137	0.88	(.00-2.66)	136	0.11	(.00-.24)	134	0.73	(.25-1.80)	130	24.4	(1.9-790)
AG-07	82	0.57	(.01-1.19)	82	0.12	(.00-.36)	79	0.74	(.07-1.70)	78	133.8	(1.1-395)

Table 5-2. Detailed distribution of NO_3-N concentration for the 11 agricultural watersheds as sampled from 1974 to April, 1977.

Watershed	Total Number of samples	% Time Concentrations recorded			
		≤0.3	≥0.3<5	≥5<10	≥10
AG-01	395.	28.9	47.1	16.2	7.8
AG-02	84.	1.2	96.4	2.4	0.
AG-03	506.	0.	46.6	46.8	6.5
AG-04	367.	1.6	84.2	13.6	2.7
AG-05	519.	0.2	67.1	31.8	1.0
AG-06	148.	2.7	97.3	0.	0.
AG-07	82.	12.2	87.8	0.	0.
AG-10	456.	32.9	62.7	3.3	1.1
AG-11	31.	64.5	35.5	0.	0.
AG-13	306.	2.3	53.3	36.9	7.5
AG-14	137.	46.	54.	0.	0.

or P needed to make a lake eutrophic. Instead any addition of N or P to surface waters is regarded as undesirable. 0.3 mg/L of NO_3-N was exceeded more than half of the samples from every watershed except AG-11, which was sampled for NO_3-N concentration only 31 times 1975-1977. In general, runoff from these agricultural watersheds contained sufficient N that algal growth in any receiving bodies of water would not be limited by N.

5.1.4 Seasonal concentration patterns

In general, N concentrations for the agricultural watersheds tended to be highest during the winter months and lowest during the summer months. This pattern was noted by Johnson et al., (1976) for monthly NO_3-N concentrations in various subwatersheds of Fall Creek, New York and expressed using a sine curve relationship. The relationship was found to exist as expressed below for most of the 11 Ontario agricultural watersheds for both dissolved and total N.

$$\text{DN or TN} = a + b \sin\Pi(m_{/12})$$

where Y = monthly average concentration of dissolved N (DN) or total N (TN)
m = monthly index (m=o for Nov., m=1 for Dec., --- m=11 for Oct.)
a,b = regression coefficients (summarized for agricultural watersheds, Table 5-3)

These relationships were often significant at $p = .01$ and predicted that dissolved and total N concentrations peak in February with a minimum in August. For watershed AG-13, a comparison between predicted and actual mean monthly total N concentration (Fig. 5-1) showed that the predicted means fell within ±1 standard deviation for every month except August. Maximum variability was found for this watershed in June at which time storm runoff had N concentrations in excess of 10 mg/L.

5.1.5 Relationship of concentration to flow

For most watersheds, there was a statistically significant relationship between NO_3-N concentration and instantaneous or mean daily discharge over the 1974-1977 sampling period of the form.

$$\ln NO_3\text{-}N = Bo + B_2 \ln Q + B_2 Q$$

where NO_3-N = nitrate plus nitrite concentration (mg/L)
Q = instantaneous (Qi) or mean daily ($\bar{Q}$) discharge (ft^3/sec)
Bo, B1, B2 = regression coefficients (Table 5-4)

Since B_2 was negative for all significant relationships, maximum NO_3-N concentration did not occur at maximum discharge. For example, for AG-13, maximum NO_3-N concentration occurred during December flows whereas maximum discharge occurred during March and April.

For AG-13, summer storm N concentrations increased above baseflow N concentrations but not in proportion to the rate of increase of discharge (Cameron et al., 1977). Since surface runoff represented a high proportion of storm runoff, this would suggest that surface runoff could make a significant contribution to annual stream N loadings. The proportion of total annual runoff occurring as surface runoff would determine the significance

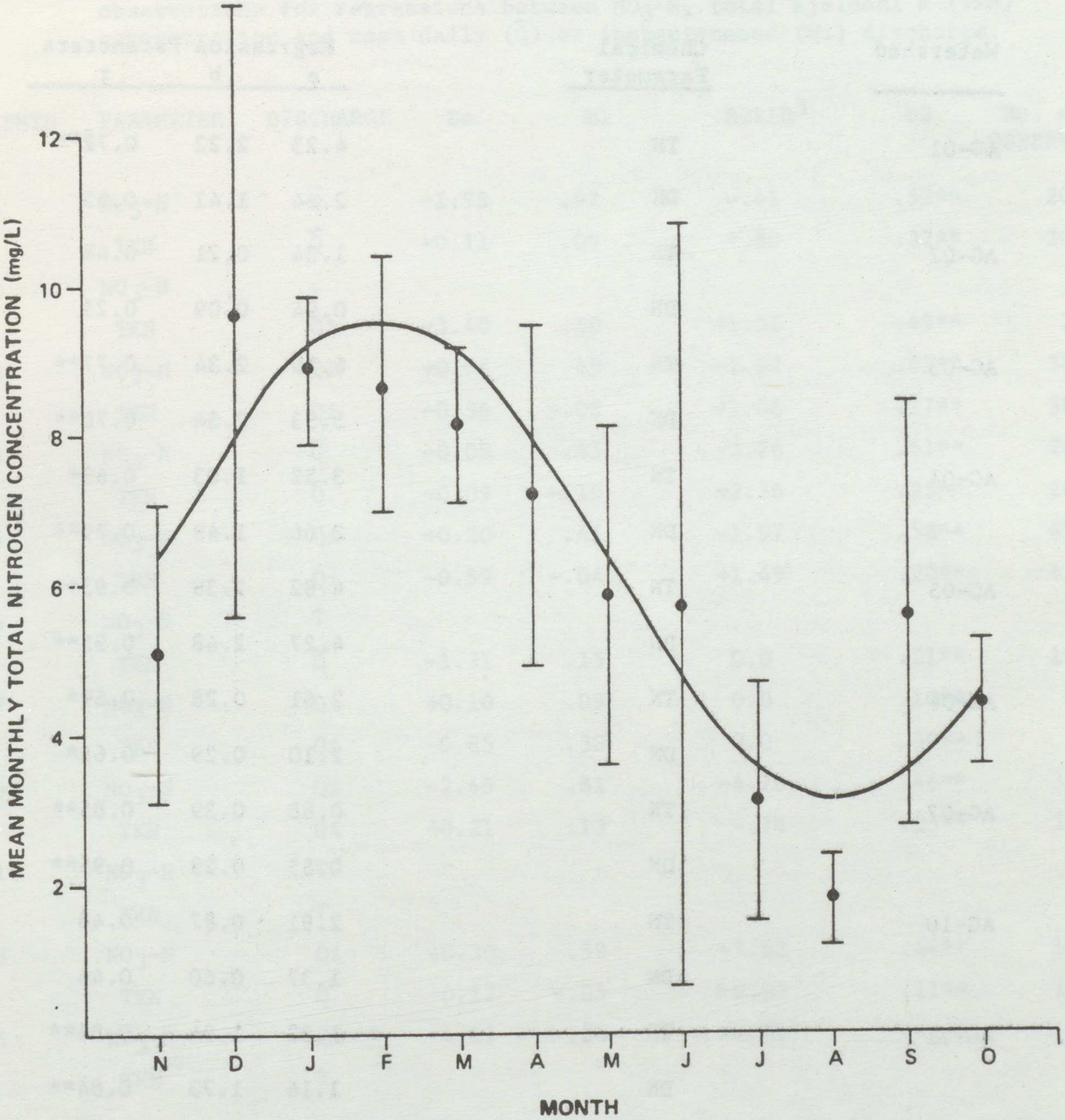

Fig. 5-1 Predicted and actual monthly mean ±1 standard deviation of stream total N concentration, Watershed AG-13, 1975 and 1976

Table 5-3. **Summary of regression parameters for dissolved (DN) and total N (TN), agricultural watersheds, Jan.1975-Dec.1976.**

Watershed	Chemical Parameter	Regression Parameters		
		a	b	r
AG-01	TN	4.23	2.22	0.72**
	DN	2.64	1.41	0.55
AG-02	TN	1.34	0.21	0.48
	DN	0.94	0.09	0.25
AG-03	TN	6.10	2.34	0.77**
	DN	5.53	2.34	0.76**
AG-04	TN	3.52	1.03	0.63*
	DN	2.66	1.49	0.79**
AG-05	TN	4.82	2.39	0.93**
	DN	4.27	2.48	0.95**
AG-06	TN	2.61	0.28	0.69*
	DN	2.10	0.29	0.65*
AG-07	TN	0.88	0.39	0.85**
	DN	0.55	0.29	0.95**
AG-10	TN	2.91	0.87	0.48
	DN	1.37	0.60	0.46
AG-11	TN	1.82	1.84	0.86**
	DN	1.16	1.73	0.84**
AG-13	TN	6.35	3.25	0.90**
	DN	5.35	2.89	0.88**
AG-14	TN	1.29	0.29	0.41
	DN	0.61	0.47	0.61

*, ** Significant at 5% and 1% level respectively.

Table 5-4. Regression coefficients, coefficient of determination and number of observations for regressions between NO_3-N, total Kjeldahl N (TKN) concentration and mean daily ($\overline{Q}$) or instantaneous (Qi) discharge.

WATERSHED	PARAMETER	DISCHARGE	Bo	B1	B2X10^3	r2	No. of OBSERVATIONS
AG-01	NO_3-N	$\overline{Q}$	-1.98	.92	-.41	.53**	208
	TKN	$\overline{Q}$	-0.11	.09	+.80	.32**	208
AG-02	NO_3-N	T					
	TKN	Qi	-3.40	.50	+1.55	.49**	72
AG-03	NO_3-N	Qi	+0.05	.49	-1.97	.62**	385
	TKN	Qi	-0.36	-.08	+1.06	.17**	385
AG-04	NO_3-N	$\overline{Q}$	-0.08	.45	-3.26	.61**	208
	TKN	$\overline{Q}$	-0.09	-.10	+2.76	.25**	208
AG-05	NO_3-N	Qi	+0.20	.41	-1.97	.58**	422
	TKN	Qi	-0.59	-.04	+1.49	.20**	422
AG-06	NO_3-N	T					
	TKN	$\overline{Q}$	-1.31	.15	0.0	.21**	108
AG-07	NO_3-N	Qi	+0.10	.09	0.0	.10**	72
	TKN	Qi	-0.85	.30	0.0	.59**	72
AG-10	NO_3-N	Qi	-2.65	.81	-4.76	.48**	383
	TKN	Qi	+0.21	.13	-.74	.25**	383
AG-11	NO_3-N	T					
	TKN	T					
AG-13	NO_3-N	Qi	+0.30	.59	-7.62	.46**	195
	TKN	$\overline{Q}$	-0.12	-.05	+6.53	.11**	192
AG-14	NO_3-N	Qi	-4.19	+.86	-1.71	.51**	83
	TKN	T					

** denotes r value significant at $p = .01$ level.

† regression of form $\ell n\ NO_3+NO_2 = Bo + B1\ \ell nQ + B2Q$.

T very low Coefficients of determination.

of this contribution. The relative contribution of surface versus groundwater flow to total stream N loadings was not assessed since baseflow and surface runoff separations were not performed for these watersheds. The difficulties inherent in such analysis were outlined by Gillham et al. (1977).

However, NO_3-N concentrations for the agricultural watersheds during periods of baseflow recession in January 1976 varied from watershed to watershed. Highest NO_3-N concentrations (Table 5-5) occurred in watersheds with high N fertilization rates and high corn hectarage. Since stream flow under such conditions contained a high component of groundwater flow, the N contamination of at least the near stream groundwater is a distinct possibility.

Most of the agricultural watersheds had statistically significant positive relationships between discharge and total Kjeldahl N of a similar form to that for NO_3-N (Table 5-4) but of low R^2 values indicating a wide scatter in the plot of TKN against discharge. The higher variability of TKN may reflect the dependence of this concentration on variation of both discharge and sediment concentration.

5.1.6 Relationship to watershed characteristics

Correlation analyses between monthly flow weighted mean dissolved N concentration and the watershed characteristics (Table 3-1) suggested that watersheds with greater corn hectarage tile drainage area and fertilizer N input had higher monthly dissolved N concentrations (Table 5-6). Most significant correlations occurred during the Nov.-May period of each year. These three watershed characteristics were not independent since they were all in turn correlated with row crops. In addition, there was no adequate index among all watersheds of native soil N fertility. Consequently, it was not possible to test whether high watershed soil organic-N contents alone would result in high DN contents of runoff.

Negative relationships between stream DN concentrations and watershed area of woodland suggested lower concentrations of DN in runoff from watersheds with extensive wooded areas. It should follow from this that increased wooded area in a watershed would decrease stream DN concentration. There were a small number of significant correlations at various times between housing density, erosion potential, stream gradient, and stream DN concentration. There were not a sufficient number of these correlations to suggest any important trends. With the exception of stream gradient, all of these correlations occurred with land use variables. The only significant correlation with soils occurred between the June stream concentrations and watershed area of pollution group 5 soils. Since this soil grouping contained fine and medium textured, poorly drained soils, it would appear that large areas of such soils, can mean high June stream N contents. Higher soil moisture contents and reduced infiltration of such soils together with low crop cover may result in more storm runoff of higher DN concentration in this month.

Elevated TKN concentrations occurred on watersheds with more impermeable soils as suggested by positive correlations of monthly TKN concentration, average watershed clay content and % of soil area in relatively impermeable pollution group 5 or hydrologic class D soils (Table 5-7). The runoff from these watersheds, containing a higher relative proportion of surface runoff, was enriched in the soluble organic-N and sediment associated exchangeable NH_4^+ or organic -N detected as TKN.

Table 5-5. **Summary of NO_3-N concentration in streamflow from agricultural watersheds in non-thaw periods, January 1976 and regression relationship between these mean concentrations and watershed fertilizer N input.**

WATERSHED	NUMBER OF SAMPLES	MEAN NO_3-N -mg/L-	REGRESSION RELATIONSHIP
AG-01	- - - - frozen - - - - - -		
AG-02	1	0.80	
AG-03	15	6.59	Y = 1.03 + 0.81 X r=0.84**
AG-04	1	1.91	
AG-05	22	5.16	
AG-06	3	2.79	where Y = mean January watershed NO_3-N concentration (mg/L) X = fertilizer N input (kg/watershed ha)
AG-07	2	0.61	
AG-10	19	0.91	
AG-11	- no measurements -		
AG-13	3	7.06	
AG-14	3	0.55	

Table 5-6. **Significant correlations* between** monthly flow weighted dissolved N **concentrations and various land use and soil characteristics for the 11 agricultural watersheds, January 1975 - December 1976.**

Monthly mean dissolved N concentration (DN)

WATERSHED CHARACTERISTIC	1975 F	M	A	M	J	J	A	S	O	N	D	1976 J	F	M	A	M	J	J	A	S	O	N	D
LAND USE																							
corn (%)	+		+	+	+					+	+	+	+	+	+	+					+	+	+
woodland (%)			-		-						-						-						
tile drainage (%)			+	+	+			+			+	+	+	+	+	+					+		+
Fert-N (kg/ha)			+	+	+			+			+	+		+	+	+							+
Man-N (kg/ha)																							
Housing density (houses/km^2)								+	+														+
Stream gradient (m/km)							-																
Erosion potential (MT/ha)	+		+																				
KIND OF SOIL																							
Pollution Group 5 (%)					+												+						

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* -positive (+) or negative (-) correlation significant at least at the 5% level.

Land use activities seemed of secondary importance in affecting TKN concentration. Monthly flow weighted TKN concentrations were only slightly related to land use with a small number of significant correlations occurring among livestock, housing density, tile drainage, corn hectarage, wooded area and monthly TKN concentrations (Table 5-7). Thus, manipulation of land management may have less impact on that portion of N lost as TKN.

5.1.7 Relationship to watershed fertilization

Amounts of fertilizer N used in these watersheds ranged from 30 000 kg (12.0 kg/watershed ha) in AG-11 to about 300 000 kg (58.4 kg/watershed ha) in AG-01 (Table 5-8). If the assumption were made that only recommended rates* of 100 kg N/ha for corn, 50 kg N/ha for hay and pasture and 30 kg N/ha for all small grains were applied, watershed application rates exceeded recommended rates in watersheds AG-01, AG-02 and AG-13. This situation probably reflected high N fertilizer rates on the large amounts of corn, vegetables, and burley tobacco found in these watersheds.

From about 40-90% of N application in the surveyed watersheds was applied on corn (Table 5-8). If N is to be conserved in agricultural watersheds, it is clear that a close matching of N fertilization to N needs by corn would be a major consideration in such plans. Furthermore, since corn area and tons of N fertilizer sold in Ontario showed 4- and 6-fold increases respectively from 1960 to 1976 (Fig. 5-2) with no apparent slowdown in the rate of increase, N losses from agricultural watersheds may increase unless there is a better matching of N fertilization and corn requirements for N in the future. The future increased cultivation of corn in lower heat unit areas could result in increased N loads especially to Lake Huron and Lake Ontario.

5.2 Watershed stream N loadings

Using the Beale ratio estimation technique (Hydroscience, 1976), unit area annual N stream loadings ($\bar{W}$/watershed area) were calculated for each of the 11 agricultural watersheds for 1975 and 1976 as:

$$W = \bar{Q} \,.\, \frac{My}{Mx} \,.\, \frac{(1 + 1/n \,.\, \frac{Sxy}{MyMx})}{(1 + 1/n \,.\, \frac{Sx^2}{Mx^2})}$$

with a variance (V) of

$$V = My^2 \,.\, (\frac{1}{n} \,.\, (\frac{Sx^2}{mx^2} + \frac{Sy^2}{My^2} - 2\frac{Sxy}{MxMy}) + \frac{1}{n^2} \,.\, (2.(\frac{Sx^2}{Mx^2})^2 - 4\,\frac{Sx^2}{Mx^2} \,.\, \frac{Sxy}{MxMy}$$

$$+ (\frac{Sxy}{MxMy})^2 + \frac{Sx^2}{Mx^2} \,.\, \frac{Sy^2}{My^2}))$$

where $\bar{W}$ - mean loading over time interval of interest

$\bar{Q}$ - mean flow

n - number of measurements

$Mx - \overset{n}{\Sigma} Qi/n$

$My - \overset{n}{\Sigma} Qici/n$

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*These rates were taken from Coote, D.R., Macdonald, E.M. and G.J. Wall. 1974. Agricultural Land Use, livestock and soils of the Canadian Great Lakes Basin. Report to Task C.

Table 5-7. **Significant correlations* between montly flow weighted total Kjeldahl N concentrations and various land use and soil characteristics for the 11 agricultural watersheds, February 1975 - December 1976.**

Monthly mean total Kjeldahl N concentration (mg/L)

WATERSHED	1975											1976											
CHARACTERISTIC	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
LAND USE																							
Livestock (animal units/ha	+		+																+			+	
Housing density (units/km^2)																	+						
Wooded area(%)							-	-												-		-	
Tile drainage(%)							+																
Corn (%)																		+					
KIND OF SOIL																							
Clay (%)			+	+	+				+	+	+	+	+	+	+	+						+	
Soil Pollution Group 5 (%)							+				+			+	+	+	+	+	+		+		
Soil Hydrologic Class D											+												
Soil Hydrologic Class B										-													

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*positive (+) or negative (-) correlations significant at least at the 5% level.

Table 5-8. **Total fertilizer N used*, % of total used on corn, and % corn** hectarage for the 11 agricultural watersheds.

WATERSHED	FERTILIZER N kg.N	PERCENT APPLIED TO CORN	CORN HECTARAGE % of WATERSHED	ACTUAL N USE AS A % OF RECOMMENDED USE †
AG-01	302,604.	60.9	24.5	172.8
AG-02	210,073.	39.2	10.	109.6
AG-03	200,409.	66.6	32.	70.6
AG-04	30,569.	73.7	19.	25.8
AG-05	134,501.	90.5	44.	74.8
AG-06	59,230.	67.1	13.	31.7
AG-07	91,448.	73.8	13.	50.8
AG-10	40,507.	57.2	17.	31.0
AG-11	29,984.	49.0	12.	31.0
AG-13	138,670.	45.0	27.5	122.9
AG-14	41,212.	72.7	10.	17.5

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* figures compiled from Agricultural Watershed Land Use Activities Report by R. Frank and B. Ripley (1977).

† assuming N would be applied at 100 kg N/ha on all corn, 50 kg/ha on all hay and pasture and at 30 kg/ha on all small grains within each watershed.

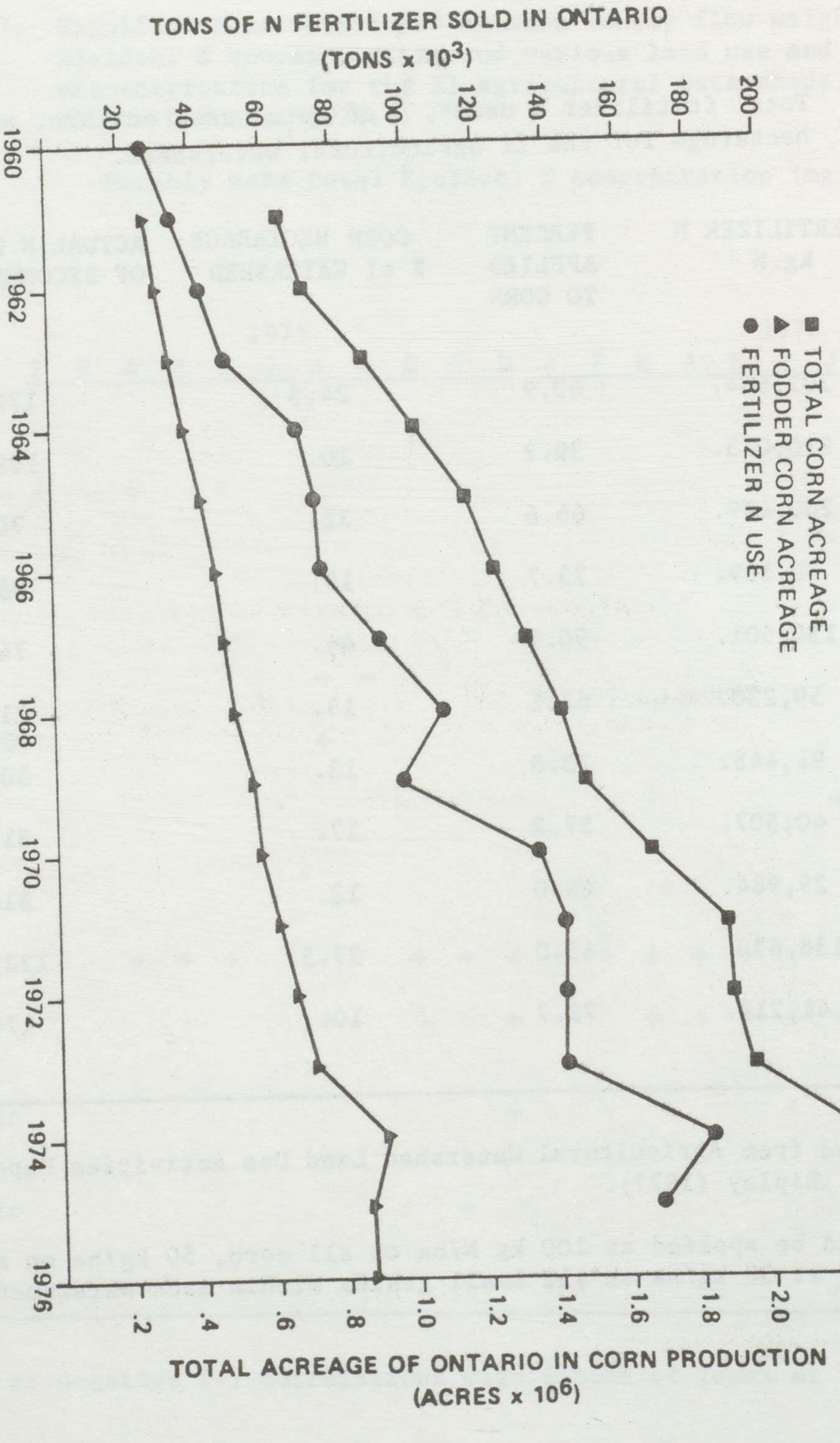

Fig. 5-2 Corn acreage and N fertilizer sales in Ontario, 1960-1976. Fertilizer data, Statistics Canada. Acreage data from OMAF, Ontario.

$$S_x^2 - \frac{\sum_{i}^{n} Qi^2 - n.M_x^2}{n-1}$$

$$S_y^2 - \frac{\sum^{n} (QiCi)^2 - n.My^2}{n-1}$$

$$Sxy - \frac{\sum^{n} Qi(QiCi) - n.My.Mx}{n-1}$$

Qi and Ci are discrete measurements of flow and concentration collected in the time interval over which the loading is to be determined.

Since for most watersheds, 1976 was the most intensively sampled year (Table 3-2), the following discussions will be concerned with loadings during this year.

5.2.1 NO_3 loadings

Annual N loadings for 1976 ranged from 2.1 ± 0.2 kg NO_3-N/ha for AG-07 to 37.4 ± 2.2 kg NO_3-N/ha for AG-03 (Table 5-9). A 0.2 to 37.1 kg total N/ha loading range has been previously noted in the literature review (section 2). Consequently, the loadings from watershed AG-03 were similar to total N loadings measured from corn cultivation in Iowa (Schuman et al., 1973; Burwell et al., 1974) although for AG-03 most of the N was lost as soluble NO_3-N rather than in association with the sediment as found in Iowa. The 2.1 kg NO_3-N stream loading from AG-07 was comparable to the 2.4 kg NO_3-N/ha loading from woodland in Coshocton, Ohio (Taylor et al., 1971) but greater than the 0.4 kg/ha NO_3-N loading from rangeland in southwestern Ontario (Campbell and Webber, 1969).

Watersheds with more than 20% corn area had stream N loadings exceeding 10 kg NO_3-N/ha. Correlations between monthly NO_3-N loadings and watershed characteristics suggested more NO_3-N from watersheds with more corn, tile drainage and fertilizer N input (Table 5-10). Correlations were particularly strong between winter N loadings and corn hectarage. Elevated N loadings from land cropped to corn have been previously noted in tile drainage (Bolton et al., 1970) and from watersheds high in corn hectarage (Neilsen and Mackenzie 1977a).

There was a close relationship between seasonal runoff pattern and NO_3-N loadings for all watersheds (Fig. 5-3 - 5-6 a,b). For example, the largest monthly loadings occurred in Feb. or Mar. at the time of peak spring melt runoff. Apparent anomalously large monthly loadings from AG-01 in June 1975 and from AG-13 in July 1976 (Fig. 5-4b) coincided with high monthly runoff (Fig. 5-4a). This suggested that variation in discharge controlled NO_3-N loading variation. The importance of discharge in nutrient loading variation has also been found for phosphorus (Sharpley et al., 1976). Therefore, accurate modelling of NO_3-N loadings would depend upon adequate modelling of discharge, particularly the spring melt events. For all watersheds, most loadings, regardless of the magnitude of annual loadings, occurred during Nov.- April in the winter and spring thaw periods. At these times, there would be no active

Table 5-9. **1975 and 1976 unit area NO_3-N and total Kjeldahl-N loadings*, standard deviations and % of total N lost as TKN for Southern Ontario agricultural watersheds as calculated using the Beale ratio estimator.**

	NO_3-N		Kjeldahl-N		Kjeldahl-N as a % of total N	
	kg/ha/yr				%	
WATERSHED	1975	1976	1975	1976	1975	1976
AG-01	18.4± 8.7	10.7±4.0	10.8±4.0	5.3±1.5	37.	33.
AG-02	3.2± 0.6	4.2±0.7	3.0±2.5	2.2±0.2	48.	34.
AG-03	39.0± 7.6	37.4±2.2	4.8±1.1	4.2±0.4	11.	10.
AG-04	18.6±12.0	14.9±1.4	5.8±3.0	5.4±1.9	24.	27.
AG-05	15.7± 5.2	24.1±6.0	5.0±3.1	7.0±3.7	24.	23.
AG-06	9.9± 1.0	11.4±1.2	3.8±0.3	3.0±0.2	28.	21.
AG-07	2.2± 1.0	2.1±0.2	4.2±6.4	1.1±0.1	66.	34.
AG-10	7.0± 2.3	7.1±0.9	9.4±1.1	8.5±0.6	57.	55.
AG-11	---	8.3±1.0	---	2.8±0.4	--	25
AG-13	32.1± 2.4	21.0±2.7	3.9±0.7	4.2±0.7	11.	17.
AG-14	3.1± 0.6	5.3±2.1	3.3±0.4	4.1±1.1	52.	44.
			weighted % (TKN/Total N)		32.	25.

*computed by B. Bodo (MOE, Ontario).

Table 5-10. **Significant correlations* between monthly unit area** loadings of NO_3-N **and various land use and soil characteristics for the 11 agricultural watersheds, April 1975 - December 1976.**

Monthly NO_3-N loading (kg/ha)

WATERSHED	1975														1976						
CHARACTERISTIC	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
LAND USE																					
corn (%)									+	+	+	+	+	+			+				+
tile drainage (%)									+	+	+										
Fert.-N (kg/ha)				+		+										+					
Man.-N (kg/ha)																					
KIND OF SOIL																					
HYDR. Class B				+														+			
HYDR. Class C																			+		

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*positive (+) or negative (-) correlation significant at least at the 5% level.

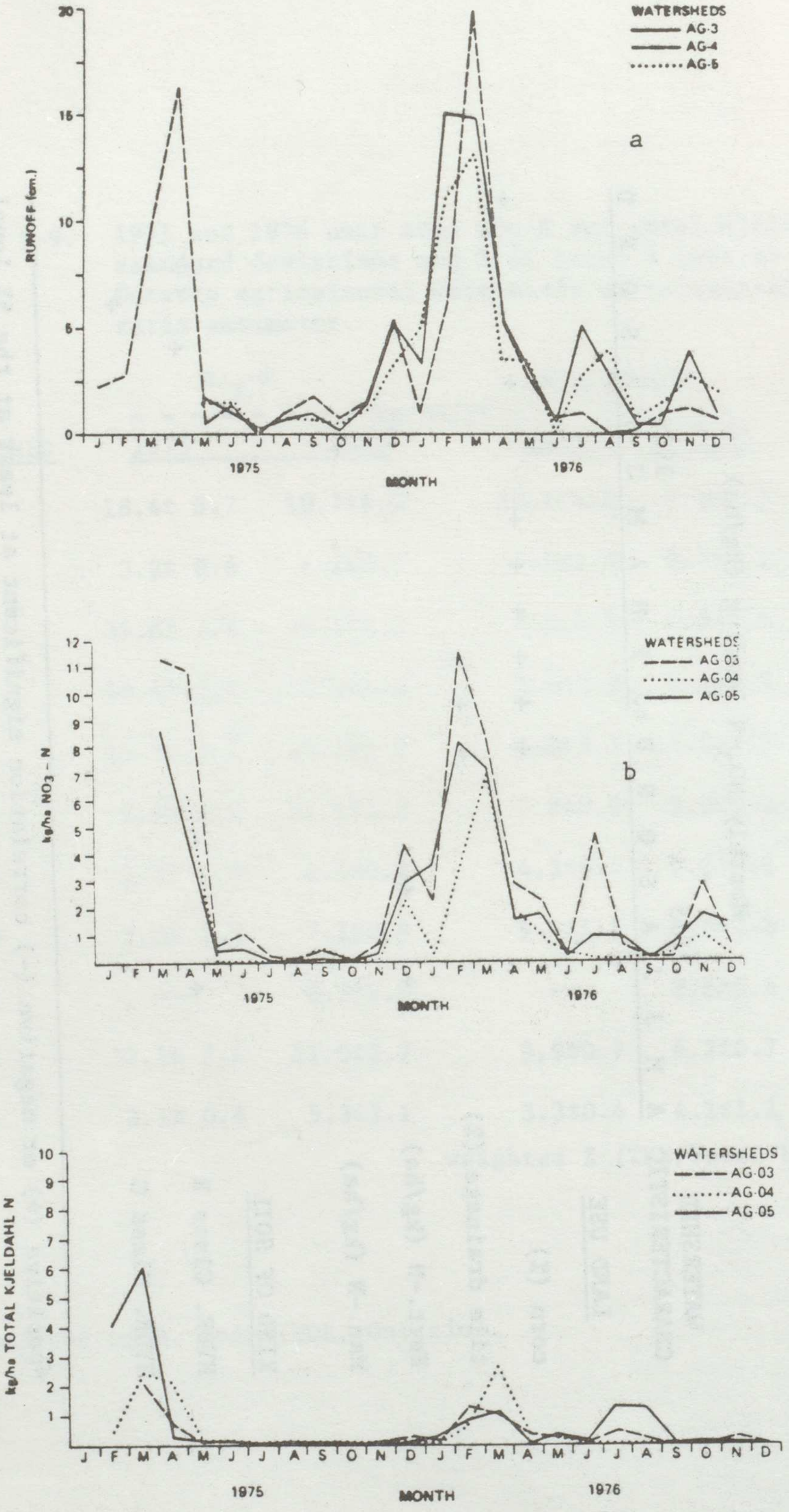


Fig. 5-3 Monthly runoff and Naquadat NO_3-N and TKN loadings for agricultural watersheds AG-03, AG-04 and AG-05, 1975-1976.

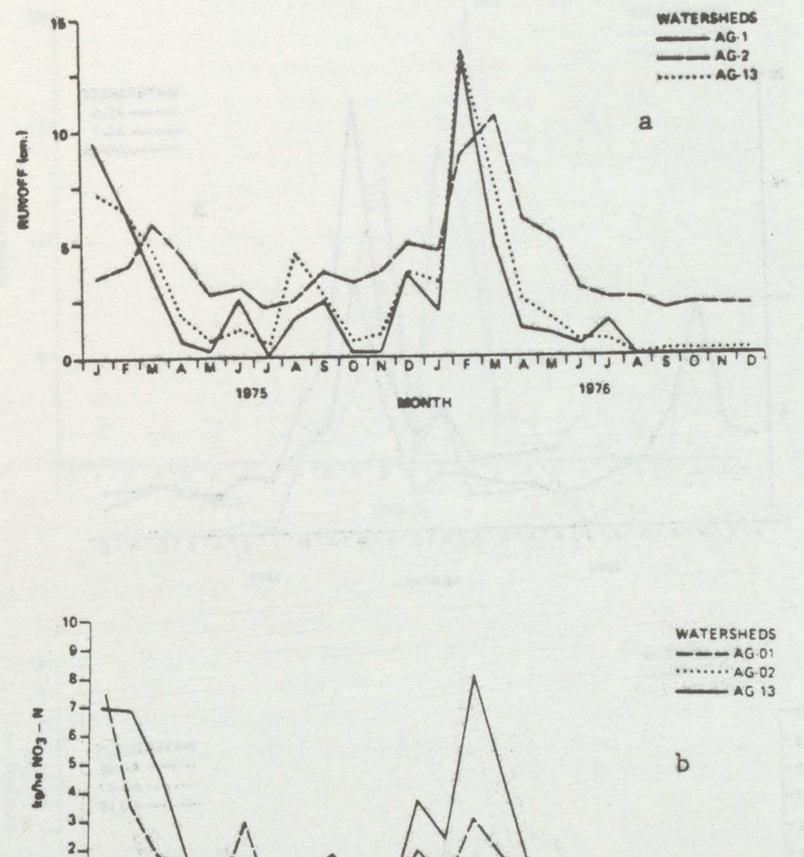


Fig. 5-4 Monthly runoff and Naquadat NO_3-N and TKN loadings for agricultural watersheds AG-01, AG-02 and AG-13, 1975-1976.

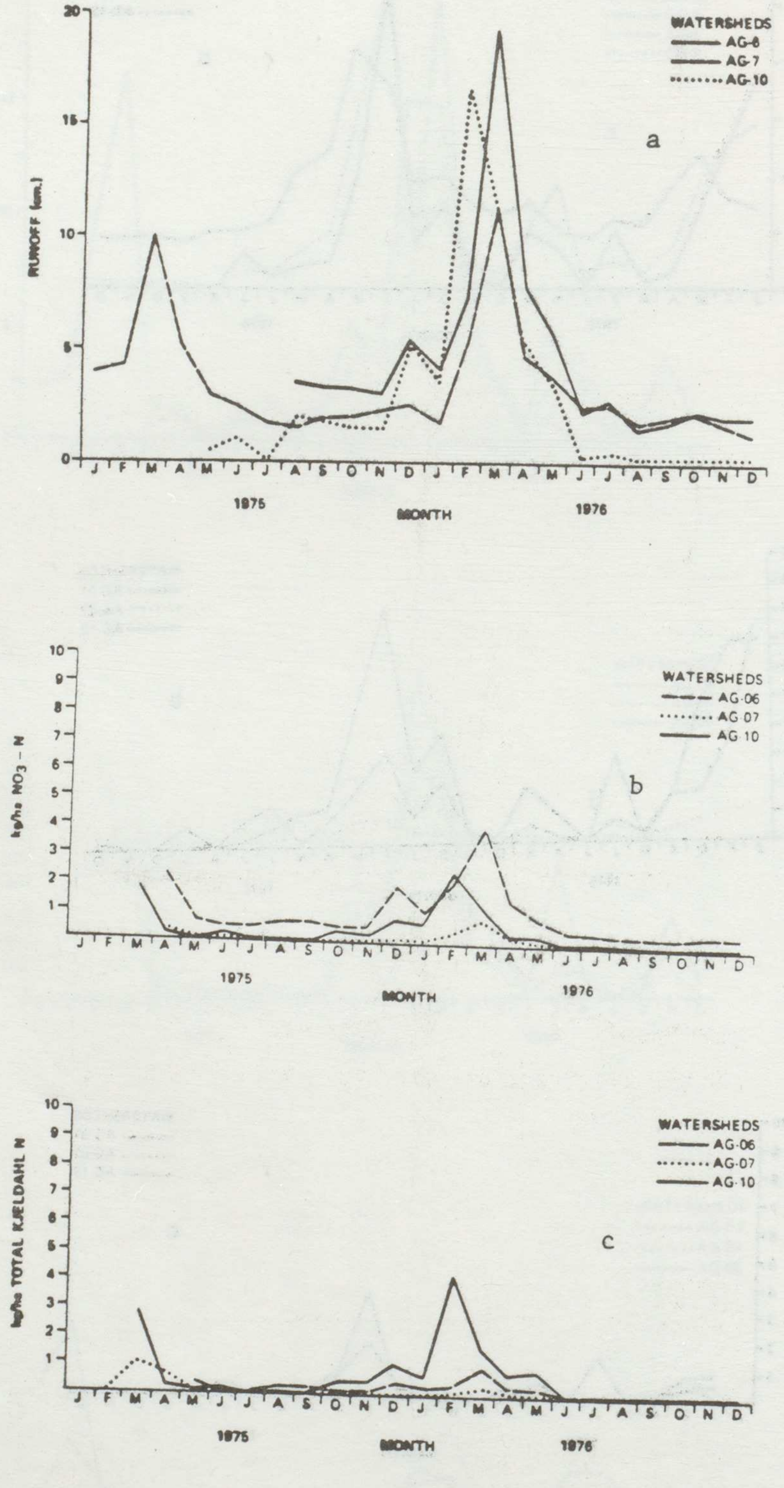


Fig. 5-5 Monthly runoff and Naquadat NO_3-N and TKN loadings for agricultural watersheds AG-06, AG-07 and AG-10.

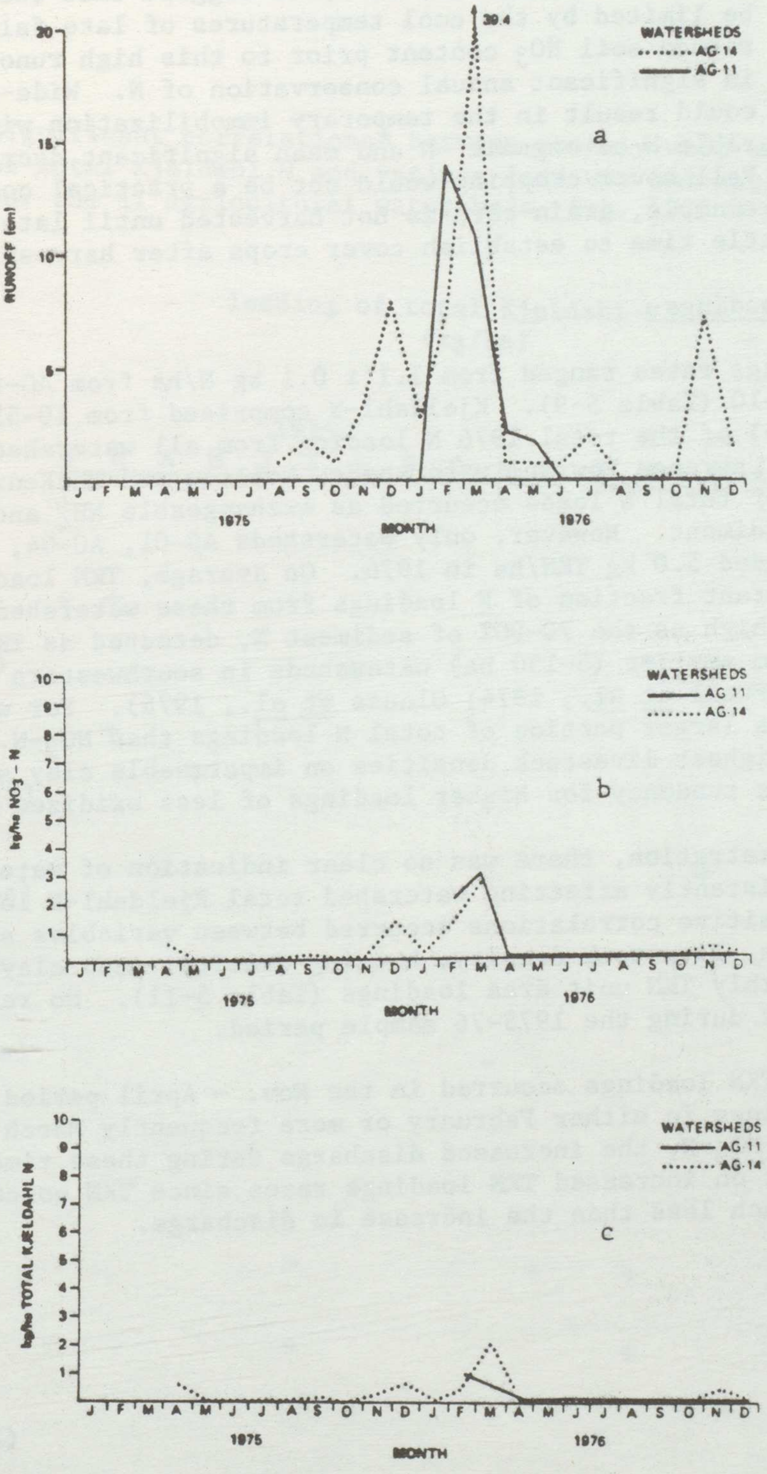


Fig. 5-6 Monthly runoff and Naquadat NO_3-N and TKN loadings for agricultural watersheds AG-11 and AG-14, 1975-1976.

plant growth and large amounts of percolating water to leach watershed soils. There was also field evidence (Kowalenko, 1978) to suggest that loss of N by denitrification may be limited by the cool temperatures of late fall and winter. Efforts to reduce soil NO_3 content prior to this high runoff period would result in significant annual conservation of N. Wide-spread fall cover cropping could result in the temporary immobilization within the root zone of considerable N as organic -N and mean significant decreases of winter N loadings. Fall cover cropping would not be a practical consideration for all crops. For example, grain corn is not harvested until late October allowing little time to establish cover crops after harvest.

5.2.2 Kjeldahl-N loadings

1976 TKN loadings rates ranged from 1.1 ± 0.1 kg N/ha from AG-07 to 8.5 ± 0.6 kg N/ha from AG-10 (Table 5-9). Kjeldahl-N comprised from 10-55% (with a 25% weighted average) of the total 1976 N loading from all watersheds. From similarly sized St. Lawrence Lowland watersheds, Neilsen and MacKenzie (1977b) estimated that 40% of total N loads occurred as exchangeable NH_4^+ and particulate N associated with sediment. However, only watersheds AG-01, AG-04, AG-05 and AG-10 loadings exceeded 5.0 kg TKN/ha in 1976. On average, TKN loadings represented an important fraction of N loadings from these watersheds. The fraction was not as high as the 70-90% of sediment N, detected as TKN, lost to stream runoff from smaller (5-150 ha) watersheds in southwestern Iowa and central Oklahoma (Burwell et al., 1974; Olness et al., 1975). For watershed AG-10 TKN comprised a larger portion of total N loadings than NO_3-N. Since this watershed had highest livestock densities on impermeable clay soils, such watersheds may have a tendency for higher loadings of less oxidized N forms.

Unlike TKN concentration, there was no clear indication of watershed characteristics consistently affecting watershed total Kjeldahl-N loadings. A small number of positive correlations occurred between variables such as % corn, % tile drainage, livestock density, housing density, mean clay content, etc. and various monthly TKN unit area loadings (Table 5-11). No relationships were consistent during the 1975-76 sample period.

Most of annual TKN loadings occurred in the Nov. - April period with highest monthly loadings in either February or more frequently March (Fig. 5-3c to 5-6c). As with NO_3-N, the increased discharge during these times was the most important effect on increased TKN loadings rates since TKN concentration increased at rates much less than the increase in discharge.

Table 5-11. Significant correlations* between monthly unit area loadings of total Kjeldahl N and various land use and soil characteristics for the 11 agricultural watersheds, Feb. 1975 - December 1976.

WATERSHED CHARACTERISTIC	loading of total Kjeldahl N (kg/ha)																						
	1975											1976											
	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
LAND USE																							
corn (%)	+	+																+	+				
Fert.-N (kg/ha)							+																
Man.-N (kg/ha)		+																					
tile drainage (%)																		+					
livestock (animal units/ha)														+									
housing density (houses/km^2)							+																
erosion potential										−													
KIND OF SOIL																							
mean clay content (%)						−					+		+										
soil pollution Group 5						+							+										
HYDR. Class D (%)																						−	+

single month correlations occur with % of roads, % of cereals, pasture and area in hectares.

*** positive (+) or negative (-) correlations significant at least at the 5% level.**

6. THE SECTORS OF THE SAUGEEN AND GRAND

6.1 River N Concentrations

6.1.1 Total Kjeldahl N

In the Saugeen (Fig. 3-2) average flow weighted TKN concentrations varied from 0.42 mg/L, North Saugeen (SR-5) to 0.78 mg/L, South Saugeen (SR-2) (Table 6-1). In the Grand, a range in mean sector outlet TKN concentrations of 0.66 mg/L (Horner) to 1.76 mg/L (Middle Grand) was observed (Table 6-2). Although Saugeen river TKN concentrations were, with the exception of SR-2, lower than any agricultural watersheds, AG-14, which composed 1/22 area of SR-6 had a similar TKN concentration of 0.73 mg/L. TKN concentrations in the Grand sectors were in the mid-range of those observed for the smaller agricultural watersheds. AG-04, a subbasin of the Middle Grand sector, had a flow weighted TKN concentration of 1.51 mg/L compared to the middle Grand (1.76 mg/L). Increased TKN concentration was positively associated with higher acreages of corn and potatoes (Table 6-3). Consequently, the differences in land use between the small agricultural watersheds and sectors of the Grand and Saugeen could explain differences in TKN concentration.

Unlike the smaller agricultural watersheds, TKN concentration was not positively associated with impermeable soils (as indicated by a higher watershed % clay). This may reflect the reduced usefulness of the % clay index on larger areas of land where extensive hectarages of soils of differing surface soil textures could be expected. For example, the six Saugeen sectors showed a 16-20% range in % clay compared to the 6-40% range in the small agricultural watersheds.

6.1.2 NO_3-N

In the Saugeen, flow weighted NO_3-N concentrations ranged from 0.45 to 1.04 mg/L with a 0.76 mg/L value at the mouth of the Saugeen. In the Grand, values ranged from 0.58 to 3.34 mg/L with a 2.31 mg/L Grand River average. The Saugeen sector concentrations were similar to those of streams draining the least agriculturally intensive watersheds (AG-07, AG-14, and AG-02). There was a similar intensity of agricultural land use in both sets of watersheds since corn plus potatoes ranged from 10-18% of total area for the less intensive agricultural watersheds while 5-16% of total area was in these crops in the Saugeen. In the Grand sectors, NO_3-N concentrations were higher than the Saugeen but similar to the mid-range of the values for the agricultural watersheds. The Horner sector which had roughly equivalent land use activities to those of AG-04 had an average NO_3-N concentration of 3.34 mg/L compared to 3.75 mg/L (AG-04).

In the Grand and Saugeen, NO_3-N concentrations were negatively correlated with area of hay and pasture, reflecting a decreased NO_3-N concentration when sector areas of hay and pasture were large. Such associations did not occur in the agricultural watersheds since area in hay and pasture was not negatively correlated with fertilizer input as in the Grand and Saugeen (Table 6-3). Sector NO_3-N concentrations did not seem unreasonable given differences in land use. For example, the maximum 5.62 mg/L NO_3-N average was measured at agricultural watershed AG-03 with 33.2% corn plus potatoes. In the sectors of the Grand and Saugeen which had lower NO_3-N concentrations, corn plus potatoe area did not exceed 28%.

Table 6-1. Outlet flow weighted TKN and NO_3-N concentrations (1975-1976), 1976 total and unit area TKN and NO_3-N loadings, 5% confidence limits 1975-1976 from sectors and from the basin, of Saugeen River.†

SECTOR	% of Basin	Number of Samples n	TKN LOADING			NO_3 LOADING			TKN % Total N
			Conc. Outlet (mg/L)	Total Loading (mt)	Unit Area Loading (kg-N/ha)	Conc. Outlet (mg/L)	Total Loading (mt)	Unit Area Loading (kg-N/ha)	
1.	10		.46	88.6	2.3	.45	87.5	2.3	50.
5% C.L.(75-76)		111			±.24			±.22	
2.	15		.78	266.0	4.4	.97	358.1	6.0	42.
		113			±1.7			±.7	
3.	29		.50	169.1	1.5	.82	537.9	4.8	24.
*		134							
4.	17		.60	218.8	3.3	1.04	409.6	6.2	35.
		122			±.3			±.5	
5.	6		.42	61.6	2.5	.59	89.04	3.6	41.
		100			±.3			±.6	
6.	23		.59	449.9	5.0	.96	670.0	7.5	40.
		455							
WHOLE SAUGEEN RIVER BASIN									
	100		.59	1254	3.2	.96	2152.1	5.0	39.
					±.3			±.3	
Component ** Sector Sums					3.3			5.5	

† courtesy Water Quality Section, O.M.O.E. (1977).

* no confidence limits (associated) with loadings from sectors composed of more than one watershed.

$** = \sum_i \text{unit loading}_i \times \text{Fractional area}_i$ (summed over all sectors)

Table 6-2. Outlet flow weighted TKN and NO_3-N concentrations (1975-1976) and 1976 total and unit area TKN and NO_3-N loadings from sectors and from the basin of the Grand River. †

Sector	% of Basin	Area (ha)	TKN LOADING			NO_3-N LOADING			% Total	Number of Samples (n)
			Conc. Outlet (mg/L)	Total Loading (mt)	Unit Area Loading (kg-N/ha)	Conc Outlet (mg/L)	Total Loading (mt)	Unit Area Loading (kg-N/ha)		
UPPER GRAND	12.	79512	.76	252.	3.2	.58	192	2.4	57.	95
CONNESTOGA	12.	77459	.83	343.	4.4	1.62	668	8.6	34.	113
MIDDLE GRAND	29.	193835	1.76	1818.	9.4	2.41	2142	11.1	32.	214
NITH	16.	103439	1.42	584	5.7	2.44	1006	9.7	37.	150
BRANTFORD	.44	29308	1.32	-109.	-3.7	2.18	335	11.4	--	106.
HORNER	.66	38438	.66	122.	3.2	3.34	616	16.0	17.	52.
CALEDONIA	12.	77065	1.60	903.	11.7	2.12	203	2.6	82.	96.
DUNNVILLE	.10	63763	1.08	-964.	-15.1	2.31	1162	18.2	--	466.
WHOLE GRAND RIVER BASIN										
	100	662819	1.08	2949	4.5	2.31	6324	9.5	--	466.
Component Sector Sums*					4.5			9.6	32.	

† courtesy Water Quality Section, O.M.O.E. (1977).

* $= \sum_i$ unit loading_i * Fractional area_i (summed over all sectors)

Table **6-3. Matrix of .01 level correlation coefficients between N** loadings and **concentrations and land use activity parameters in the Grand and Saugeen watersheds.**

	N1†	N2†	N3†	N4†	Fertilizer input kg/ha	Manure N input kg/ha	NO_3-N loading kg/ha	NO_3-N concentration mg/L	TKN concentration mg/L	Clay %
N1	1.00	-§	-0.81	-0.76	0.98	-	0.73	0.87	0.81	--
N2		1.00	-	0.84	-	-	-	-	-	-
N3			1.00	0.73	-0.85	-	-0.88	-0.95	-	-
N4				-1.00	-0.84	-0.78	-0.69	-0.77	-0.69	-
Fertilizer input					1.00	-	0.74	0.87	0.83	-
Manure N input						1.00	0.69	-	-	-
NO_3-N loading							1.00	0.94	-	-
NO_3-N concentration								1.00	-	-
TKN concentration									1.00	-
Clay (%)										1.00

† N1 - watershed fractional area of corn and potatoes
N2 - watershed fractional area of cereals, beans, vegetables and tobacco
N3 - watershed fractional area of hay, pasture and improved land
N4 - watershed fractional area of unimproved land

-§ - correlation coefficient not significant at p = .01 level.

6.2 N Loadings

The loadings discussed below were calculated for sectors rather than subwatersheds of the Grand and Saugeen. Sectors had no overlapping areas and sector loads were calculated by subtracting downstream N loadings from any upstream N loadings. All river loads were calculated by O.M.E. using the Beale ratio estimator technique as described in Section 5.

6.2.1 TKN

Sector unit area loadings varied from 2.3 to 5.0 kg. TKN/ha in the Saugeen (Table 6-1) and from 3.2 to 9.4 kg TKN/ha in the Grand (Table 6-2). For two sectors of the Grand (Brantford and Dunnville), negative loads were calculated, which would suggest TKN deposition in these sectors. The Dunnville section was located (Fig. 3-2) in the lower reaches of the Grand where stream velocities might be expected to decrease, resulting in sediment (and thus TKN) deposition. 39 and 32% of total N loads occurred as TKN at the mouths of the Saugeen and Grand rivers respectively. This proportion was similar to the 29% of total N measured for TKN in the 11 agricultural watersheds (1975-76).

6.2.2 NO_3-N

NO_3-N unit area loads ranged from 2.3 kg N/ha to 7.5 kg N/ha in the Saugeen (Table 6-1) and from 2.4 to 18.2 kg N/ha in the Grand (Table 6-2). Thus loadings from these large tracts, which have a smaller proportion of high N input crops, were not as large as loadings in excess of 20 kg N/ha/yr measured from some agricultural watersheds.

Significant positive correlations were established between sector NO_3-N loadings, fertilizer and manure N inputs and area of high fertilizer N crops (corn and potatoes) (Table 6-3). These sector relationships were thus similar to results from the smaller agricultural watersheds. This suggested that N loadings from agricultural land comprised an important fraction of N loadings in the Grand and Saugeen and that relationships developed on the small agricultural watersheds could be usefully generalized to larger sections of the Great Lakes area.

7. MODELLING AGRICULTURAL WATERSHED N

7.1 AG-01, AG-05 and AG-13

Using information from the detailed studies, (Section 4) seasonal patterns of potentially leachable soil N were modelled in order to generate useful information pertinent to reducing stream N loading from agricultural watersheds and improving runoff water quality.

The analysis which follows, frequently involved developing representative values for large land areas based upon the best available information. These values should probably be considered spatial averages. The watersheds investigated were those for which a great deal of land use and soil information was available (ie. AG-01, AG-05 and AG-13).

A number of comprehensive reviews have been concerned with the most important processes involved in N additions and losses from soils (Bartholomew and Clark, 1965). Recently, considerable effort has been put into development of hydrologic (Holtan and Lopez, 1971) and chemical models (Frere et al., 1975) of stream loading in agricultural watersheds. It will not be the purpose of this section to repeat such readily-available information. Instead, an attempt will be made to summarize the best available information concerning the addition and loss of N within selected Ontario watersheds.

Soil N additions within agricultural watersheds included N associated with precipitation, mineralization, N_2-fixation (where area of legumes is significant), fertilization and manure N. Soil N losses included denitrification, plant uptake and volatilization in addition to the runoff losses which have been the major concern of this report.

7.1.1 Soil N additions

Precipitation N additions were calculated at any time as the product of amount of precipitation and average N concentration. Amounts of precipitation were recorded by Sanderson (Project 6) and a 1.45 mg/L average N concentration was assumed for all precipitation. This value was an average of literature values (Shiomi and Kurtz, 1973; Tababatabi and Lafleur, 1976) and resulted in annual N inputs of from 12.4 to 14.5 kg N/ha in the three watersheds. This was lower than the 38.0 kg/ha value found in bulk precipitation in six Ontario watersheds by Sanderson (1977).

Net mineralization (the difference between mineralization and immobilization) was calculated based on multiple regression equations between net mineralization rate (NMR), temperature (T) and moisture content (θ) as derived by Kowalenko (1977) in a laboratory incubation of watershed soils at various temperature and moisture contents (Table 7-1). The equations were of the form $NMR = Bo + B_1T + B_2\theta + B_3T\theta$. Simulated θ values were derived using the approach of Cameron et al. (1977) while mean daily temperatures at Harrow were used as an approximation of soil temperature. Mineralization was assumed to occur only in the 0-20 cm layer from May 1st to September 30th. Since calculated seasonal unit area net mineralization quantities based on the regression equations were high, values were reduced to a magnitude which would represent the mineralization of 1% of soil organic N during the growing season by dividing simulated values by 6. Bremner (1965) suggested that between 1 and

3% of soil organic N could be mineralized over one growing season. The simulated values were therefore to the low end of this range.

It was assumed that 75% of annual watershed manure-N production (Frank and Ripley, 1977) was applied to watershed soils in equal amounts each day from May 1st to November 30th.

Annual watershed soil fertilizer-N additions were derived from the detailed land use surveys (Frank and Ripley, 1977). Using information from this survey concerning application times, N addition was assumed to occur for each crop uniformly within the indicated months (Table 7-2).

No formulation was possible to adequately describe N_2 fixation by free living or symbiotic bacteria at the watershed scale. Since plot information (Cameron et al., 1977) suggested low residual N from soybean cropping, the legume hectarage was considered relatively N conservative and N fixation and plant uptake for legumes were omitted from subsequent calculations.

7.1.2 Soil N losses

Using seasonal N uptake information for corn, grains and potatoes from 1975-1976 plot data (Cameron et al., 1977), best fit curvilinear N uptake curves were developed of the form:

$$U(t) = \text{Umax} \exp\left(-B^{(t-to)} \left(\frac{tmax-t}{t-to}\right)^2\right)$$

where U(t) = accumulated predicted N uptake at time t (kg N/ha)
Umax = maximum uptake of N at time t max
to = planting date

Umax and B values were generated by systematic variation to minimize the sum of squares of the residuals between predicted and observed N uptake. Maximum annual N uptake values were 157 kg N/ha, 133 kg N/ha and 80 kg N/ha for corn, grain and potatoes respectively. Linear regressions were developed to predict N uptake for burley tobacco and vegetables, assuming a maximum uptake of 100 kg N/ha for both these crops.

Since no detailed analyses of N uptake by hay, pasture or unimproved land was available, a hay and pasture exponential uptake curve was developed based upon literature studies (Fulkerson et al., 1967; Kim and Mackenzie, 1970; George et al., 1973; Kumelius et al., 1974; Macleod and Macleod, 1974). Two cuts were assumed, the first with maximum N uptake of 95 kg N/ha and a harvest date of June 25; the second cut removing 35 kg N/ha mid August.

For unimproved land, the results of Fulkerson et al. (1967) were followed. An exponential time function was fitted to their data (Umax = 95 kg N/ha) until late June. After this time, which corresponded to early seeding, N uptake was observed to decline linearly until full maturity. The regression model fitted to this data was extrapolated to November 1st resulting in a net N uptake of 37 kg N/ha. There would likely be considerable variation in year to year N uptake related, in part, to weather conditions. The maximum N uptake for these crops was in the mid range of values reported by de Jong et al. (1976), except for potatoes which was near the bottom end of the range.

Table 7-1. Regression coefficients and significant r^2 values relating net mineralization rate (ug-N/g soil and environmental parameters for AG-01, AG-05 and AG-13†.

	AG-01	AG-05	AG-13
Samples (n)			
Temperature (B_1)	-.025	-	-.005
Gravimetric (B_2) Water Content	.016	.074	.009
Interaction (B_3)	.003	.002	.002
Intercept (B_0)	.042	-.943	-.015
Coefficient of Determination (r^2)	.73**	.93**	.20**

† G. Kowalenko (personal communication)

** Significant at .01 level.

Table 7-2. Assumed nitrogen fertilizer application periods for field crops of AG-01, AG-05, and AG-13†.

CROP	PERIOD OF PLANTING TIME FERTILIZER APPLICATIONS	PERIOD OF POST-PLANTING TIME APPLICATION
Corn	May	May - June
Winter Wheat	September - October 15	April
Spring Grains	April	April - May
Vegetables Soybeans Tobacco	May	May - June
Orchards		April - May
Hay & Pasture	May - June	

† based on Frank and Ripley (1977)

Field observations indicated that denitrification occurred primarily during the spring and early summer (Kowalenko, 1978). However, no statistical formulations such as those developed for mineralization, adequately described the seasonal pattern of denitrification. Gillham et al. (1977) estimated 30 kg N/ha were denitrified in sandy watershed AG-13 using balance sheet assumptions of uncertain precision. Although it was likely that volatized N losses from the soil were small and concentrated at the time of fertilization, no seasonal pattern for the magnitude of N volatilization losses was assumed.

7.1.3 Seasonal pattern of leachable soil N

The seasonal pattern of soil N available for leaching during the growing season was calculated for watersheds AG-01, AG-05 and AG-13 by subtracting plant uptake from soil N additions from precipitation, mineralization, manuring and fertilization. Volatilization, denitrification, and any runoff N losses were not taken into account. Consequently, the values calculated represented the N potentially available for leaching in soils of AG-01 (Fig. 7-1), AG-05 (Fig. 7-2), and AG-13 (Fig. 7-3).

At the end of the growing season, soil N excesses of 73, 89 and 25 kg N/ha were estimated to be present in the root zone in AG-01, AG-05, and AG-13 respectively. These same watersheds had measured total N stream loadings of 16, 34 and 24 kg N/ha. For sandy loam watershed AG-13, there was a close correspondence between soil N excess and stream loading but for the finer textured watersheds, soil N excess greatly exceeded N loading. This may reflect greater loss of soil N through denitrification in fine textured watersheds.

Largest plant N uptake occurred during the months of June and July for all watersheds. Best fit N uptake curves (Fig. 7-4) for most of the field crops in AG-13, for example, illustrated this pattern. The composite net N uptake curve for watershed AG-13 which represented an average of the individual crop curves weighed by their watershed area showed a sharp increase in June-July. Without watershed N fertilization, soil N (bottom curve Fig. 7-1 - 7-3) would have been insufficient to meet crop N requirements and N deficits were created that would be recovered later in the season for watersheds AG-01 and AG-05 but not AG-13. This suggested that to attain the yields upon which the N uptake curves were based, N fertilization addition was necessary. Plant uptake was particularly pronounced in June and July but N fertilizer additions prevented N limited growth. For all watersheds, the late crop growth - post harvest period was a time of soil accumulation. Thus it appeared that soil N additions after August which resulted from mineralization, manure and precipitation-N were more than adequate for plant needs. Watershed AG-13, with a lower mineralization rate (25 kg N/ha) had smaller amounts of soil N in excess of crop needs during the fall. Reduction of fall N which is susceptible to leaching loss would be important from a water quality point of view. The high concentration of N in stream runoff during the late fall and winter months in AG-01, AG-05 and AG-13 could be predicted considering the excess soil N available at the end of the growing season in these watersheds. Plough down of high C/N ratio organic residues or fall cover cropping could be investigated as to their potential for temporary immobilization of some of this excess soil N.

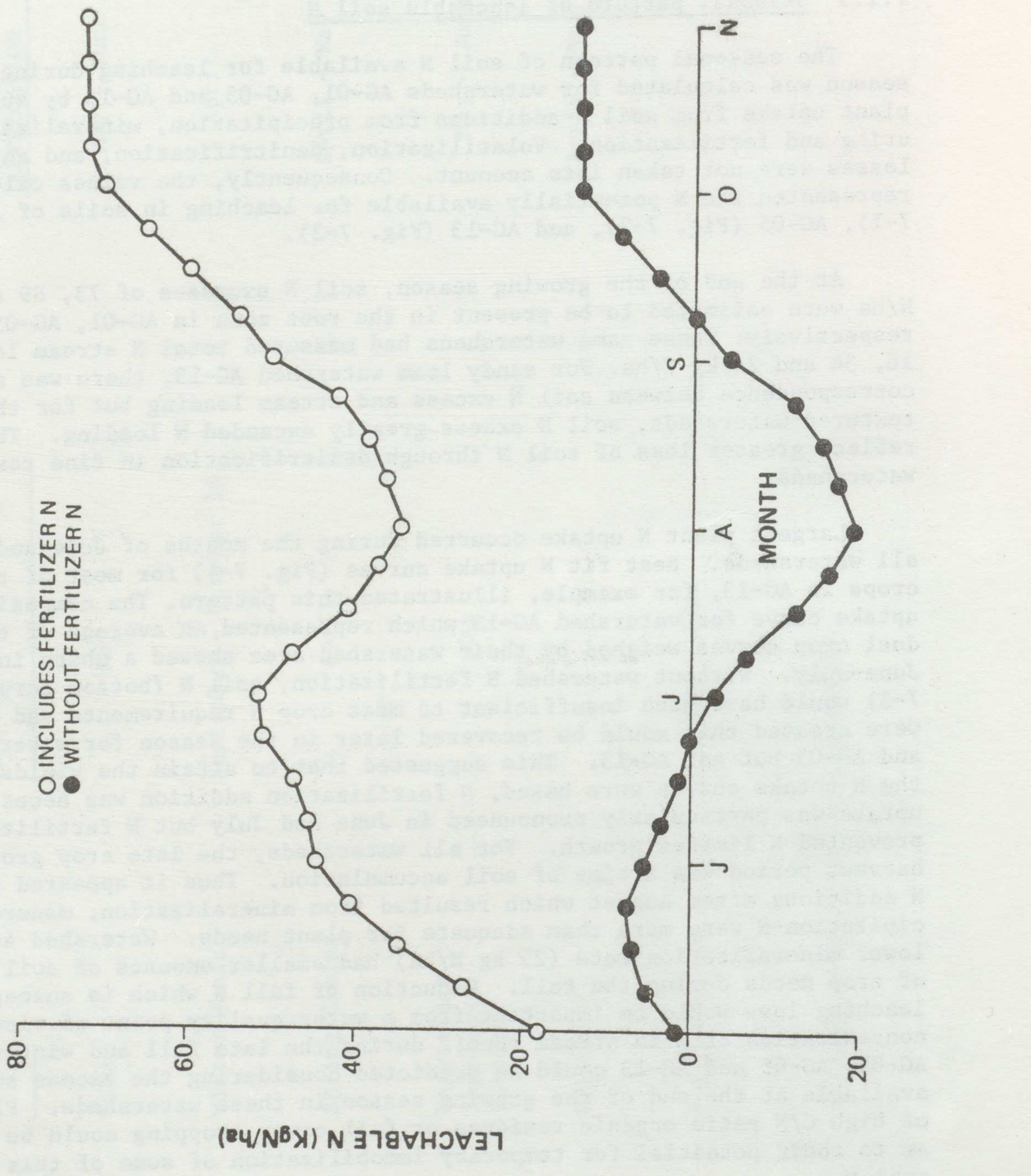


Fig. 7-1. Soil N potentially leachable from AG-01 in 1975.

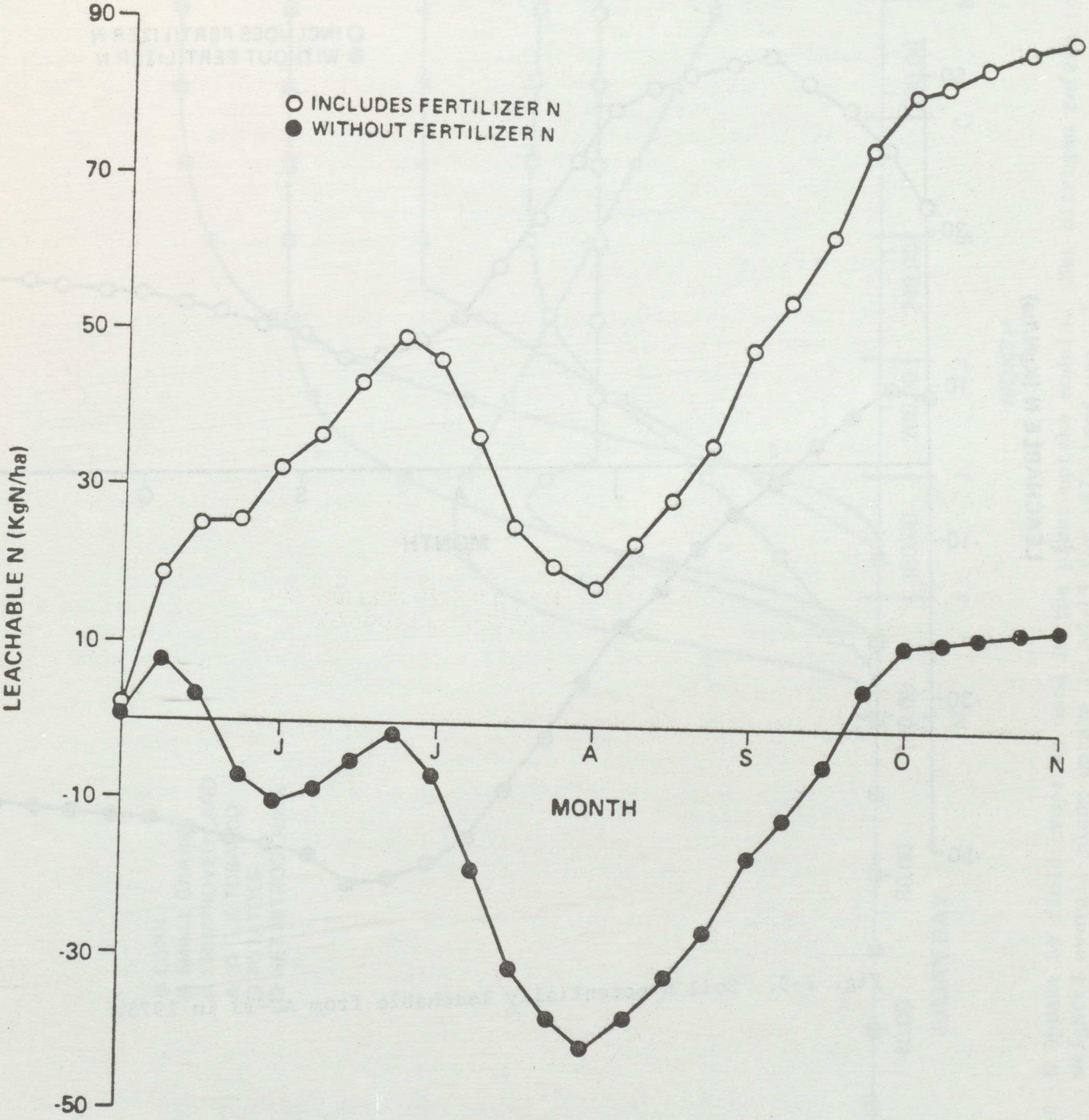


Fig. 7-2. Soil N potentially leachable from AG-05.

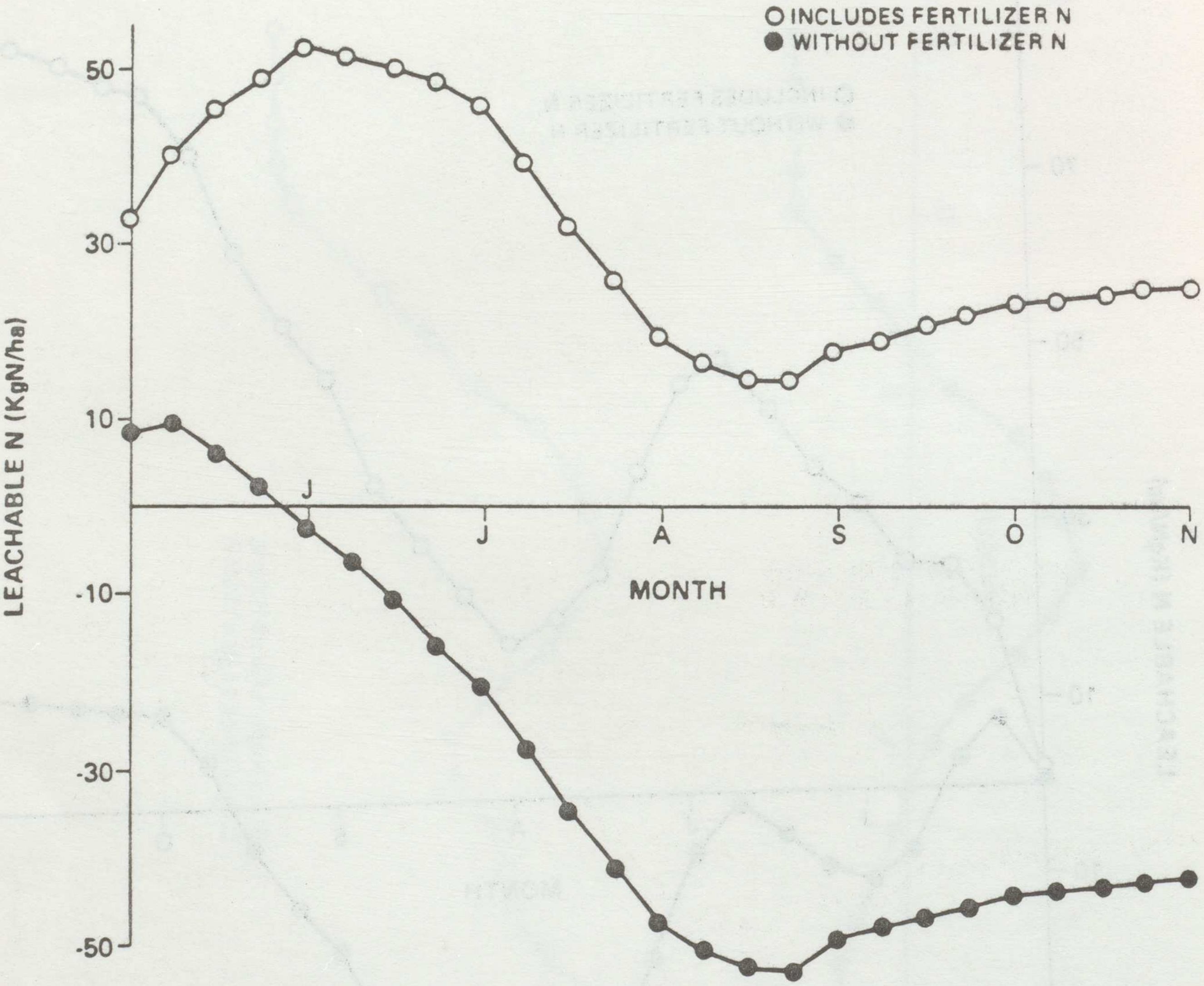


Fig. 7-3. Soil N potentially leachable from AG-13 in 1975.

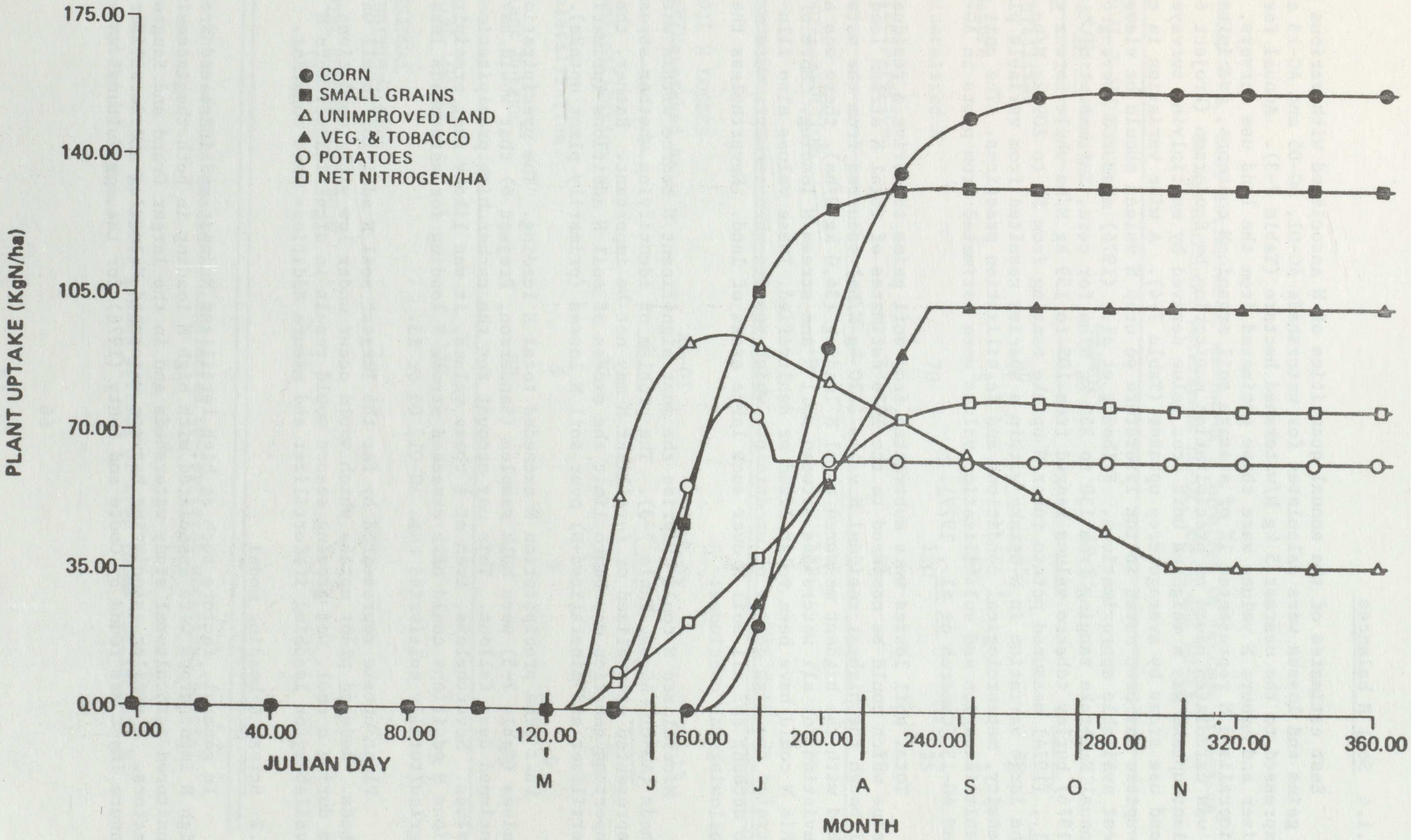


Fig. 7-4 N Uptake by field crops as used in the plant uptake models. Net Nitrogen refers to area weighted overall plant uptake in AG-13 for 1975 land use.

7.1.4 Soil N balances

Best estimates of the annual quantities of N associated with various soil N gains and losses were calculated for watersheds AG-01, AG-05 and AG-13 and expressed to the nearest 5 kg N/watershed hectare (Table 7-3). Annual fertilizer and manure N values were those estimated from the land use surveys, mineralized N represented 1% of average soil organic-N contents, precipitation N was calculated based on precipitation monitoring by Sanderson (Project 6). Plant uptake was a weighted unit area value derived by multiplying surveyed land use areas by average crop uptakes (Table 7-4). A wide variation in crop N uptake has been noted in the literature so crop N values should be viewed as best available approximations. Fribourg et al., (1976) measured above-ground annual N uptake ranging from 130 to 250 kg N/ha for corn, Zartman et al., (1976) burley tobacco values ranged from 105 to 159 kg N/ha while Lorenz et al., (1974) measured potato tuber N uptake ranging from 58 to 209 kg N/ha. The large variation in N uptake within a species resulted from variable plant density, meteorological conditions and fertilization practices. The unit area denitrification and volatilization values were estimated from plots in AG-01 and AG-13 (Cameron et al., 1977).

Total soil losses were subtracted from soil gains to derive a residual N value which could be compared to the 1976 estimates of total N stream loading. Although the highest residual N value (120 kg N/ha) occurred from the watershed with the highest measured total N loading (34.0 kg N/ha), there was a deviation for all watersheds between soil N and stream N loading. More of this N could have been volatilized or denitrified. These values also illustrated the high degree of uncertainty which results when attempts were made to account for all soil N over such large areas of land. Nevertheless the following was concluded:

Mineralized N could comprise the most significant N source within watersheds (AG-01, AG-05, Table 7-3). The problem of identifying whether stream N represented mineralized or fertilizer N may not be important. Rather, the important question may be to limit the excess of soil N additions (primarily fertilizer and mineralized-N) over soil N losses (primarily plant uptake).

Unit area precipitation N exceeded total N loading. The precipitation N values (Table 7-3) were bulk samples (Sanderson, Project 6) that would have included dust fallout. This may account for the rather high precipitation N values. Nevertheless, even at ½ these values, it was likely that precipitations N additions could have exceeded stream N loading for watersheds less agriculturally cultivated than AG-01, 05 or 13.

Plant uptake represented by far the largest soil N addition in all watersheds. Reduced plant uptake which would occur under low yield conditions such as during a cool, wet growing season would result in significantly more N available for leaching if fertilizer and manure additions were constant.

7.2 Stream N Loading model

In general, factors such as high fertilizer N input and increased area of high N input crops were associated with high N loading in both the intensively monitored agricultural study watersheds and in the larger Grand and Saugeen sectors. A similar association between watershed N loading and fertilizer and manure input was found by Coote and Leuty (1976) for the agricultural watersheds.

Table 7-3. Best estimates of amount of N involved in various processes[1] in agricultural watersheds AG-01, AG-05 and AG-13.

SOIL N ADDITIONS kgN/Watershed ha	AG-01	AG-05	AG-13
Fertilizer	60	45	70
Manure	5	45	0
Mineralized N	70	120	25
Precipitation	25	45	25
TOTAL ADDITION	160	255	120

SOIL N LOSSES kgN/Watershed ha	AG-01	AG-05	AG-13
Denitrification	30	30	30
Volatilization	5	5	0
Plant Uptake[2]	85	100	95
TOTAL LOSSES	120	135	125
RESIDUAL (ADDITION-LOSS)	40	120	-5
TOTAL RUNOFF LOADING N (1976)	16	34	24

1. These values should be considered to represent watershed spatial averages.

2. Plant uptake by above-ground portion of crop (does not include N uptake by legumes).

Table 7-4. Nitrogen uptake rates by farm crops used in calculating total plant uptake in agricultural watersheds in balance sheet calculations.

CROP	N - Uptake (kg-N/ha/yr)
Cereals	75.
Corn	136.
Tobacco	90.
Soybeans	140 (70)*
Beans	99 (50)
Potatoes	140
Tomatoes	77
Hay & Pasture	100
Unimproved Land	40

*Term in brackets refers to Estimated N Uptake from soil (excludes that which is symbiotically fixed).

Thus efforts to develop a general model relating stream N loading to watershed N addition seemed possible.

Using 1976 estimated loadings adjusted to long term discharges and surveyed fertilizer and manure N additions for the 11 agricultural watersheds, best fit (maximum R^2) regressions between NO_3-N and total N unit area loadings were developed as:-

$$\hat{L} = B_1X + B_2X^2$$

where $\hat{L}$ = predicted long term total N or NO_3-N loading (kg/ha)
X = sum of fertilizer N (kg/ha) and αx watershed manure N values (kg/ha)
α = 1.0 for total N, 0.9 for NO_3-N
B_1, B_2 -regression coefficients (Table 7-5)

The α values were systematically varied from 0 to 1 in steps of 0.1 until a maximum R^2 was achieved for the equation above. A value of 1.0 was found for total N and a value of 0.9 for NO_3-N. The portion of the stream N loading resulting from manure N inputs was assumed to be the fraction of the above equation associated with manure (i.e. B_1 (α x manure-N) + B_2 ((α x manure-N)^2 + B_1B_2 (Fertilizer -N x α x manure -N)).

The difference between predicted long term N loadings and N loadings associated with manure -N were assumed to represent crop loadings and henceforth were referred to as Lc. Using detailed land use information compiled by Frank and Ripley (1977) cropping loadings represented the sums of unit area crop loadings and crop areas as:

$$\hat{Lc} = \gamma_1A_1 + \gamma_2A_2 + \gamma_3A_3 + \gamma_4A_4$$

where $\hat{Lc}$ - predicted crop loading (KgN/ha)
A_1 - watershed fractional area of high N input crops (corn and potatoes)
A_2 - watershed fractional area of cereals, beans, vegetables and tobacco
A_3 - watershed fractional area of hay and improved pasture
A_4 - fractional area of unimproved land
γ_1, γ_2, γ_3 and γ_4 - unit area N loading rates for each of the 4 crop groups above.

Values of γi were systematically varied so that $(Lc - \hat{Lc})^2$ was minimized. The unit area loading for corn and potatoes (Table 7-5) of 26 kg/ha total N compared to the 7 year average of 15 kg N/ha from fertilized tile drainage lines measured by Bolton (1970). Kilmer (1974) concluded that stream N loadings in water discharged from actively growing humid region pastures and meadows were typically very low. Model loadings were 0.1 kg total N/ha for hay and improved pasture and 0.0 kg total N/ha for unimproved land. Although an actual 0.0 kg/ha N loading from unimproved land was unlikely, the model related stream loading to manure and fertilizer inputs which were zero for unimproved land.

As noted by Bolton (1970), wide variations could be expected in stream N loading from a given crop for the same field. N loadings >30 kg N/ha/yr were measured for corn during the 7 years when average N loadings were 15 kg N/ha/yr. Calculated unit area loadings in the model reflected averages of conditions in 11 watersheds arrived at by measuring stream N loadings and assuming the sole source of N was derived from fertilizers or manures. It should be noted that previous discussions pointed out that significant N could

Table 7-5. Regression statistics for best fit models relating long term total N or NO_3-N stream loadings to total N or NO_3 loadings from various crops.

					Crop* unit area loadings to stream			
PARAMETER	β_1	β_2	α	r^2	γ^1 kg-N/ha/yr	γ^2 kg-N/ha/yr	γ^3 kg-N/ha/yr	γ^4 kg-N/ha/yr
TN	.11742	.001589	1.0	.956	26.	3.6	.1	0.0
(NO_3)	.07268	.001711	0.9	.906	22.	2.4	.1	0.0

* γ1 refers to corn plus potatoes, γ2 refers to cereals, beans, vegetables and tobacco, γ3 refers to hay, pasture and other improved land, γ4 refers to unimproved land.

be added from precipitation and mineralization. These factors were not considered in development of this statistical model. As a result these unit loads for cropping activities may represent very crude averages for these particular watersheds in these particular years.

The model developed on the small agricultural watersheds was tested on the Grand and Saugeen for prediction of total N and NO_3-N loadings. Long term N loadings predicted from the equation developed on the small agricultural watersheds were adjusted to 1976 values by multiplying by the ratio of 1976/long term flows in nearby Water Survey of Canada monitoring stations (Water Resources Branch, 1977). The predicted 1976 unit area total N and NO_3-N loadings could then be compared to 1976 unit area loadings (Fig. 7-5, 7-6) as calculated from Ontario Ministry of Environment data on the sectors of the Grand and Saugeen. In general, the models tended to overpredict N loadings as indicated by slopes significantly different from 1, for the best fit equations, although the relationship was statistically significant at $p = .01$.

The predicted Saugeen sector loadings were closer to measured values when compared to loadings for the Grand. Residual analysis indicated that overprediction of loadings was related to increased watershed non-agricultural N input (Fig. 7-7). Possibly, coincident inputs of organic-C with non-agricultural N inputs, which stimulated denitrification could account for lower than predicted N loadings in the Grand.

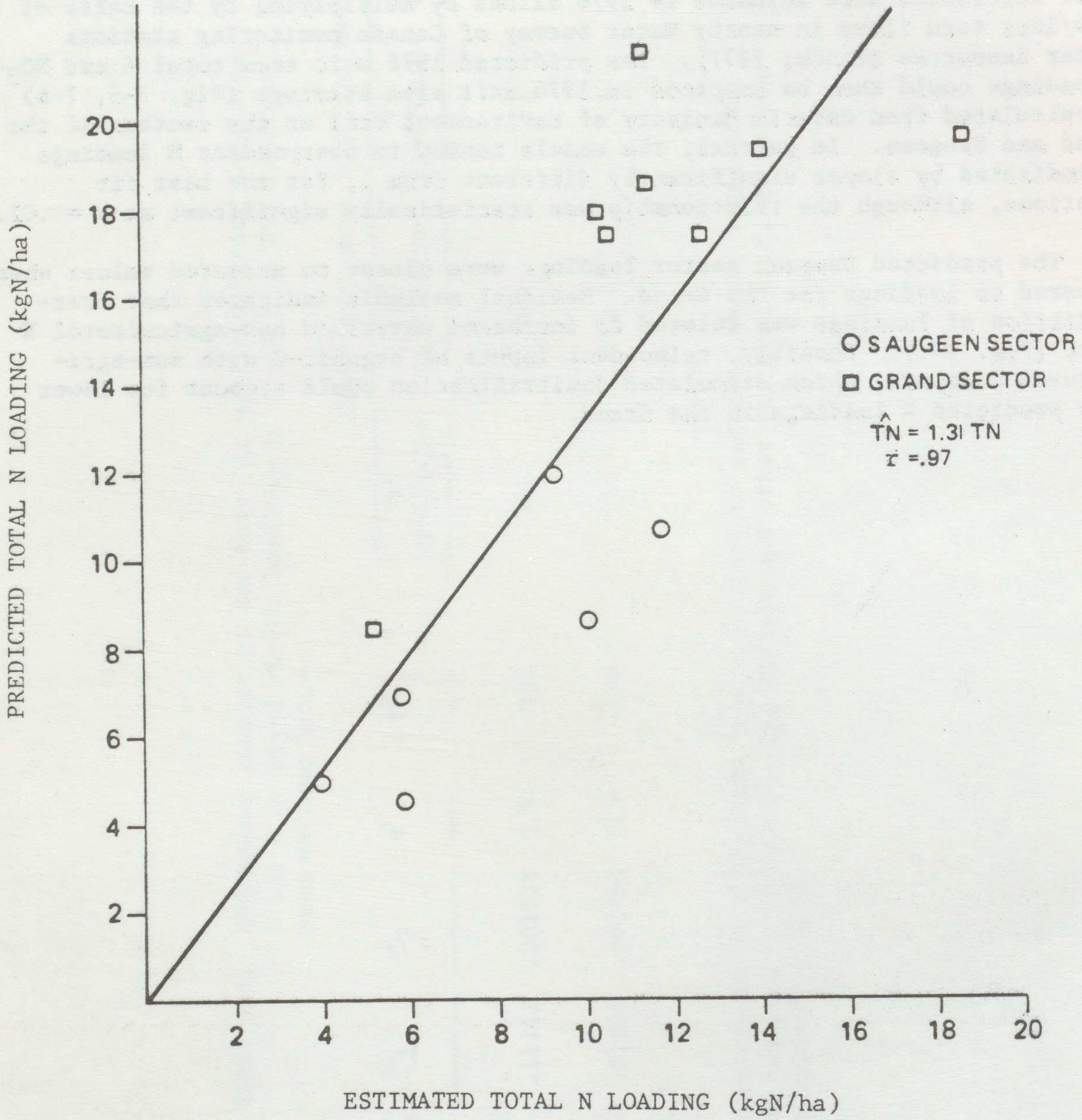


Fig. 7-5 **Comparison of predicted 1975-1976 unit Total-N loadings with those estimated using Beale ratio estimator technique.**

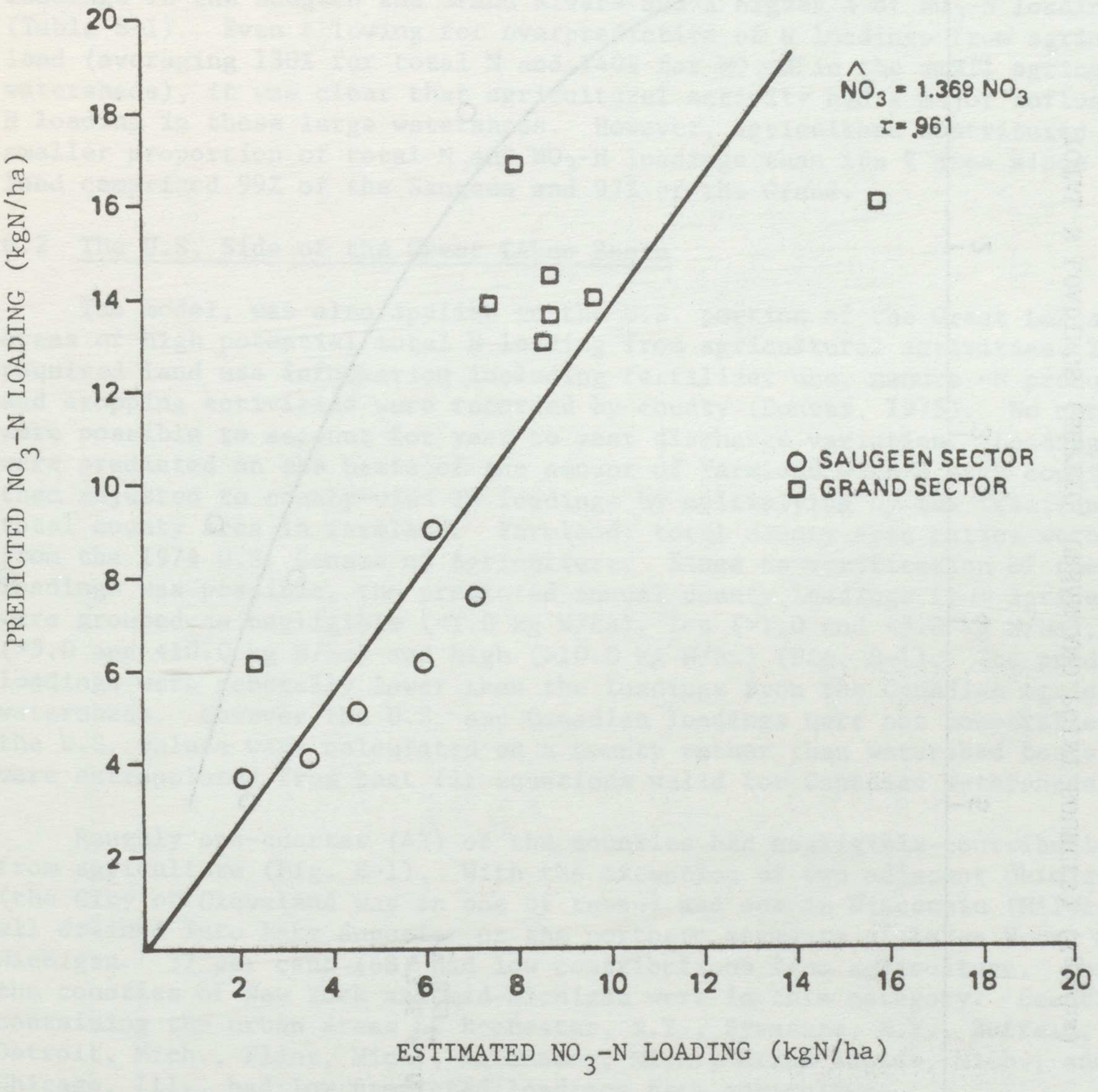


Fig. 7-6 **Comparison of predicted 1975-1976 unit NO$_3$-N loadings with those estimated using the Beale ratio estimator technique.**

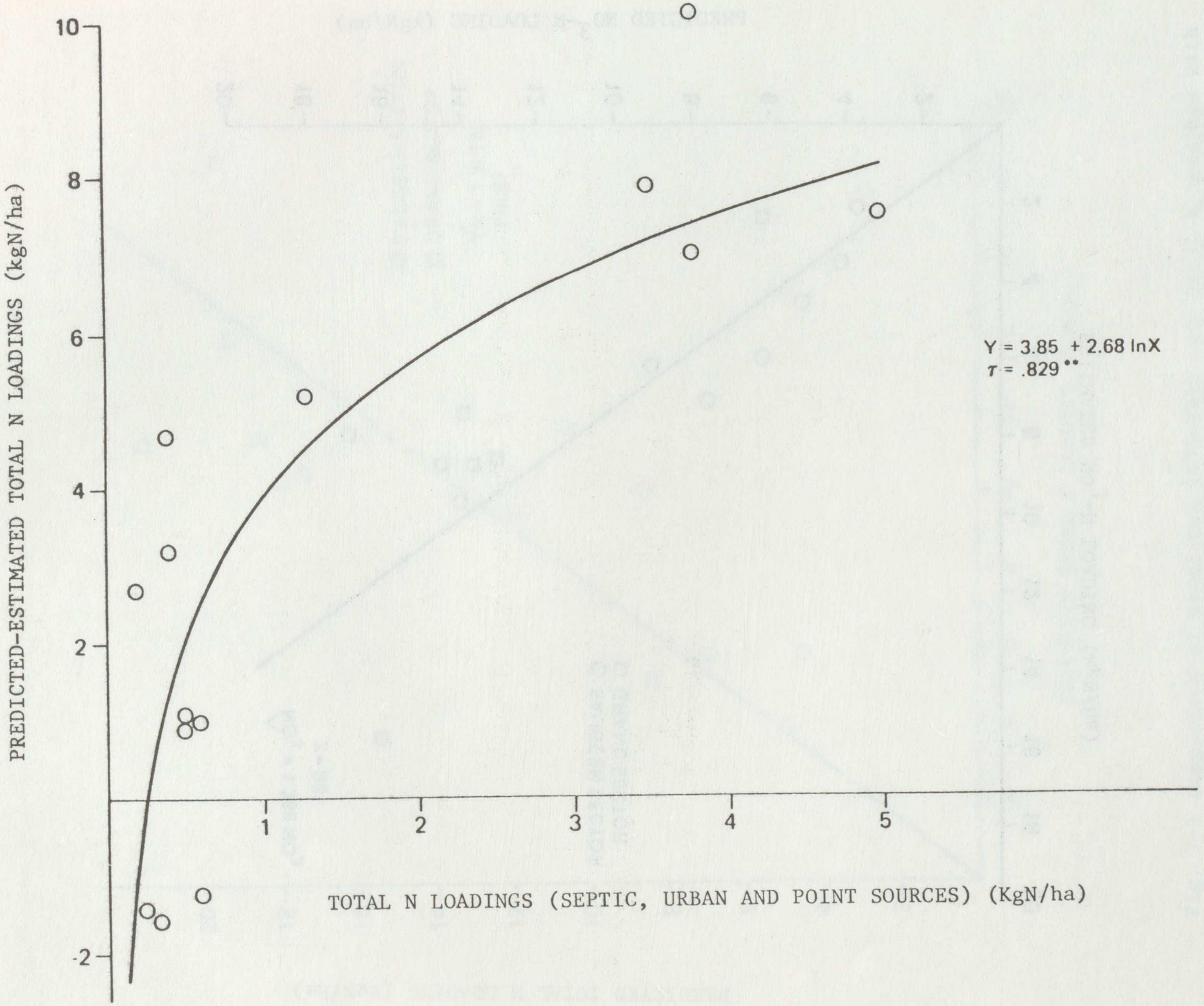


Fig. 7-7 Relationship between the residual of predicted and estimated stream loadings of N from agriculture and nonagricultural total N inputs.

8. EXTRAPOLATIONS TO ESTIMATE AGRICULTURE'S CONTRIBUTION TO ADDITION OF N TO THE GREAT LAKES

8.1 The Grand and Saugeen

Predicted N loadings from agricultural activity were made for the sectors of the Grand and Saugeen (Table 8-1) using the model developed in section 7 and the Grand and Saugeen land use information (Table 3-6). These loadings could be compared to loadings from non agricultural activities in these sectors as supplied by the Ontario Ministry of the Environment. Reference to their methods of estimation can be obtained from their reports. Predicted N loadings from agricultural activities accounted for 94% and 83% of predicted total N loadings in the Saugeen and Grand Rivers and a higher % of NO_3-N loadings (Table 8-1). Even allowing for overprediction of N loadings from agricultural land (averaging 130% for total N and 140% for NO_3-N in the small agricultural watersheds), it was clear that agricultural activity had a major influence on N loading in these large watersheds. However, agriculture contributed a smaller proportion of total N and NO_3-N loadings than its % area since rural land comprised 99% of the Saugeen and 97% of the Grand.

8.2 The U.S. Side of the Great Lakes Basin

The model, was also applied to the U.S. portion of the Great Lakes to suggest areas of high potential total N loading from agricultural activities. The required land use information including fertilizer use, manure -N production and cropping activities were recorded by county (Donetz, 1975). No corrections were possible to account for year to year discharge variation. Loadings were predicted on the basis of the amount of farmland within each county and then adjusted to county-wide TN loadings by multiplying by the fraction of the total county area in farmland. Farmland: total county area ratios were available from the 1974 U.S. Census of Agriculture. Since no verification of the predicted loadings was possible, the predicted annual county loadings from agriculture were grouped as negligible (<1.0 kg N/ha), low (>1.0 and <5.0 kg N/ha), medium (>5.0 and <10.0 kg N/ha) and high (>10.0 kg N/ha) (Fig. 8-1). The predicted loadings were generally lower than the loadings from the Canadian agricultural watersheds. However the U.S. and Canadian loadings were not comparable since the U.S. values were calculated on a county rather than watershed basis and were extrapolated from best fit equations valid for Canadian watersheds.

Roughly one-quarter (42) of the counties had negligible contributions from agriculture (Fig. 8-1). With the exception of two adjacent Ohio counties (the City of Cleveland was in one of these) and one in Wisconsin (Milwaukee) all drained into Lake Superior or the northern segments of Lakes Huron and Michigan. 37 per cent (68) had low contributions from agriculture. Most of the counties of New York and mid-Michigan were in this category. Counties containing the urban areas of Rochester, N.Y., Syracuse, N.Y., Buffalo, N.Y., Detroit, Mich., Flint, Mich., Kalamazoo, Mich., Grand Rapids, Mich., and Chicago, Ill., had low predicted loadings from agriculture.

Just 14 of the counties had predicted loadings from agriculture in excess of 10 kg -N/ha/yr. They were located in Wisconsin, Indiana and Ohio. Except for two high density dairy counties in Wisconsin (Outagawie and Calumet), all these high-contributing counties had more than 18% of the county area in high N requiring crops (corn and potatoes).

Table 8-1.

1976 total N, NO_3-N, loadings from Grand and Saugeen sectors resulting from urban and rural activities.

		TN LOADINGS (METRIC TONS)								NO_3-N LOADINGS (METRIC TONS)					
BASIN	Fraction of total area	Urban* Runoff	Point* Sources	Septic Tanks*	Agriculture	% due to crops	Predict. Total	Measured Total	% due to Agric.	Urban* Runoff	Point* Sources	Agriculture	Predict. Total	Measured Total	% due to Agric.
							THE SAUGEEN RIVER								
SR-1	.10	3.6	14.7	4.3	194.4	52	217.0	176.1	90	1.64	3.09	132.66	137.39	87.45	97
SR-2	.15	4.1	8.6	8.3	500.9	43	521.9	624.1	96	1.85	7.71	306.95	316.51	358.05	97
SR-3	.29	6.0	50.1	16.1	738.2	46	810.4	707.0	91	2.71	19.40	454.26	476.37	537.92	95
SR-4	.17	2.2	0.0	10.3	777.8	48	788.1	628.4	98	1.00	0.0	489.23	490.23	409.64	100
SR-5	.06	1.7	0.0	3.5	108.3	42	113.5	150.6	94	0.75	0.0	75.57	76.32	89.04	99
SR-6	.23	9.8	99.0	13.3	1813.9	41	1936.0	1119.9	94	4.66	0.087	1034.08	1038.80	669.99	100.
							WHOLE WATERSHED								
		27.4	172.4	55.8	4133.5	45	4386.9	3406.1	94	12.61	30.29	2492.75	2535.62	2152.10	98
							THE GRAND RIVER								
UPPER GRAND	.12	6.7	10.1	16.3	661.2	49	694.3	444.0	95	2.41	5.71	478.8	486.8	191.6	98
CONNESTOGA	.12	6.6	3.0	21.9	1334.3	34	1365.8	1011.0	98	2.35	2.70	1048.2	1053.2	667.9	100
MIDDLE GRAND	.29	99.4	1411.8	102.7	3259.1	55	4873.0	3960.0	67	35.60	369.00	3164.2	3568.9	2142.4	89
NITH	.16	8.7	72.2	45.6	1976.4	50	2102.9	1590.0	94	3.13	3.78	1528.9	1535.8	1005.3	100
BRANTFORD	.04	12.1	11.4	15.9	515.7	60	551.1	226.0	94	4.35	1.10	508.8	514.3	335.5	99
HORNER	.06	3.2	0.0	15.8	745.9	52	764.9	738.0	98	1.16	0.0	573.2	574.3	615.5	100
CALEDONIA	.12	25.3	216.9	44.3	1592.7	60	1879.2	1106.0	85	9.01	47.49	1694.5	1751.0	203.3	97
DUNNVILLE	.10	6.0	23.4	35.4	1097.0	60	1161.8	198.0	94	2.16	12.95	579.6	594.7	1161.9	98
							WHOLE WATERSHED								
		168.0	1748.8	297.9	11182.3	53	13393.0	9273.0	83	60.3	442.70	9576.3	10079.0	6323.7	95

* data supplied by Ontario Ministry of Environment - Water Quality Section.

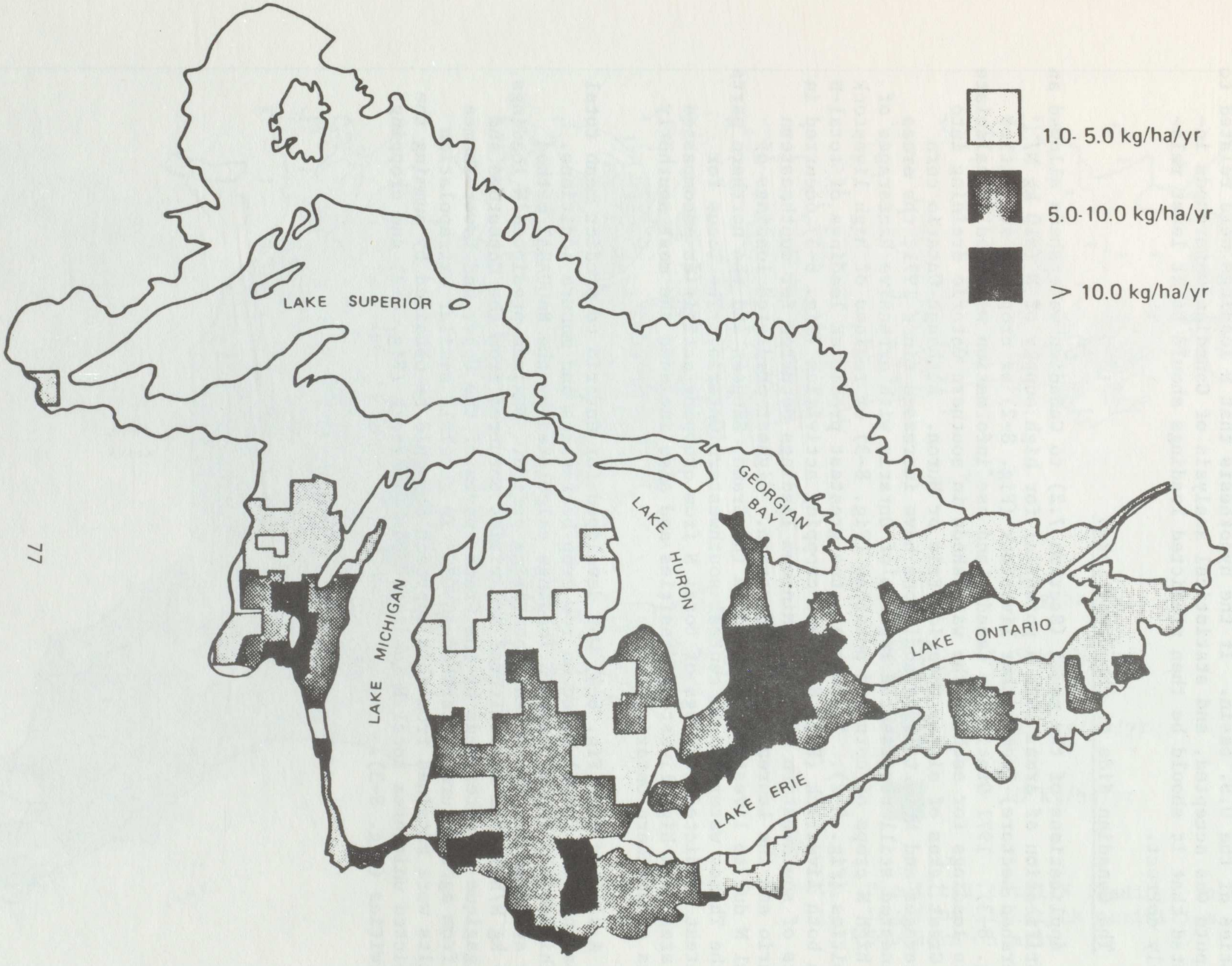


Fig. 8-1 Predicted total Nitrogen loadings due to agricultural activities from counties of the Great Lakes Basin. Counties with loadings less than 1 kg/ha/yr have been left blank.

Fig. 8-1 thus is an indication of the agricultural intensities of the counties of the U.S. basin. If the hypothesis that N loadings were related to N inputs was accepted, and statistical analysis of Canadian watersheds indicated that it should be then predicted loadings should be at least relatively correct.

8.3 The Canadian Side of the Great Lakes

Applications of the model (Section 7.2) to Canadian watersheds allowed an identification of areas with a potential for high supply of N (>10 kg N/watershed hectare) from either livestock (Fig. 8-2) or cropping activities (Fig. 8-3). 1971 Statistics Canada Land use information was used to calculate these loadings for each of the watersheds in southern Ontario draining into the Great Lakes of either Ontario, Erie or Huron. Although Ontario corn hectarages and N fertilizer additions have increased since 1971, the areas delineated still represented regions of Ontario with extensive hectarages of the high N crops of corn and potatoes (Fig. 8-3) or regions of high livestock densities (Fig. 8-2). In general, the greatest predicted loadings of total-N from both livestock (Fig. 8-2) and cropping activities (Fig. 8-3) occurred in parts of southwestern Ontario. Minimum loadings occurred for southeastern Ontario and the Laurentian shield region. Highest predicted loadings of total N due to livestock occurred in the Grand, Saugeen and the northern parts of the Thames watershed in central southwestern Ontario. The locus for greatest predicted loadings of total N from cropping activities encompassed the area with high livestock densities and also included the most southerly parts of southern Ontario.

A similar map (Fig. 8-4) was developed for Ontario to predict mean total N loadings (D. Coote) based on row crop hectarages and manure additions. In this model, annual total N loadings calculated by the NAQUADAT method were averaged for the 2 year monitoring period. Maximum predicted N loadings (>25 kg N/ha) from agricultural activities occurred from the Conestoga and Canagagique subwatersheds of the Grand, parts of the Upper and Lower Thames and from agricultural watershed AG-03. In general, similar extrapolation results were obtained from this approach as would be obtained by summing the predicted unit area total N loadings from livestock (Fig. 8-2) and cropping activities (Fig. 8-3).

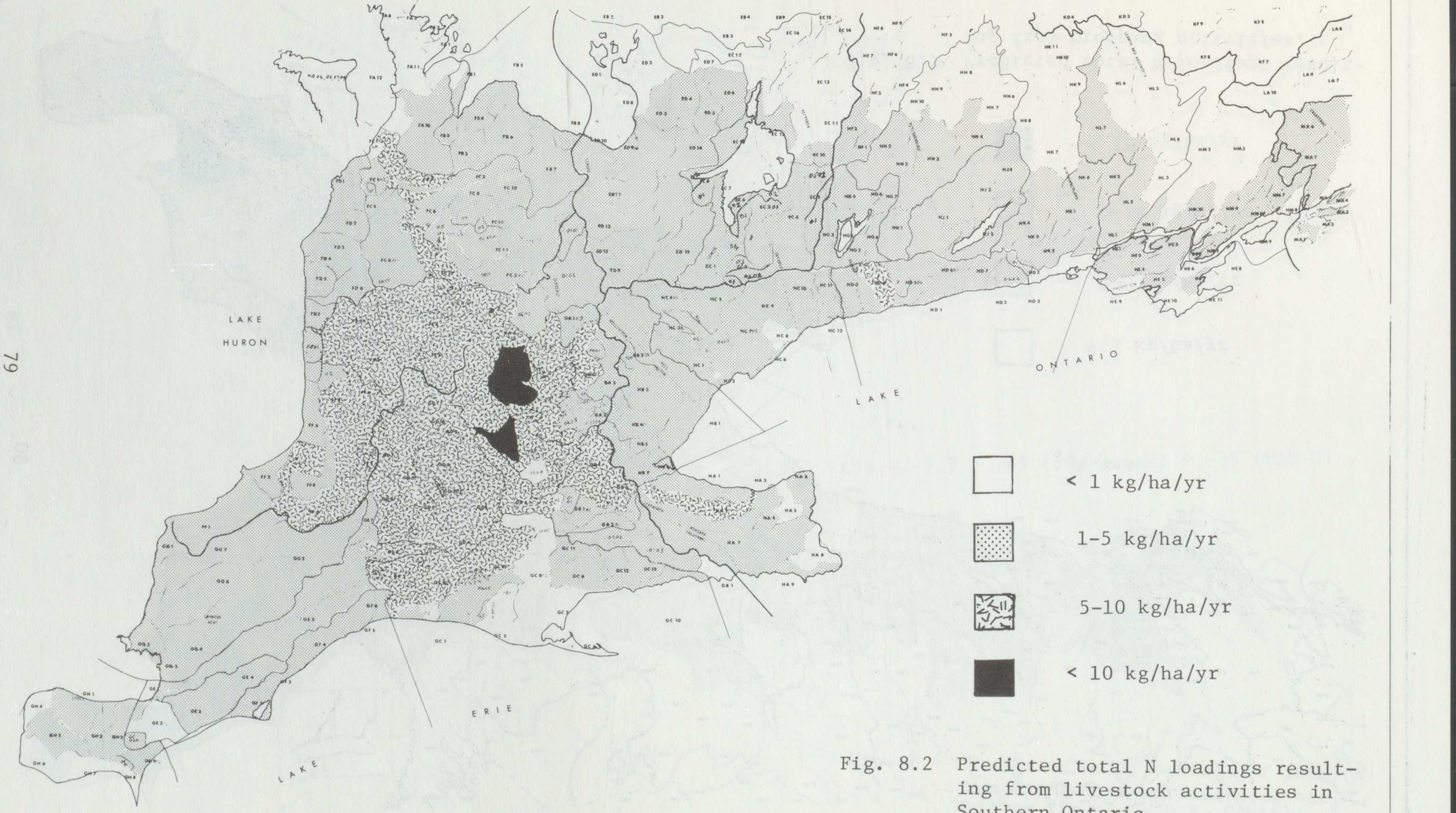


Fig. 8.2 Predicted total N loadings resulting from livestock activities in Southern Ontario.

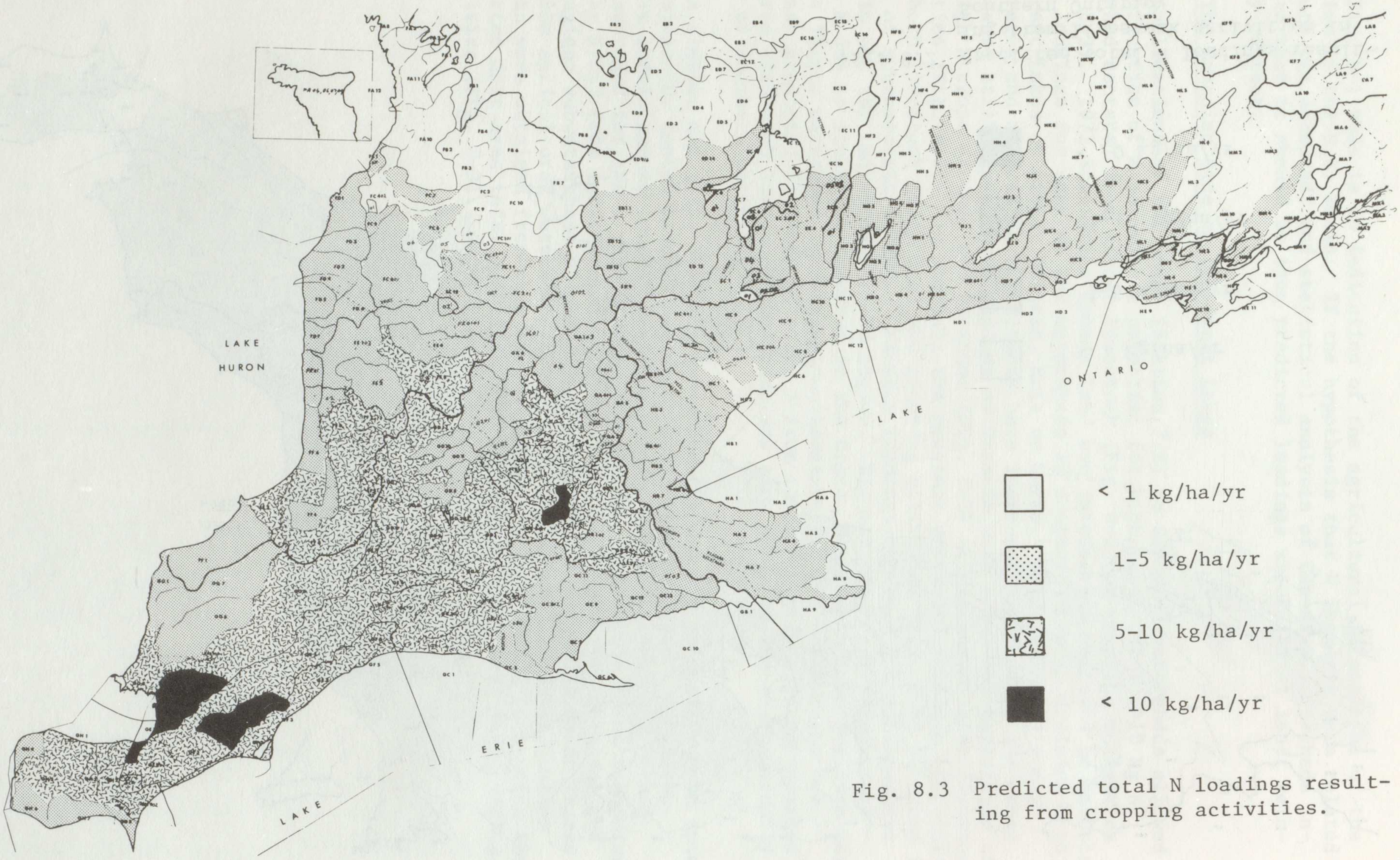
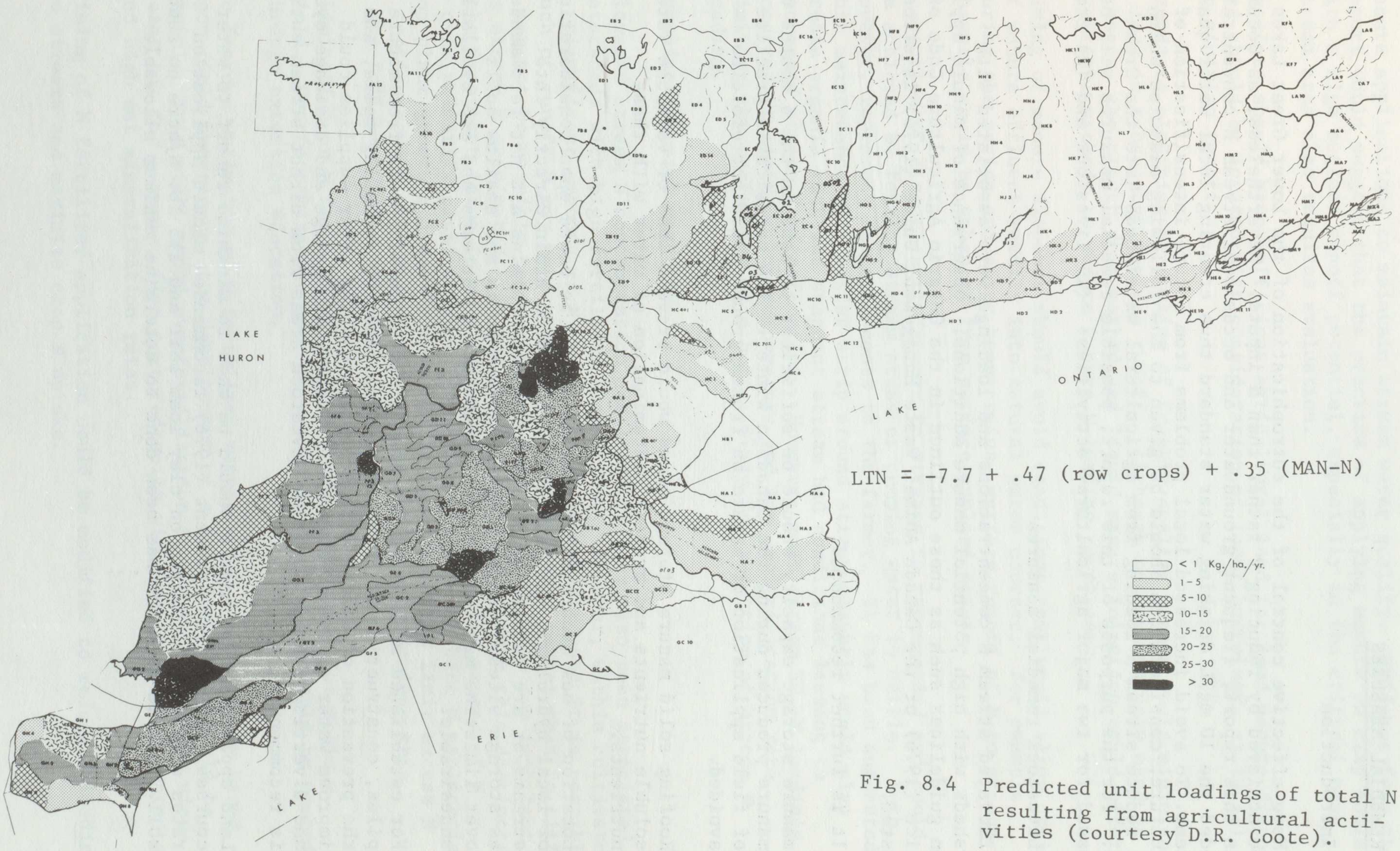


Fig. 8.3 Predicted total N loadings resulting from cropping activities.



LTN = -7.7 + .47 (row crops) + .35 (MAN-N)

Fig. 8.4 Predicted unit loadings of total N resulting from agricultural activities (courtesy D.R. Coote).

9. REMEDIAL MEASURES

9.1 Introduction

More effective control of the eutrophication of the Lower Great Lakes may be achieved by reducing P rather than N inputs. Nevertheless, as documented within this report, frequent groundwater and occasional stream N concentrations exceeded the 10 mg/L drinking water standard thus creating local water quality problems. To avoid increased local problems from future intensification of agriculture, consideration should be given to the following measures which might reduce stream N loading from agricultural watersheds into the Great Lakes. For the purposes of this report, possible remedial measures will be discussed for two major agricultural activities: (1) livestock and (2) crops.

9.2 Livestock remedial measures

Elevated stream N concentrations and loadings were associated with watersheds with high potential manure additions. Observance of manure application guidelines such as those outlined in the Ontario Agriculture Code of Practice (1976) or the Canada Animal Waste Management Guide (1976) is strongly suggested.

It is further recommended:

(1) manure storage capacity should be sufficient to contain the 6 months of manure produced during the Canadian winter. The undesirable practice of field application of manure on frozen ground could therefore be avoided.

(2) Roofing solid manure storage areas would prevent loss of valuable water soluble nutrients and prevent contamination of water with these nutrients.

(3) Location of new manure storage areas should be based upon considerations of local hydrology. For example, areas which drain directly into streams or are located in stream spring floodplains are not recommended as storage sites. Coarse grained, porous soils and shallow soils over limestone may too readily transport N to streams and are similarly undesirable.

(4) For established manure storage areas, diversion of runoff from manure piles, construction of concrete holding tanks or retaining walls, and the prevention of silage effluent from reaching water supplies could improve water quality. Preventing linked barn sewage and drainage systems and diverting ditches draining livestock areas from direct stream entry, is recommended.

(5) Land application of manure should be made to minimize runoff to water courses. In Ontario, present (1976) recommended manure application rates were 320 lb. N/acre on clay loam soil and 213 lb. N/acre on sandy soil. Little research has been done to determine maximum allowable

manure applications to maintain stream water quality. Evidence from this report would suggest that the practise of applying manure on clay soils with a high surface runoff potential, especially in the critical near stream area also requires evaluation.

(6) Feedlots should have sufficient agricultural land for land manure disposal and should be located with consideration of local hydrology, as in (3), to minimize runoff.

(7) Immediate ploughing or disking of freshly applied manure would minimize N loss in subsequent surface runoff. Although not extensively used at present, the plough down method and liquid manure injection could offer practical methods to reduce manure N loading to streams.

(8) Timing of manure disposal should avoid conditions that would allow drainage of manure effluent readily into natural water courses. For example, during the spring and after heavy rains, surface runoff of N to stream channels could be enhanced from surface applied manure.

(9) Prevention of direct cattle access to streams is recommended and could be achieved by fencing stream areas or pumping water to cattle. Both, however, represent economic costs to the farmer. It has been suggested that maintenance of a buffer strip around stream channels would also create organic rich and stagnant stream bed conditions leading to increased stream denitrification. However, most stream NO_3-N loadings occurred at times of low temperature and low denitrification rate limiting the usefulness of a buffer strip for reduction of stream N loading.

9.3 Cropping remedial measures

Elevated stream N concentration and loadings have also been associated with watersheds with high fertilizer N additions. However, within cultivated fields, significant amounts of N were annually mineralized and it is possible that much of runoff N may have originated as mineralized rather than fertilizer N. It may not be possible to distinguish from which of these two important sources stream N originated. It may not be important to make this distinction since the important issue is more likely to be limiting the excess of N inputs over primarily plant uptake. The ideal would be to base N application rates on plant growth and development during the season and limit excess N in the rooting zone at the end of the growing season. To achieve this ideal, the following merit consideration.

(1) Elimination of N fertilization above rates recommended for optimum yield. Overfertilization was not common in Ontario and could be remedied through extension education.

(2) To improve estimates of N fertilizer rates, which are currently based upon field experience, the development of a soil test for N would be useful. This might avoid overfertilization from a water quality viewpoint on, for example, fine textured soils with high organic N contents and high net mineralization rates.

(3) Timing of N fertilizer application could be modified to reduce N loadings to streams and maximize crop N uptake.

(i) For example, split application of N to corn could be encouraged since maximum NO_3-N uptake occurs from 3-6 weeks after seedling emergence. Preplant and sidedressing of N to corn during the period of maximum uptake could decrease N leaching loss. However, the additional time (economic cost) and risk to the individual farmer should be recognized. Delayed application of sidedressing due to wet weather could result in reduced yields and profit. There could also be an inevitable higher N loss during years with heavy rain after fertilization.

(ii) Fall application of N fertilizers is a questionable practice in Canada. U.S. studies (Stewart et al., 1975) recommended against NO_3-N application and estimated 10-30% loss of fall applied NH_4-N in agricultural areas immediately south of Lakes Ontario and Erie. Similar figures for fall NH_4-N loss were not available for Canada but could be higher as a result of extensive soil leaching by snowmelt.

(iii) Application of N fertilizers such as sulphur or pesticide coated urea have the potential for controlling N release which may allow for more efficient plant N uptake. However, preliminary studies in southwestern Ontario (Beauchamp, 1977) found that controlled N release merely resulted in more N available for leaching in the fall or winter.

(iv) Green manuring or ploughdown of green legumes add to the soil a more slowly available N for future crops. To the farmer, this could again mean loss of cash crop income on the legume areas and require additional labour. Legumes may not be adapted to some soils with low pH or poor drainage.

(v) Land application of animal wastes could also provide N more slowly for optimum uptake during crop growth. Such application could reduce manure N loading to water providing precautions such as following recommended application rates, as previously discussed, were taken.

(4) Banding instead of surface broadcasting can reduce surface runoff losses of N (Whitaker et al., 1978). New machinery may however be required by the farmer.

(5) Winter cover cropping with, for example, small grains might reduce percolation of water and unused (from previous crop) N prior to the large volumes of runoff which occur from December - March in southwestern Ontario. This solution would be dependent upon the possibility of achieving good growth of the cover crop prior to the winter. A late season crop such as grain corn would not allow time for growth of cover crops.

(6) The incorporation into a farm rotation of crops which require little (small grains, grasses) or no N addition (soybeans, legumes) would allow reduction of overall watershed N additions. However, for an individual farmer, this could result in reduced income from cash crops and necessitate livestock to use added forage production.

(7) Changed land use so as to increase watershed hay and pasture areas would reduce stream N loading but have severe economic effects on individual and possibly regional economies.

(8) Early spring seeding of small grains could improve yields and reduce soil N in April.

(9) Crop breeding programmes to develop, for example, high yield corn varieties with reduced N fertility requirements could result in marked water quality benefits. Most significant conservation of N from agricultural areas would be achieved if N fertilization and plant uptake were matched for corn. This was a result of high fertilizer rates and the extensive areas of corn in the Great Lakes basin. Other crops with high N leaching losses such as potatoes and Burley tobacco have small areas.

(10) For the 1/4 to 1/3 of N lost as Kjeldahl N from Ontario watersheds and associated with sediment, remedial measures concerned with erosion control would be most effective. Such practices include conservation tillage, sod-based rotations, winter cover crops, contour planting and ploughing, strip cropping, improved soil fertility, grassed waterways and elimination of fall ploughing where possible.

9.4 General Conclusions

(1) A number of management methods already exist to reduce stream N loading. However, management studies such as those conducted across Ontario for PLUARG (1977) or within the Thames Valley Conservation Authority (1978) suggested that, with the exception of crop rotation, such methods were being used by a minority (10-20%) of farmers. Thus, expanded emphasis of conservation practices by agricultural extension workers could result in improved farm management and reduced stream N loading.

(2) A number of these recommended practices may require special modification in Canada. For example, as a result of cool soil temperatures and large snowmelt runoff, no tillage and slow release fertilizers respectively may be of reduced usefulness. Questions such as these could be researched at local agricultural research stations where the effectiveness of management practices for the control of nutrient losses could be evaluated as extensively as have been crop impacts on runoff and erosion.

(3) Finally, it should be recognized that increased N use has resulted in large positive economic advantages to agriculture. Most important among these are the increased yields and economic returns associated with N fertilization and the resulting ability to produce these higher yields on a diminishing amount of cultivated land. Thus, institution of measures to reduce NO_3-N loss from fields should consider the effects such measures would have upon achieving satisfactory production.

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APPENDIX 3-1. Sample and flow duration curves for the 11 agricultural watersheds.

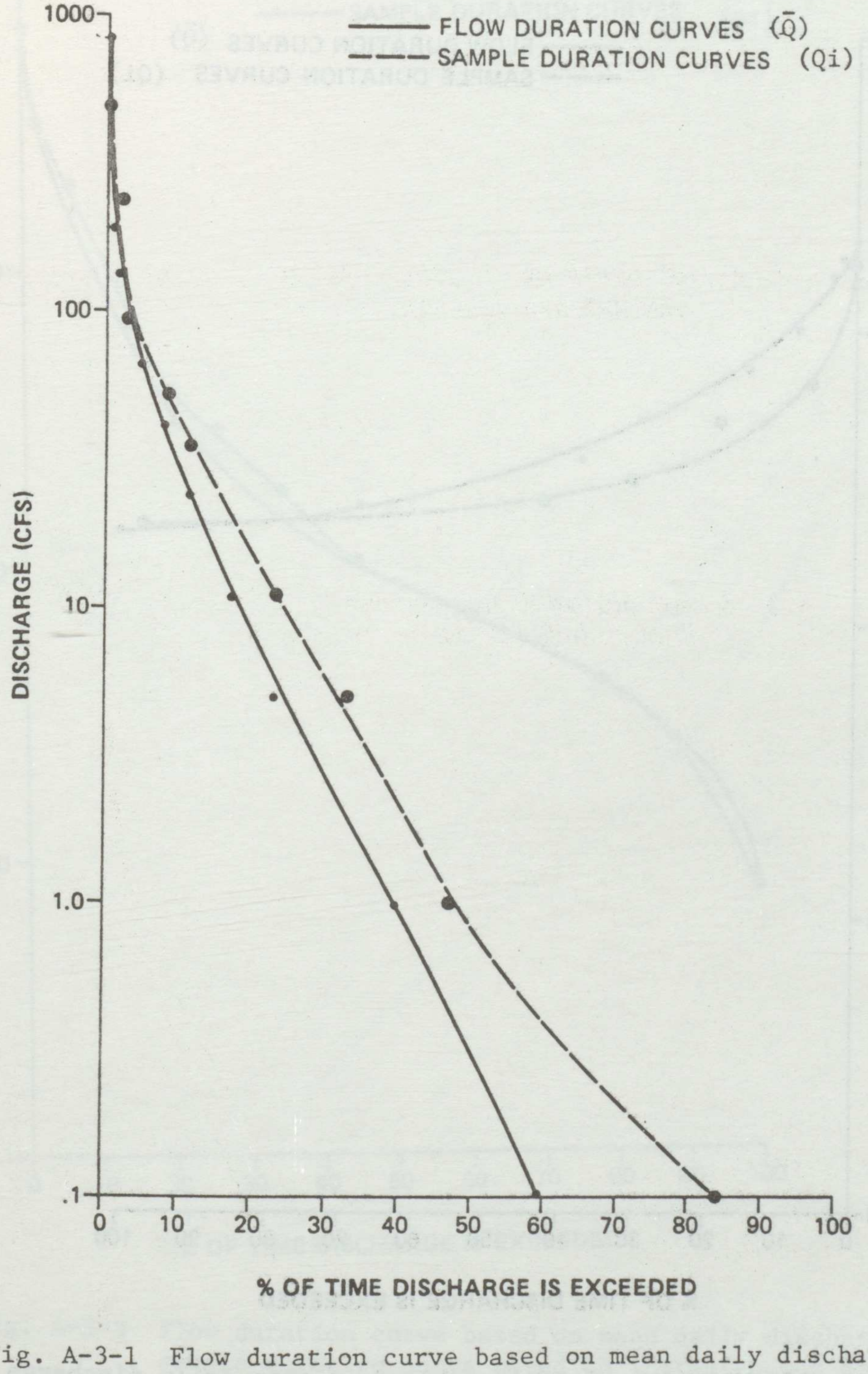

Fig. A-3-1 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for watershed AG-01.

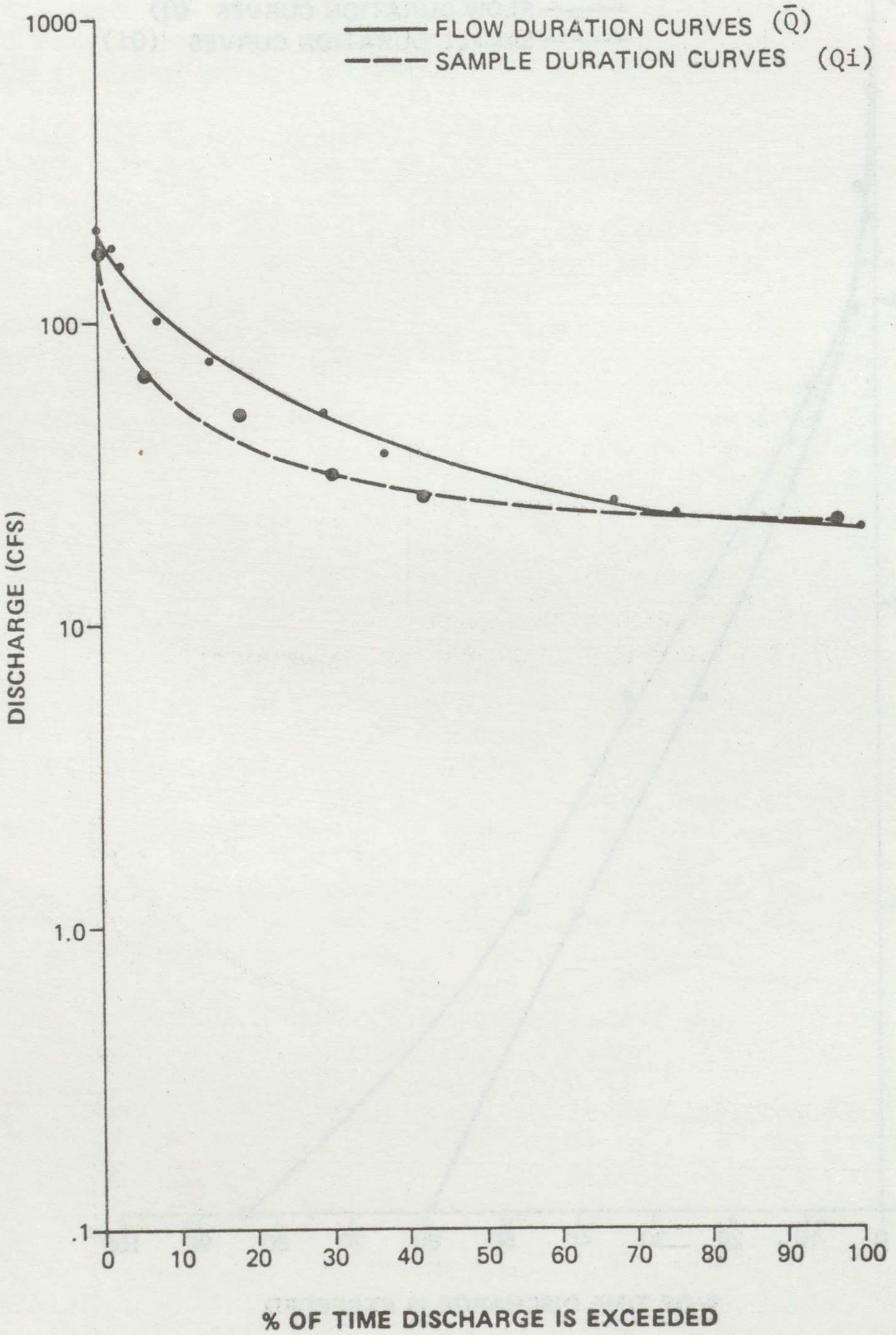

Fig. A-3-2 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-02.

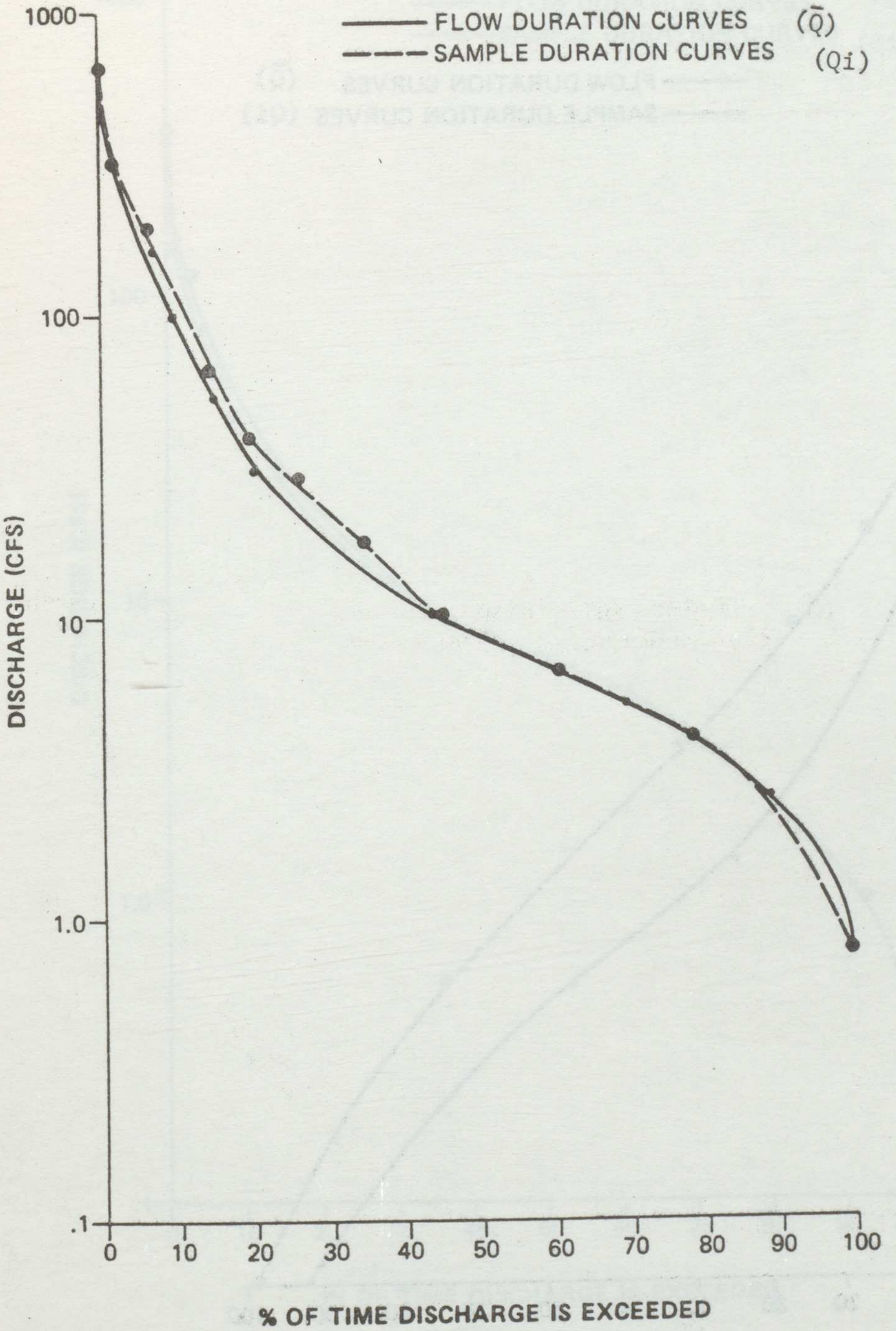

Fig. A-3-3 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-03.

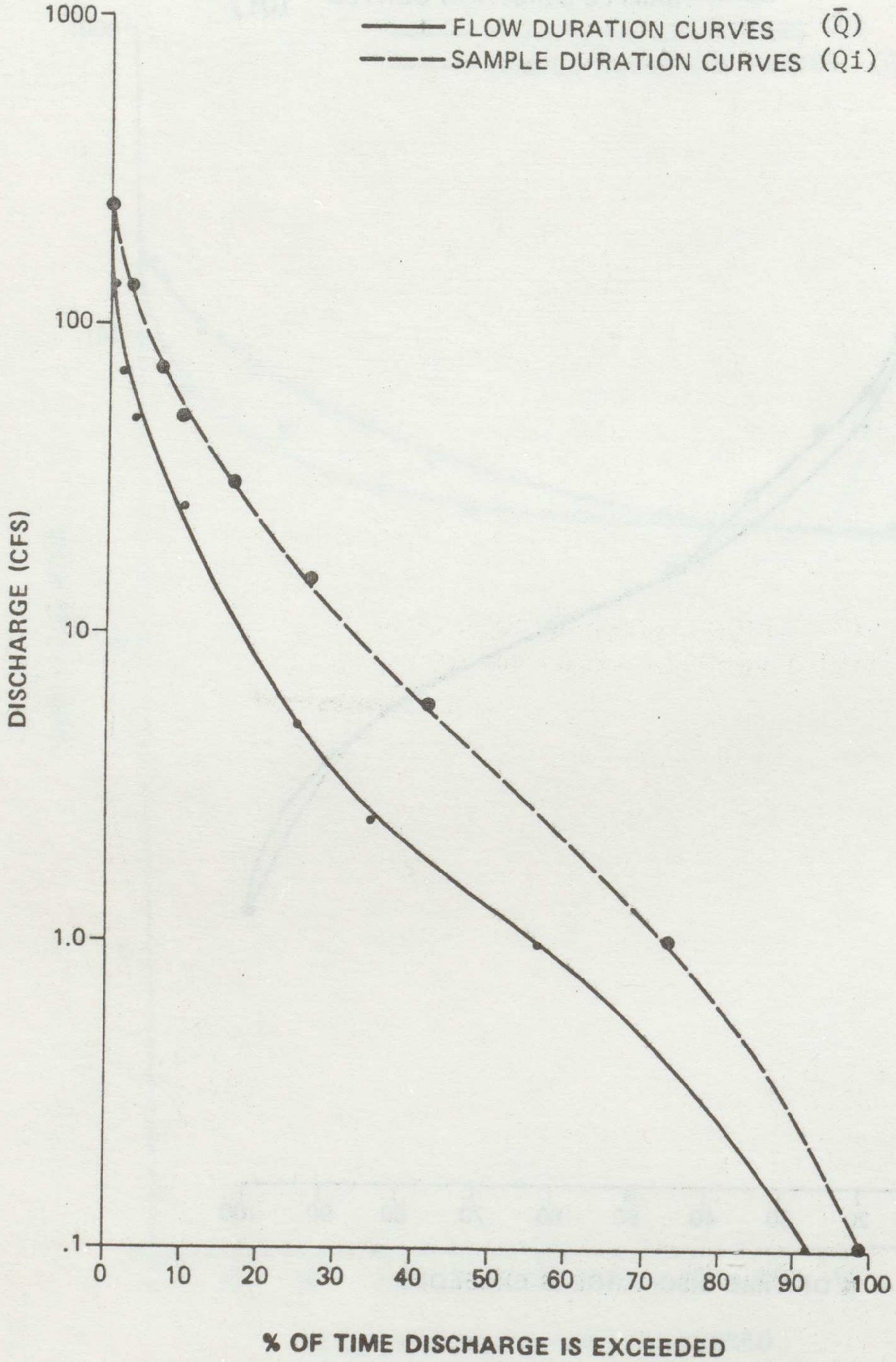

Fig. A-3-4 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-04.

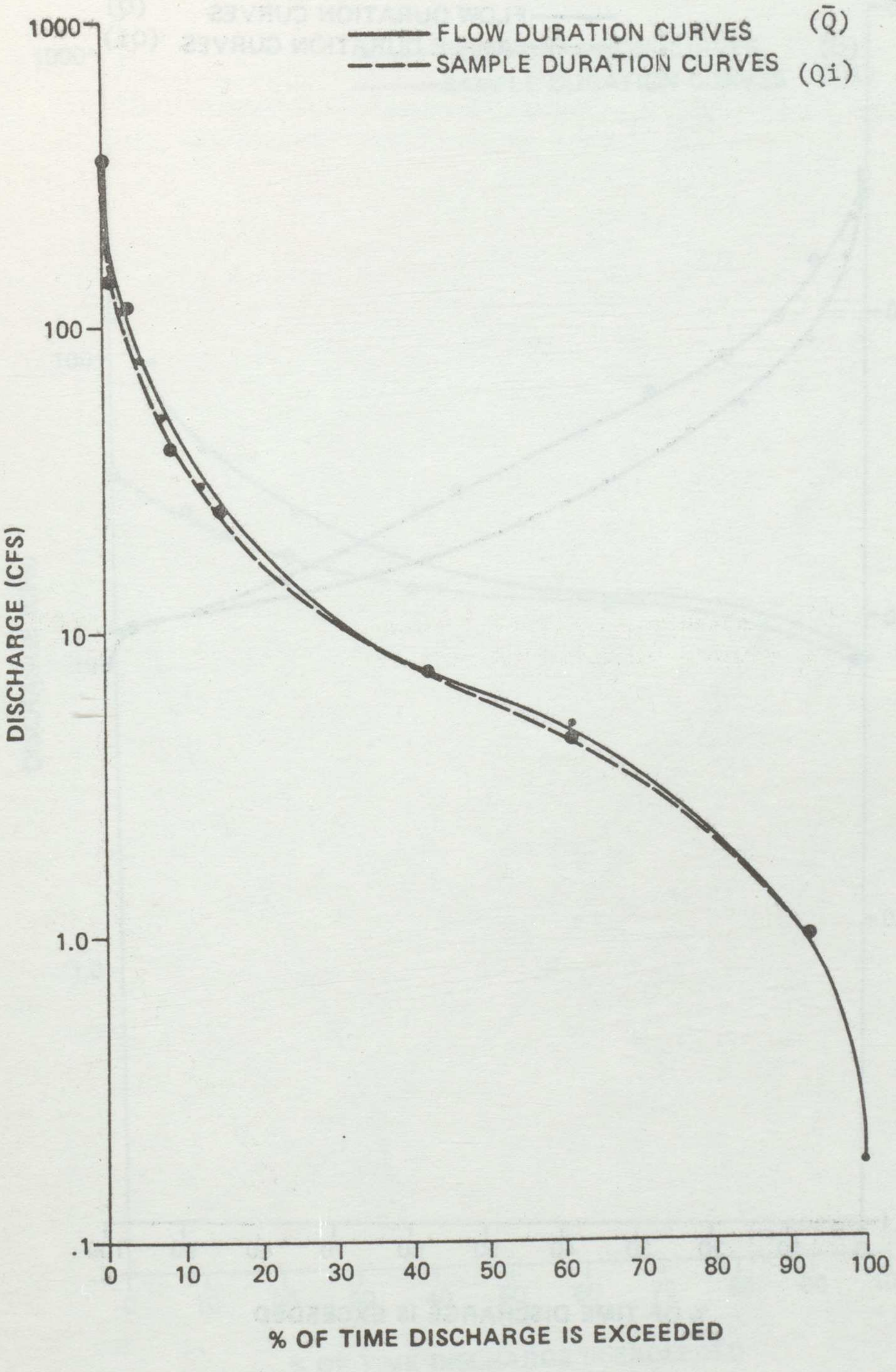

Fig. A-3-5 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-05.

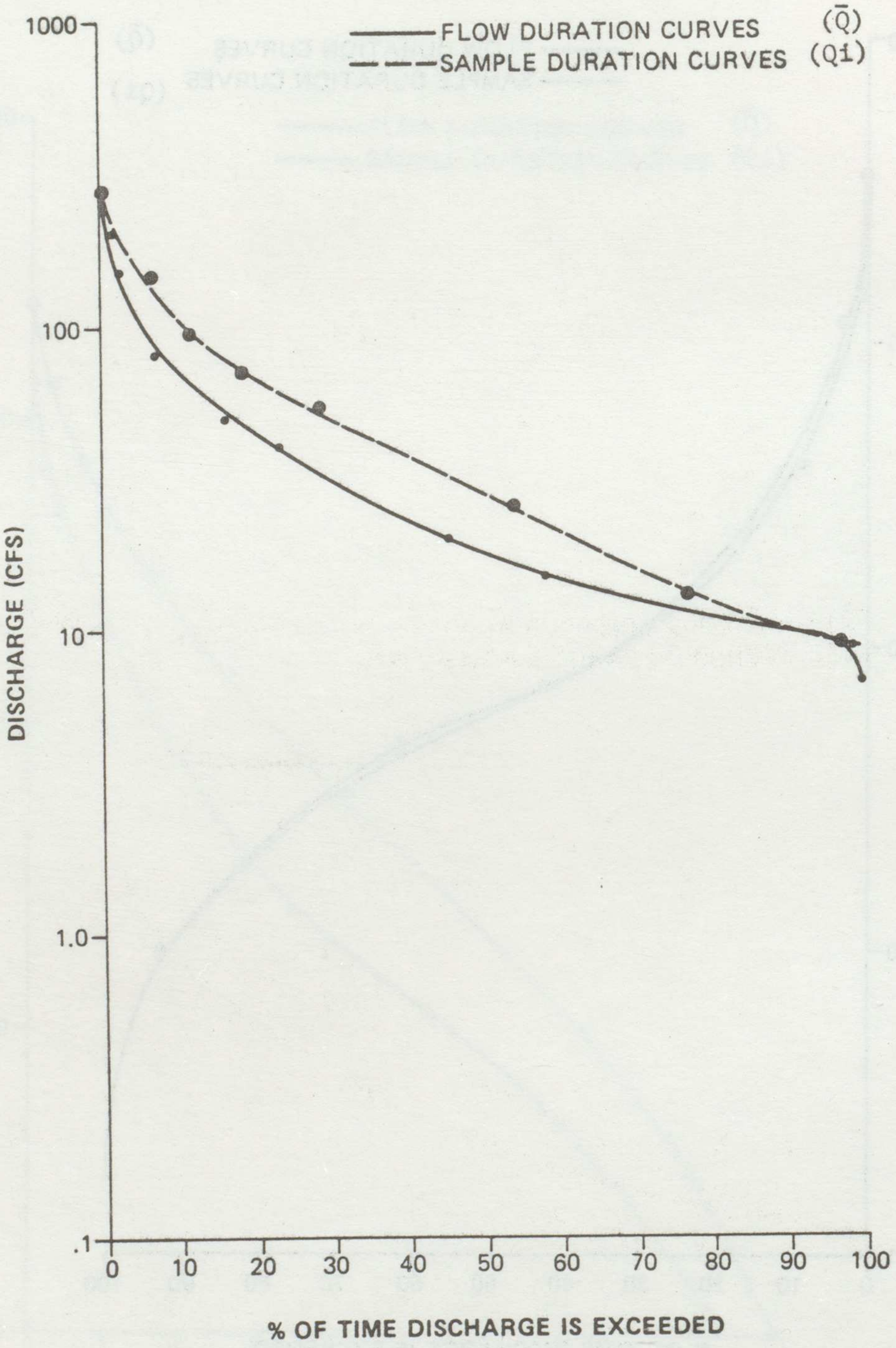

Fig. A-3-6 Flow duration curve based on mean daily discharge $(\bar{Q})$ and sample duration curve based on instantaneous discharge (Q_i) for Watershed AG-06.

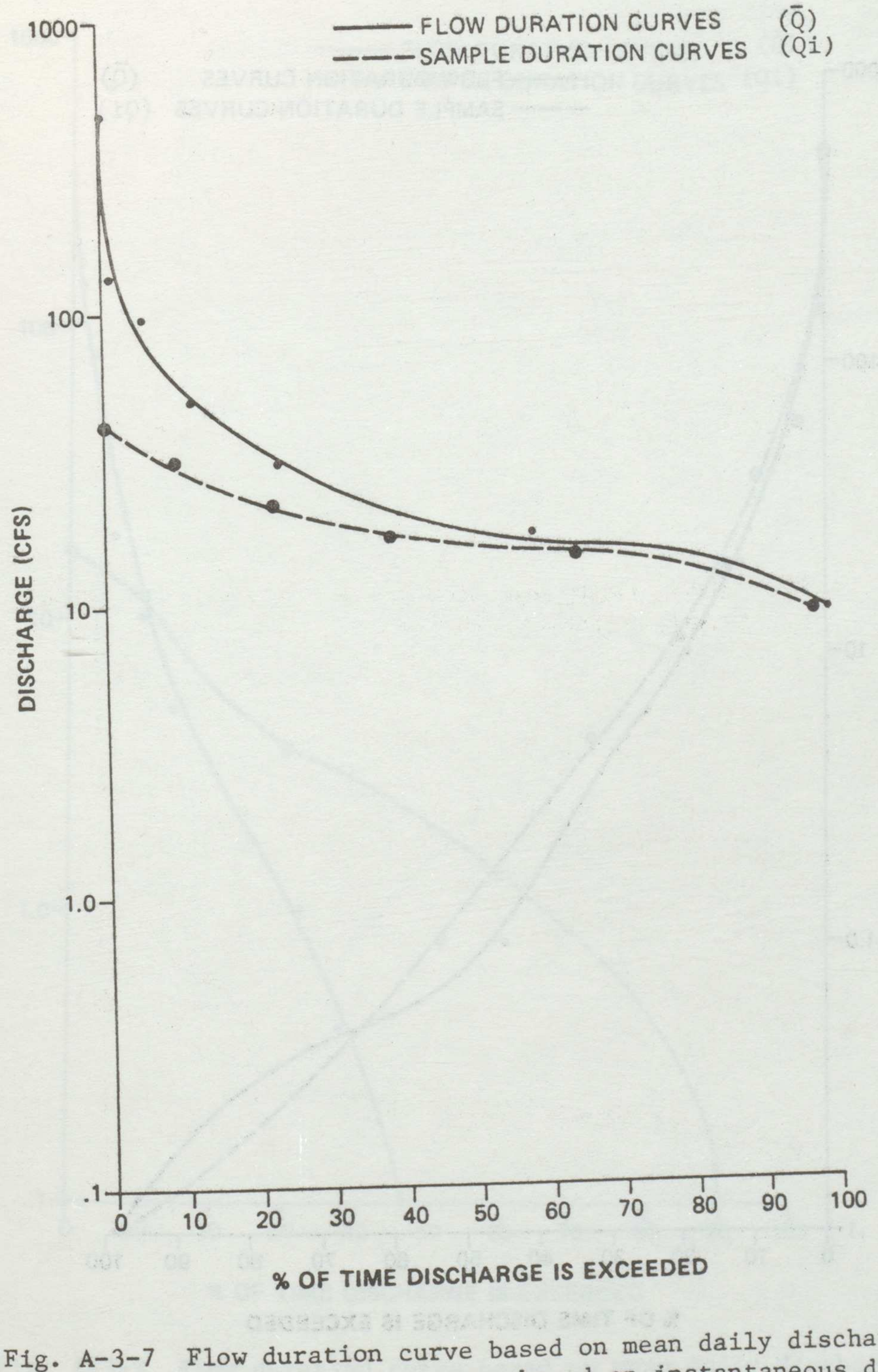

Fig. A-3-7 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-07.

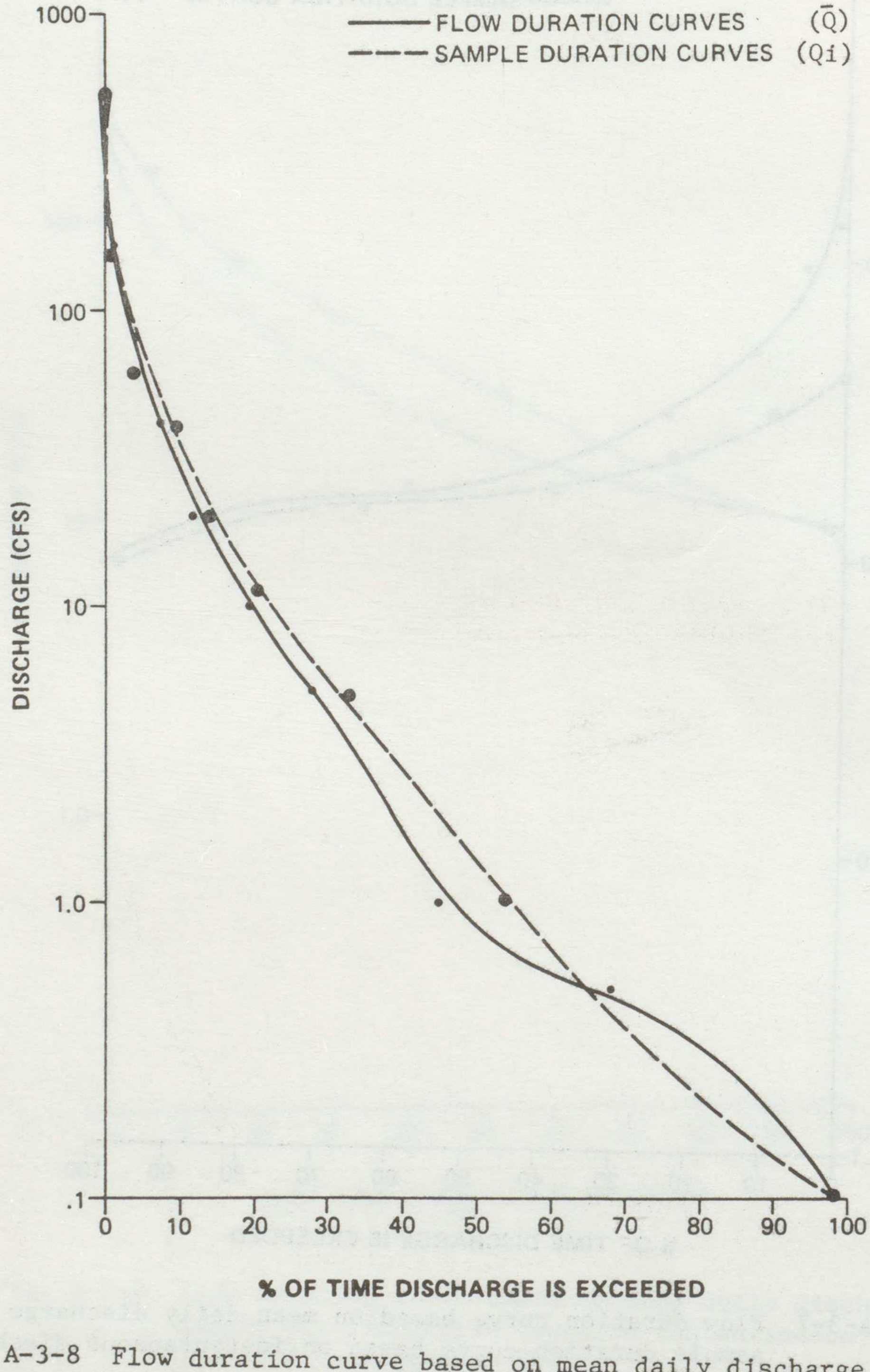

Fig. A-3-8 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-10.

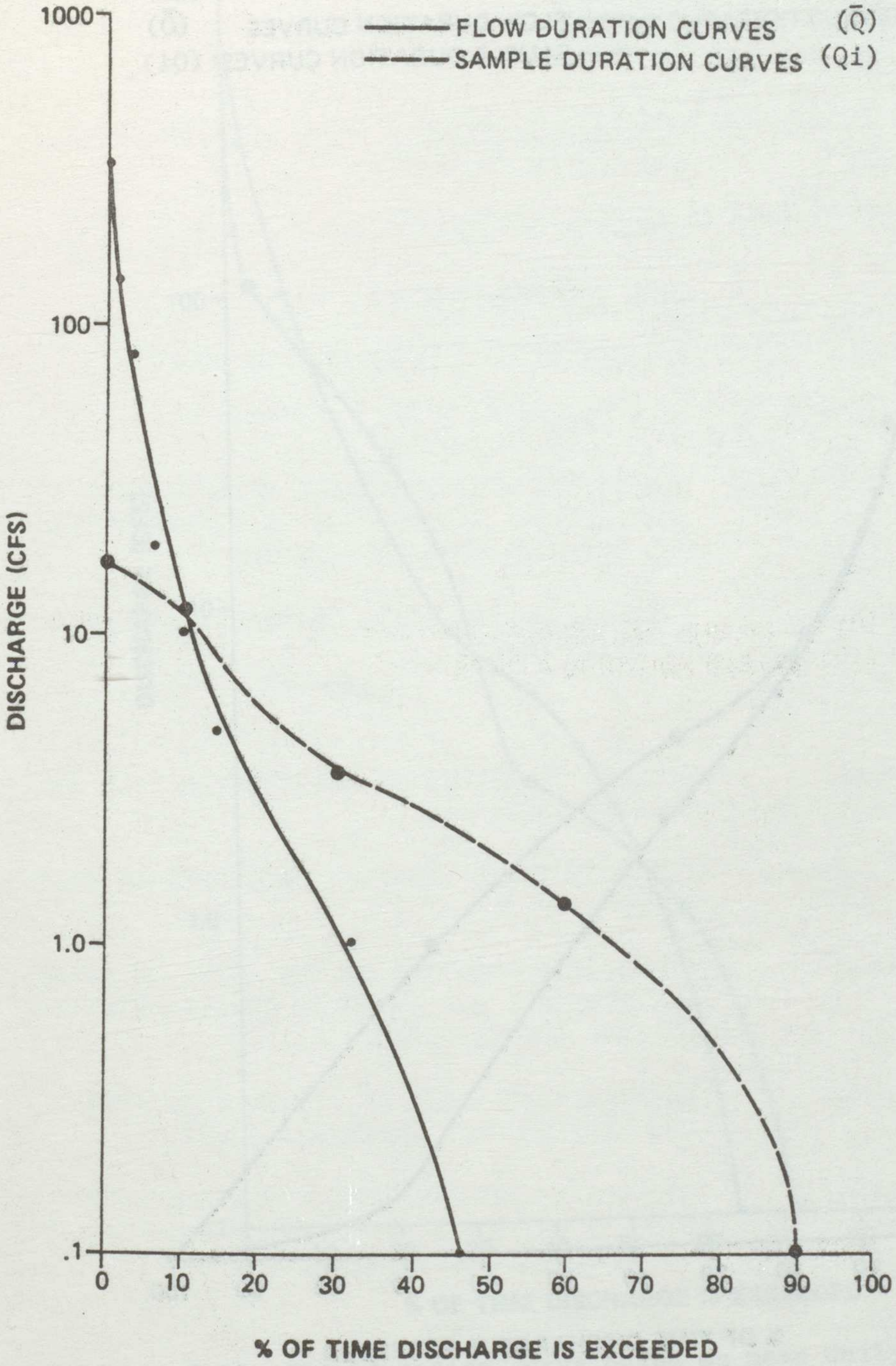

Fig. A-3-9 Flow duration curve based on mean daily discharge (Q̄) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-11.

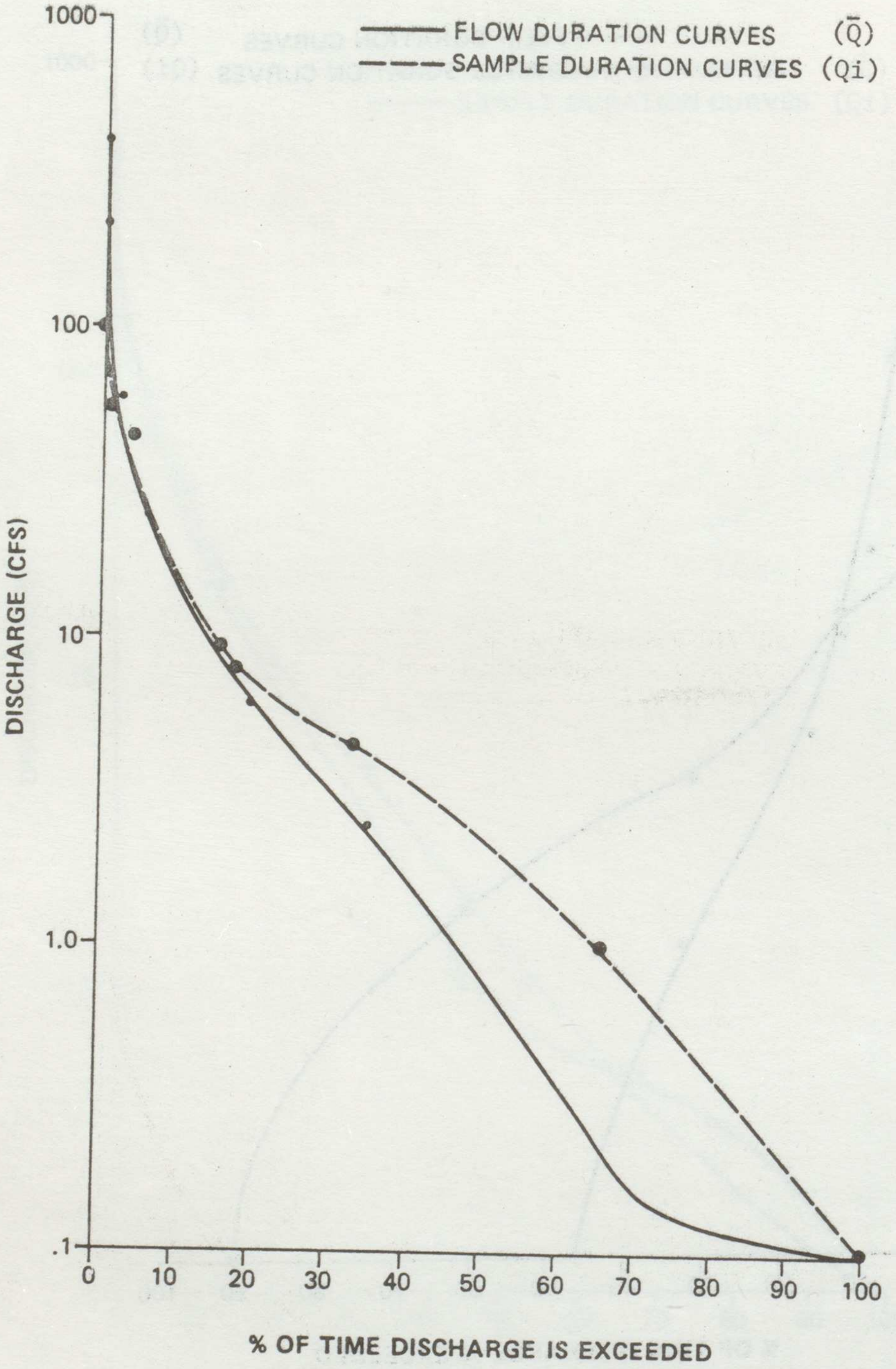

Fig. A-3-10 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Q_i) for Watershed AG-13.

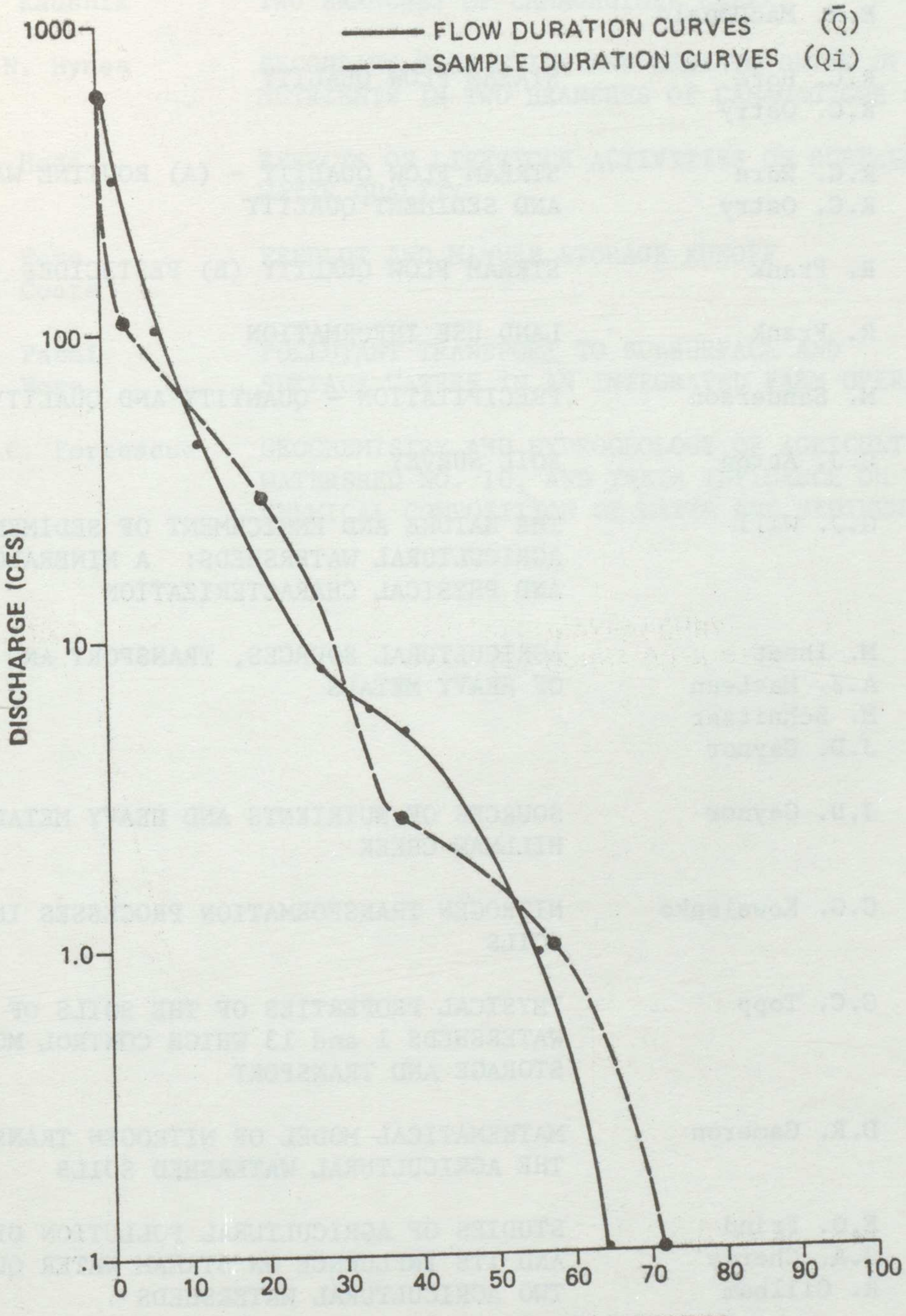

Fig. A-3-11 Flow duration curve based on mean daily discharge ($\bar{Q}$) and sample duration curve based on instantaneous discharge (Qi) for Watershed AG-14.

APPENDIX 4.1 Complete list of detailed projects in agricultural watershed studies.

PROJECT NO.	PRINCIPAL INVESTIGATORS	TITLE
1	D.R. Coote E.M. MacDonald	COORDINATION; DATA HANDLING AND TRANSFER
2	R.C. Hore R.C. Ostry	STREAM FLOW QUALITY
3	R.C. Hore R.C. Ostry	STREAM FLOW QUALITY - (A) ROUTINE WATER AND SEDIMENT QUALITY
4	R. Frank	STREAM FLOW QUALITY (B) PESTICIDES
5	R. Frank	LAND USE INFORMATION
6	M. Sanderson	PRECIPITATION - QUANTITY AND QUALITY
7	C.J. Acton	SOIL SURVEY
8	G.J. Wall	THE NATURE AND ENRICHMENT OF SEDIMENTS IN AGRICULTURAL WATERSHEDS: A MINERALOGICAL AND PHYSICAL CHARACTERIZATION
9	M. Ihnat A.J. MacLean M. Schnitzer J.D. Gaynor	AGRICULTURAL SOURCES, TRANSPORT AND STORAGE OF HEAVY METALS
10	J.D. Gaynor	SOURCES OF NUTRIENTS AND HEAVY METALS IN HILLMAN CREEK
11	C.G. Kowalenko	NITROGEN TRANSFORMATION PROCESSES IN WATERSHED SOILS
12	G.C. Topp	PHYSICAL PROPERTIES OF THE SOILS OF AGRICULTURAL WATERSHEDS 1 and 13 WHICH CONTROL MOISTURE STORAGE AND TRANSPORT
13	D.R. Cameron	MATHEMATICAL MODEL OF NITROGEN TRANSPORT IN THE AGRICULTURAL WATERSHED SOILS
14	E.O. Frind J.A. Cherry R. Gillham	STUDIES OF AGRICULTURAL POLLUTION OF GROUNDWATER AND ITS INFLUENCE ON STREAM WATER QUALITY IN TWO AGRICULTURAL WATERSHEDS
15	H.R. Whitely	HYDROLOGICAL MODEL
16	G.J. Wall	EROSIONAL LOSSES FROM AGRICULTURAL LAND
17	W.T. Dickinson	SEDIMENT DELIVERY RATIOS IN SMALL AGRICULTURAL WATERSHEDS

PROJECT NO.	PRINCIPAL INVESTIGATORS	TITLE
18	M.H. Miller	CONTRIBUTION OF PHOSPHORUS FROM AGRICULTURAL LAND TO STREAMS BY SURFACE RUNOFF
19-A	J.B. Robinson N.K. Kaushik	NITROGEN TRANSPORT AND TRANSFORMATIONS IN TWO BRANCHES OF CANAGAGIGUE CREEK
19-B	H.B.N. Hynes	SECONDARY PRODUCTION AND ORGANIC DRIFT OF NUTRIENTS IN TWO BRANCHES OF CANAGAGIGUE CREEK
20	S.L. Hodd	EFFECTS OF LIVESTOCK ACTIVITIES ON SURFACE WATER QUALITY
21	F.R. Hore D.R. Coote	FEEDLOT AND MANURE STORAGE RUNOFF
22	N.K. Patni F.R. Hore	POLLUTANT TRANSPORT TO SUBSURFACE AND SURFACE WATERS IN AN INTEGRATED FARM OPERATION
23	J.A.C. Fortescue	GEOCHEMISTRY AND HYDROGEOLOGY OF AGRICULTURAL WATERSHED NO. 10, AND THEIR INFLUENCE ON THE CHEMICAL COMPOSITION OF WATER AND SEDIMENTS

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