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Sources of Nutrients and Metals in Hillman Creek: Technical Report to Agricultural Watershed Studies, Task Group C, Canadian

International Reference Group on Great Lakes Pollution from Land Use Activities

Canada. Department of Agriculture. Harrow Research Station

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INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES

INTERNATIONAL JOINT COMMISSION

SOURCES OF NUTRIENTS AND METALS IN HILLMAN CREEK

TECHNICAL REPORT

to

AGRICULTURAL WATERSHED STUDIES

Task Group C - [Canadian] - PLUARG - IJC

on

SOURCES OF NUTRIENTS AND METALS

IN HILLMAN CREEK

by

J. D. Gaynor, Research Station

Agriculture Canada

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DISCLAIMER

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SUMMARY

This study was initiated to quantify inputs of suspended solids, nutrients, soluble cations, and metals in five subwatersheds of Hillman Creek; to relate the quantitative information for these inputs to land use in the subwatersheds; and to present remedial measures which would reduce the magnitude of these inputs where necessary.

Two land uses, i.e., predominantly rural housing and agriculture, were selected by the location of five sampling sites on the west branch of the Hillman Creek. The monitoring at these sites occurred from April 4, 1975 to March 10, 1976. The concentrations of the various parameters and discharge were determined periodically throughout the year and during rain and snow-melt events. Stream load and annual subwatershed loss were calculated from the concentration and discharge data at each site and statistical comparisons were made to determine significant inputs attributable to the land use.

Suspended solids concentration, annual stream load and watershed loss increased as drainage area increased but could not be related to land use. Soil loss ranged from 253 to 943 kg/ha/yr with the major portion (77-95%) of the solids transported during the hydrologically active period from January to March. The establishment of fall cover crops and grassed buffer zones along the drainage channel may reduce overland transport of solids but the average farm size in this watershed is 17 ha and the benefit/cost of permanent grassed buffer zones on productive land would need assessment.

Nitrogen loss for this watershed was similar at each sampling site and averaged 54 kg/ha/yr. A considerable proportion (63-81%) of the total-N loss occurred during spring runoff and NO_3-N comprised 80-94% of the total-N discharged. Nitrogen loss could not be related to current fertilizer use as little NO_3-N was lost during the cropping season. This relates to increased utilization through crop growth and insufficient precipitation for leaching of soil mineralized and fertilizer applied nitrogen. The NO_3-N concentration seldom exceeded 10 mg/l and this only

at the farthest downstream sites and during high runoff.

No point source for nitrogen input was found in the watershed. Nitrogen in the drainage system could have originated from mineralized soil nitrogen due to cultivation or from past fertilizer use. Eighty three percent of the watershed is intensively farmed and cultivation and fertilizer use are essential for maximum production.

Phosphorus in Hillman Creek appeared to be significantly influenced by rural housing. Total-P and PO_4-P concentrations and numbers of biological indicator organisms were significantly increased at sampling locations downstream of rural housing areas and the fecal coliform/fecal streptococci ratio was $>$0.7 suggestive of domestic input. Unit area losses for the agricultural and rural housing subwatersheds were 2.23 and 2.86 kg total-P/ha, and 0.58 and 0.83 kg PO_4-P/ha respectively.

The quantity of PO_4-P contributed by rural housing (assuming all of the PO_4-P from these areas arose from housing) amounted to 63% of the total load (932 kg PO_4-P/yr) discharged from the study area. The average amount of orthophosphate discharged from each house in the watershed was estimated at 5 g PO_4-P/house/day. Rural housing may only be responsible for part of the PO_4-P from these areas due to the presence of interspersed agriculture. Assuming agriculture only contributed 0.58 kg PO_4-P/ha/yr to the load from rural housing areas then housing would constitute 27% of the total PO_4-P load transported from the study area and the average contribution from each house would be reduced to 2 g PO_4-P/house/day. These estimates probably represent the extremes for the average contribution from housing. The magnitude of phosphorus losses for the agricultural and housing subwatersheds would vary seasonally and between watersheds but the results demonstrate that for some watersheds domestic input of phosphorous to the drainage system is significant and needs to be more adequately identified and quantified in order for remedial measures to be effective. Total-P and PO_4-P losses from all sources in the total study area (1295 ha) were respectively 2.57 and 0.72 kg/ha/yr.

Soluble cations and metals were either derived from geologic weathering or precipitation. The use of limestone as a soil additive near the source of the creek contributed significantly to the Ca stream load but lime use in the lower reaches of the study area did not. Calcium loss could be reduced by regulating application near the creek or on tiled fields although the importance of this cation as a pollutant needs to be assessed. Cadmium, Cr, and Pb concentrations were below the detection limit of 0.6, 2, and

11 ug/l respectively. Detectable concentrations of Cu, Fe, and Zn were found at all sites and at all sampling periods but concentrations did not exceed the Ontario Water Quality guidelines for irrigated use. Copper and Fe transport occurred on the suspended solids while Zn was transported as the soluble species.

INTRODUCTION

The Hillman Creek watershed is representative of many intensively farmed regions in Ontario where the land use and sandy soil favor a high pollution potential. The extensive use of fertilizers and intensive crop management necessary for crop production could lead to nutrient enrichment of the drainage system. This study was initiated to quantify the suspended solids, nitrogen and phosphorus forms, soluble cations, and metals at selected sites in Hillman Creek; to relate the results to land use, i.e., predominantly rural housing and agriculture; and to locate point sources in the area. Watershed losses and the monthly distribution of these parameters were calculated for the various subwatersheds. Additional water samples were collected for analysis of biological indicator organisms, i.e., total and fecal coliforms, and fecal streptococci, contributed by housing and domestic animals.

For the purpose of this report, pollution refers to the introduction of an element added by, or produced as a result of man's activity at levels above those naturally found which may render the water quality unusable for the desired activity. This report is not intended to determine whether or not the parameters measured constitute pollutants which may limit the water for a particular water quality standard or use but rather to report results and suggest remedial measures which may reduce inputs.

WATERSHED DESCRIPTION

The Hillman Creek watershed is located 1.5 km north of the town of Leamington in Essex County in southwestern Ontario at 42° 05' latitude and 82°35' longitude. The west branch of the Hillman Creek encompassing 13 km^2 was selected as the sampling area. The area is intensively farmed and agriculture constitutes the primary (83%) land use with runoff entering Hillman Creek along Highways 77 and 3. Approximately 75% of the watershed is drained through municipal drains or ditches while the remainder of the runoff enters natural water courses. Horticultural crops (potatoes, tomatoes, beans, and sweetcorn), field (small grains, corn, soybeans, and tobacco), and orchard crops constitute the main agricultural activity. The soil type is predominantly Berrien sandy loam (85%) over clay with the remainder composed of equal amounts of Fox sandy loam, Tuscola fine sandy loam, and the sand phase of Castor clay. The average annual precipitation is 76 cm of which 20-23 cm leaves the watershed as stream flow.

DATA COLLECTION METHODS

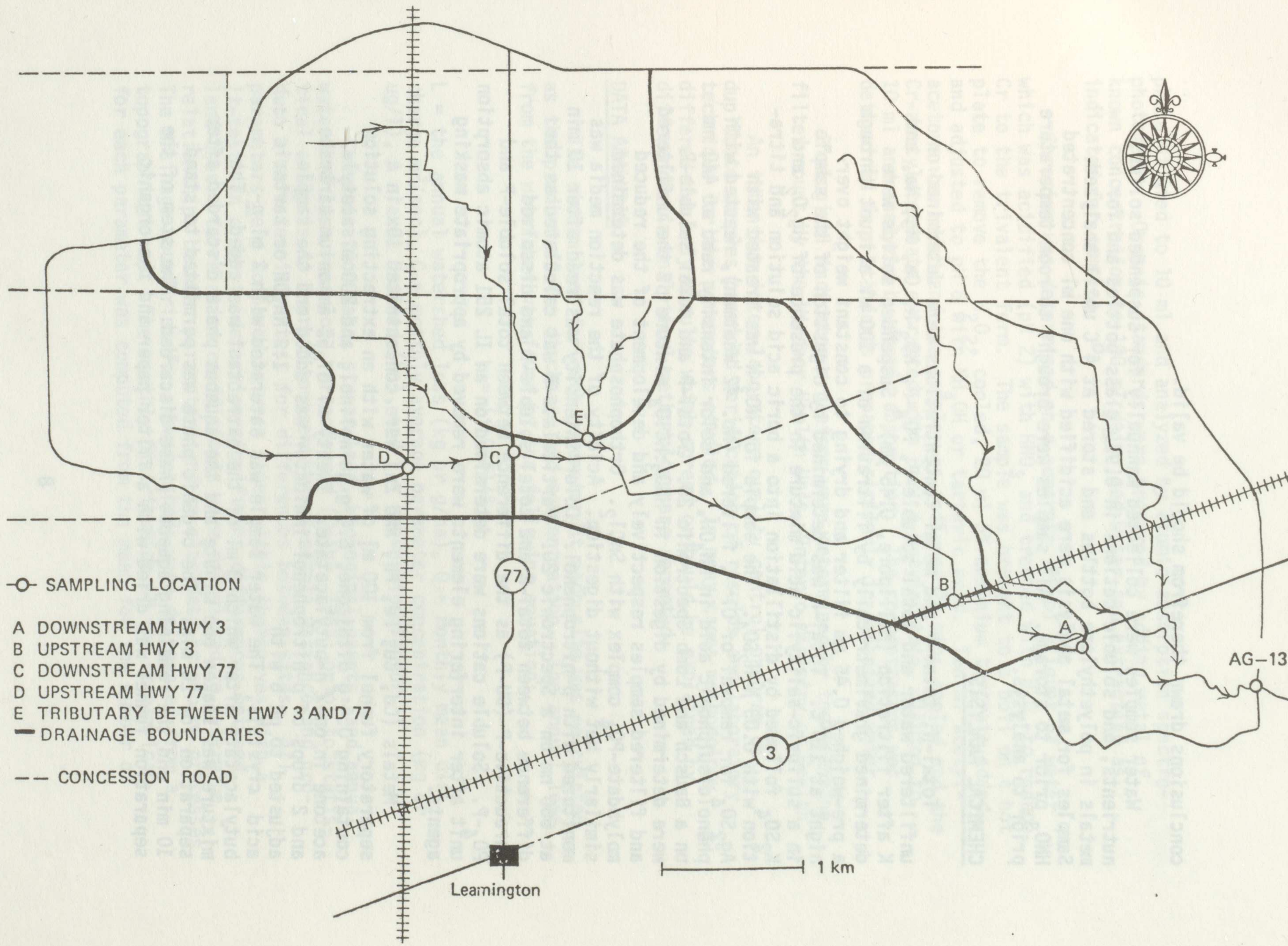
SITE INSTRUMENTATION AND SAMPLE COLLECTION

Four sampling sites were established in April, 1975 at points downstream and upstream of highways 3 and 77 to assess inputs from housing along the highways (Figure 1). A fifth sampling site (E), which drained a housing area, was established in August, 1975 on a tributary entering the main branch between highways 3 and 77. This site was not initially sampled since flow generally ceased during the summer. For this site, monthly losses for April - July, 1975 for each parameter, except dissolved unreactive-phosphorus (r=0.32), were estimated from site B, by the logarithm of the general regression equation y=mx+b. Inputs at sites upstream of highway 77 and between the two highways were assessed from the respective sampling sites to determine the contribution from agriculture. The sampling period reported herein extended from April 4, 1975 to the end of the spring runoff on March 10, 1976.

Staff gauges were installed at each of the sampling sites and were calibrated for flow with a propellor type (Ott) flow meter. Discharge was calculated by the velocity-area technique using the mean section method. Theheight on the staff gauge was recorded each time a water sample was taken and discharge calculated from the appropriate rating curve for that site.

Sampling periods were selected to coincide with rain or snowmelt events occurring in the watershed or at least once a week if flow conditions permitted. In total 30 to 34 samples were collected at each site which provided sufficient sampling to determine base or low flow concentrations but peak runoff events were not sufficiently sampled to provide adequate data for accurate loading estimates during this period. Since runoff events were sampled at peak flows loading and watershed losses are probably overestimated. A comparison of the annual watershed losses estimated in this study with those calculated from concentration and discharge data supplied by the Ontario Ministry of the Environment for the corresponding sampling period indicate that the annual losses were 40% higher for suspended solids and 25-50% higher for nutrients and soluble salts. Although the magnitude of the values reported for each parameter may not be accurate the relative differences between sites and the

Figure 1. Drainage boundaries and sampling locations for the Hillman Creek watershed study.



conclusions drawn therefrom should be valid.

Water samples were collected mannually for suspended solids, nutrients, and soluble cations in 0.95 ℓ glass bottles and for metals in polyethylene bottles and stored at 4^oC until analyzed. Samples for metal analysis were acidified with one ml concentrated HNO_3 prior to storage. All samples were brought to room temperature prior to analysis.

CHEMICAL ANALYSIS

Total-N, total-P and metal concentrations were determined on unfiltered water and total soluble-P, PO_4-P, NO_3-N, Ca, Mg, Na, and K after filtration (Millipore, 0.45 µm). Suspended solids were determined gravimetrically by filtration of a 100 ml aliquot through a pre-weighed 0.45 µm filter and drying to constant weight overnight at 110^oC. Total-N was determined by digestion of the sample in a sulfuric-salicylic acid mixture in the presence of Hg_2O_2 and K_2SO_4 followed by distillation into a boric acid solution and titration with 0.05 N H_2SO_4. The sample for NO_3-N was treated with Ag_2SO_4 for removal of Cl- , filtered (No. 42 Whatman), reacted with phenoldisulphonic acid in NH_4OH, and color intensity read at 440 nm on a Bausch and Lomb Spectronic 20. Total-P and total soluble-P were determined by digestion in HNO_3:$HClO_4$ mixture of the unfiltered and filtered samples respectively and development of the reduced molybdate-PO_4 complex with $SnCl_2$. Orthophosphate was determined similarly but without digestion. Acidity of the reaction media was monitored with p-nitrophenol. Color intensity was read after 10 min at 660 nm on a Spectronic 20. Particulate-P was calculated as the difference between total-P and total-soluble-P and dissolved unreactive-P (DU-P) as the difference between total soluble-P and PO_4-P. Soluble cations were determined on an IL 251 atomic absorption unit after interfering elements were removed by appropriate masking agents.

Metals (Cd, Cu, Fe, Pb, and Zn) were concentrated 10x in a separatory funnel from 100 ml of water with an extracting solution containing 0.4 g dithizone, 6.0 g quinolinol, and 200 ml acetylacetone in one ℓ n-butylacetate. Twenty ml of 5% ammonium tartrate and 2 drops of p-nitrophenol indicator was added and the sample adjusted to pH 6 with 1:2 NH_4OH or tartaric acid crystals. The water sample was saturated with 2 ml n-butylacetate after which 8 ml of the extractant was added. The mixture was shaken one minute and the aqueous phase discarded after separation for 20 min. The organic phase was permitted to stand 10 min and the remaining aqueous phase discarded. The stem of the separation funnel was dried with a filter paper and the organic phase diluted to 10 ml and analyzed by atomic absorption spectrophotometry. Organic standards were prepared by adding metal of known concentration to 100 ml deionized water and extracting as indicated for samples.

Chromium was determined on a separate 100 ml aliquot of water which was acidified (pH 2) with HNO_3 and treated with H_2O_2 to reduce Cr to the trivalent form. The sample was brought to a boil on a hot plate to remove the H_2O_2, cooled, 20 ml 5% ammonium tartrate added, and adjusted to pH 6 with NH_4OH or tartaric acid. Ten ml acetylacetone was added and the sample was refluxed 20 min, cooled and the Cr-acetylacetonate extracted with 8 ml n-butylacetate, diluted to 10 ml and analyzed by atomic absorption. The concentration was determined from standards prepared similarly in deionized water.

Biological indicator organisms were determined by the membrane filter count by the Windsor Health Unit, Ontario Ministry of Health.

An intensive inter-laboratory quality control program on duplicate samples provided verification of results and laboratory technique for the parameters studied. In many cases methodology differed but only results which agreed or could be explained by differences in analytical methodology are reported.

DATA ANALYSIS

The stream load for each parameter at each site was calculated as the product of the discharge and concentration. The annual loss from the watershed was found by the following equation:

$$L = (\sum QCF)/A$$

L = the annual watershed loss (kg or g/ha), Q = monthly mean discharge m^3/sec), C = monthly average parameter concentration (mg or ug/l), A = area drained (ha), and F = conversion factor.

Concentration data, stream load, biological counts, and annual watershed loss were $\log_{10}$ transformed (Dolby, 1963) prior to statistical analysis to improve homogeneity of sample variance and produce a more sensitive test for differences between sites. All parameters were compared between sites within themselves with a 't-test' in order to determine significant differences between land uses. Correlation coefficients were calculated to determine relationships between parameters and to elucidate transport processes. The drainage boundaries for subwatersheds were delineated from a topographical map. The monthly distribution of the stream load for each parameter was computed from the mean for the number of analyses determined in that month.

EXPERIMENTAL RESULTS

The total sampling area amounted to 1295.3 ha of the west branch of the Hillman Creek and constituted a subwatershed of the 2070 ha monitored by the Ontario Ministry of the Environment (Ag-13, Figure 1). The study area, i.e., that area upstream of sampling site A (Figure 1), was subdivided into five subwatersheds by the location of four sampling sites. Thus the monitoring network at the five locations, i.e., sites A-E, each provided a separate estimate of the unit area loss for the total drainage area assuming no change in pollutant sources between sites. For example, the stream load for each parameter at the site downstream of highway 3 (site A) reflects input from 1295.3 ha (Table 1) while the load at the site upstream of highway 3 reflects input from 1253.0 ha. If the unit area loss for a particular parameter, e.g., phosphorus, were independent of the land use along highway 3 (42.3 ha between sites A and B) the stream load at the two sites would have similar unit area losses and be proportional to the area drained. An increase in unit area loss for the downstream site would reflect a pollutant source between the two sites over which the increase occurred.

The five sites within the watershed (sites A-E) were located to differentiate inputs from rural housing along highways 3 and 77 (sites A-B and C-D respectively) and on the tributary (site E) from the more agricultural portions of the watershed, i.e., upstream of highway 77 (site D) and between the two highways [sites B-(C+E)]. The three rural housing subwatersheds had housing densities of 19, 31 and 33 houses/km^2 within 115.3, 42.3 and 549.4 ha (Table 1) while the agricultural subwatersheds had 15 and 13 houses/km^2 in 246.2 and 342.1 ha (Table 1). The soil and element losses reported in the tables for each parameter reflect the contribution from the total drainage area at that site, e.g., site A, 1295.3 ha; site B 1253.0 ha, etc., unless otherwise noted. Where statistical differences in unit area losses were noted between sites for each of the total drainage areas the unit area loss from the land use between sites was calculated, e.g., rural housing around highway 3, (load at A - load at B)/42.3 ha; agriculture between highways 3 and 77, [load at B - load at (C+E)]/342.1 ha; etc.

Table 1. Area drained at each sampling site and between sampling sites and accompanying housing densities for the Hillman Creek watershed.

Sampling Location	Area drained		Housing density	
	Total	Between sites	Total	Between sites
	ha		houses/km^2	
Downstream hwy 3 (A)	1295.3	42.3	23	31
Upstream hwy 3 (B)	1253.0	342.1	23	13
Downstream hwy 77 (C)	361.5	115.3	16	19
Upstream hwy 77 (D)	246.2	246.2	15	15
Tributary between hwy 3 and 77 (E)	549.4	549.4	33	33

SUSPENDED SOLIDS

Average discharge and suspended solids concentration, and annual stream load and soil loss are presented in table 2. As the distance from the stream source increased discharge and suspended solids concentration increased. The site upstream of highway 77 (site D) was nearest the source and had the lowest discharge (0.06 m^3/sec) and suspended solids concentration (18 mg/l) while the downstream site at highway 3 (site A) at 7.5 km from the source had the highest discharge (0.25 m^3/sec) and suspended solids concentration (40 mg/l). The additional area drained by the site downstream of highway 77 (site C) was smaller (115 ha) than that upstream of the highway (246 ha) but contributed as much to the discharge as the upstream site. This site is downstream of a rural housing area along highway 77 and the increased discharge is attributed to the interception of runoff from the roadside drains. The tributary which entered the main branch between highways 3 and 77 (site E) discharged as much water (0.15 m^3/sec) and had a higher suspended solids concentration (32 mg/l) than that contributed by the area above the tributary (site C, 0.12 m^3/sec and 19 mg/l respectively). There appeared to be little contribution to the discharge and suspended solids concentration from agriculture between highways 3 and 77 if the input from the tributary is considered. Runoff from highway 3 did not add significantly to the stream discharge or suspended solids concentration (Table 2), however, as will be discussed later, the soil loss from the 42 ha represented was considerable (11 t/ha vs <1 t/ha from the other sites). This finding puts considerable question on the use of concentration data alone for determining inputs attributable to a land use.

The suspended solids load carried by the creek increased as discharge increased and was significantly correlated to area drained (r = 0.82). The area yield of soil at each site, although statistically not significant, increased from 253 to 943 kg/ha/yr suggesting that stream load increased disproportionately to the area. The largest increase in stream load appeared to occur in the area around highway 3, i.e., between sites A and B. This area constituted the smallest subwatershed (42.3 ha) in the study area but yielded 454 t soil/yr whereas the tributary which drained the largest area (549.4 ha) yielded only 167 t soil/yr. Both subwatersheds had similar housing densities (31 and 33 houses/km^2) and were classed as representing rural housing land use. Soil loss from the agricultural subwatersheds upstream of highway 77 (246.2 ha) and between highways 3 and 77 (342.1 ha) amounted to 62 and 448 t soil/ha/yr respectively. Unit area soil loss around highway 3 and between highways 3 and 77 were considerable (10.7 and 1.3 t/ha) compared to those areas near the stream source (0.3 t/ha). Part of this increase could be due to the increased discharge of the creek and hence more energy for stream erosion.

Table 2. Average discharge and suspended solids concentration at each site and annual stream load and watershed loss for Hillman Creek, 1975-1976.[1/]

Sampling location	Discharge	Suspended solids		
		Concentration	Stream load	Soil loss
	m^3/sec	mg/l	t/yr	kg/ha/yr
Downstream of highway 3	0.25 ab*	40 a	1221 a	943 a
Upstream of highway 3	0.27 a	35 a	767 a	612 a
Downstream of highway 77	0.12 b	19 ab	152 b	420 a
Upstream of highway 77	0.06 c	18 b	62 b	253 a
Tributary between highway 3 and 77[2/]	0.15	32	167	303

1/ Data $\log_{10}$ transformed prior to statistical analysis to provide more sensitive test

2/ Means not compared in t-test due to insufficient data

* Mean values with similar letters did not differ significantly at P = 0.05

From these results it appears evident that soil loss was more related to management factors near the stream rather than to general land use, i.e., agriculture or rural housing. Examination of the study area revealed that greater slope gradients to the drainage channel, smaller grass borders between the creek and the adjoining fields, sparse vegetation at bends in the creek, and the practice of constructing temporary ditches through the fields to quickly remove excess water during spring runoff where characteristic of the high sediment yielding subwatersheds. Lower sediment yielding subwatersheds were characterized by lower slope gradients to the drainage channel, fewer sharp bends in the stream channel, and wider grass covered areas along the watercourse.

The unit area loss of soil from the total watershed in this study (943 kg/ha) compared favorably with that calculated by the author from loading data supplied by the Ontario Ministry of the Environment (674 kg/ha).

The monthly suspended solids load, precipitation, and discharge at the site downstream of highway 3 (site A) are presented in figure 2. Monthly patterns for the other sites were similar but differed in magnitude. The majority of suspended solids transported by Hillman Creek was primarily removed during the spring thaw in February-March, however, an increase in suspended solids load was observed in September following a high intensity (9.3 cm), short duration (3 h) thunderstorm on August 29. During the spring thaw when ground cover was sparse 77-95% of the annual suspended solids load was removed. Olness et al. (1975) reported that with sparse ground cover up to 50% of the annual sediment loss may occur during a few events. The suspended solids load for this study is probably overestimated for the spring thaw because sample concentrations and discharge were determined at peak flows which were never sustained longer than 24 hours for any one event. Nevertheless substantial amounts of material were transported during this period. Flooding was observed in the immediate vicinity of the creek during the major runoff but did not extend beyond 150 m of the creek. Discharge exceeded precipitation during the spring thaw due to snow-melt from the winter accumulation. The major part of the suspended solids, nutrients, soluble cations and metals transported from the study area occurred during the spring thaw which lasted about six weeks in this hydrologic year.

The suspended solids concentration was correlated positively with discharge. The increase in concentration with increasing discharge reflects a non-point source which is probably derived from erosion of the stream channel although substantial overland

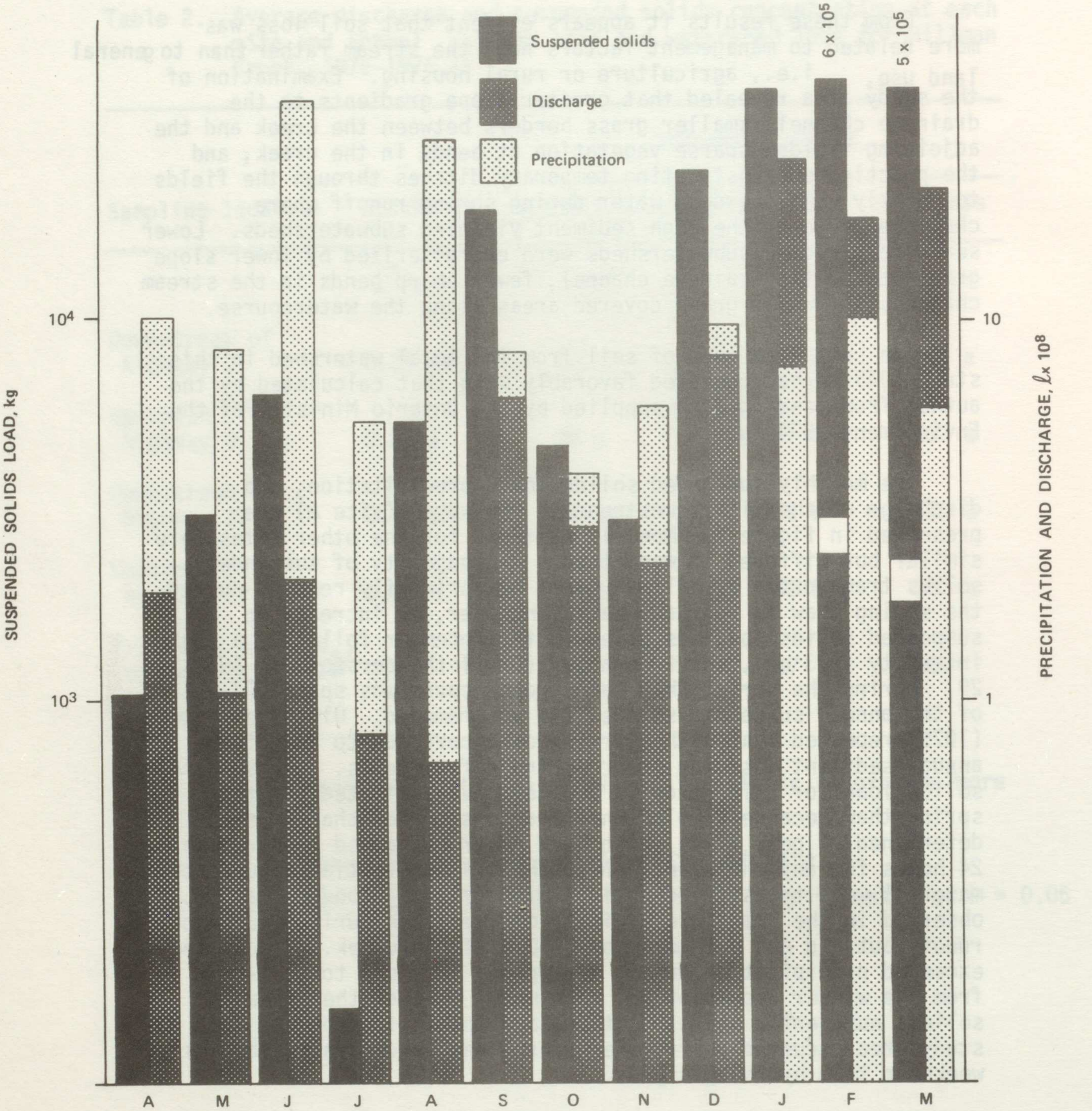


Figure 2. Monthly suspended solids load, precipitation, and discharge at the site downstream of highway 3 on Hillman Creek.

flow was observed during the spring thaw. The increase in stream load reflects the greater energy of the water available for erosion of the stream channel as the drainage area increased.

NITROGEN

The average nitrogen concentration and annual stream load and watershed loss are presented in table 3. The total-N and NO_3-N concentration in Hillman Creek did not differ significantly between any of the sites but were slightly higher at the sites farthest from the source. The concentration of total-N and NO_3-N for the tributary (7.3 and 6.5 mg/l resp.) was slightly higher than that found elsewhere in the creek and the tributary appeared to be the main contributor to the increased concentration at the site upstream of highway 3. The drainage area for the tributary above station E received inputs from rural housing and agriculture, however as will be shown later, rural housing on the tributary appeared to dominate inputs. The total-N and NO_3-N concentrations only exceeded the Ontario water quality standard of 10 mg/l (Anonymous, 1967) in 10% of the samples collected at sites A and B (Appendix I).

The total-N and NO_3-N load carried by the creek increased proportionately to the drainage area (Table 3). Unit area losses averaged 54 kg/ha/yr and were similar at all sites except for an increase at the site downstream of highway 77 (site C). As will be shown later rural housing around highway 77 and on the tributary significantly contributed inputs to the creek and may have been responsible for the increased N yield at this site. Unit area N loss from the subwatersheds representing agricultural and rural housing land use were similar to the losses calculated in table 3 for the total areas drained at each site which further supports the conclusion that no point sources for nitrogen were in the study area.

The loss of nitrogen from the Hillman Creek watershed was considerable (54 kg/ha/yr) compared to the 2-14 kg/ha/yr loss determined by others (Olness et al., 1975) for watersheds under similar agricultural practices. One study (Kausner, Zwerman and Ellis, 1974) reported losses near 30 kg/ha/yr for a watershed which had received 224 kg N/ha. The highest amount of fertilizer N applied in this study was 35.3 t applied to 280 ha of potatoes (126 kg/ha; Frank and Ripley, 1977). Over the total study area the average nitrogen application was 64 kg/ha but the constant yield of N at each site suggests that annual fertilizer application was not the major source of N in the drainage system.

Table 3. Average nitrogen concentration at each site and annual stream load and watershed loss for Hillman Creek, 1975-1976.[1]

Sampling location	Concentration		Stream load		Watershed loss	
	Total-N	NO_3-N	Total-N	NO_3-N	Total-N	NO_3-N
	-----mg/l-----		------t/yr----		---------kg/ha/yr----------	
Downstream of highway 3	7.0 a*	5.4 a	73 a	69 a	57 b	53 a
Upstream of highway 3	7.2 a	5.4 a	71 a	66 a	56 b	52 a
Downstream of highway 77	5.8 a	4.0 a	24 b	19 b	66 a	53 a
Upstream of highway 77	6.1 a	3.9 a	11 b	10 b	46 a b	40 a
Tributary between hwy 3 and 77[2]	7.3	6.5	24	21	43	38

[1] Data $\log_{10}$ transformed prior to statistical analysis to provide more sensitive test

[2] Means not compared in t-tests due to insufficient data

* Mean values with similar letters did not differ significantly at P=0.05

Agricultural production has been practiced in this watershed for over 100 years and the losses could reflect inputs from previous years activities. One such source is mineralization of soil organic nitrogen brought about by cultivation which is essential to crop production in this watershed. Keeney and Bremner (1964) determined that 17-57% of the nitrogen in soil organic matter may be released by cultivation while others (Keeney and Gardner, 1968; Reinhorn and Avnimelech, 1974) have shown that degraded organic matter could contribute up to four times more NO_3-N in drainage systems than that from fertilizer. The following example illustrates the significance cultivation could have on nitrogen release from organic matter. The average N content of soils in Ontario ranges from 300 to 3200 ug N/g soil (Sowden, 1977). If 10% of the 300 ug N/g were mineralized annually, 39 kg N/ha would be released from the 0-8 cm depth (bulk density 1.63 g/cm^3). The mineralized nitrogen would be available for leaching during periods of excessive precipitation, e.g., spring thaw. Precipitation may also contribute significantly to N input (Olness et al., 1975) and 36 kg N/ha/yr has been estimated from this source for the Hillman Creek watershed (Sanderson, 1977). Thus it can be seen that the major source of nitrogen in the drainage system cannot easily be determined.

The monthly stream loads show that the bulk of the nitrogen (70%) transported from the watershed occurred during the Jan - March period (Figure 3). The figure also shows that NO_3-N made up a greater proportion of the total-N during periods of high discharge indicating its susceptibility to leaching. Soil denitrification may be more rapid at low discharge periods due to the higher temperatures which occurred during the summer months (Kowalenko, 1978) or increased crop uptake and low rainfall may have reduced leaching (Cameron, Kowalenko and Ivarson, 1978).

PHOSPHORUS

Four phosphorus forms (total-P, particulate-P, PO_4-P, and dissolved unreactive-P) were measured in the Hillman Creek study. Table 4 presents the average phosphorus concentrations found at each site. The concentration of all the phosphorus forms increased as discharge increased and as the drainage area increased. Total-P was significantly increased from 0.09 to 0.23 mg/l between sites C and B (Figure 1) with the increase attributed to the tributary which had a concentration of 0.32 mg/l. Phosphorus concentration of all four forms was highest on the tributary. Rural housing along highway 77 may have been responsible for the significant increase in PO_4-P concentrations from 0.023 to 0.032 mg/l but particulate-P, or DU-P concentration

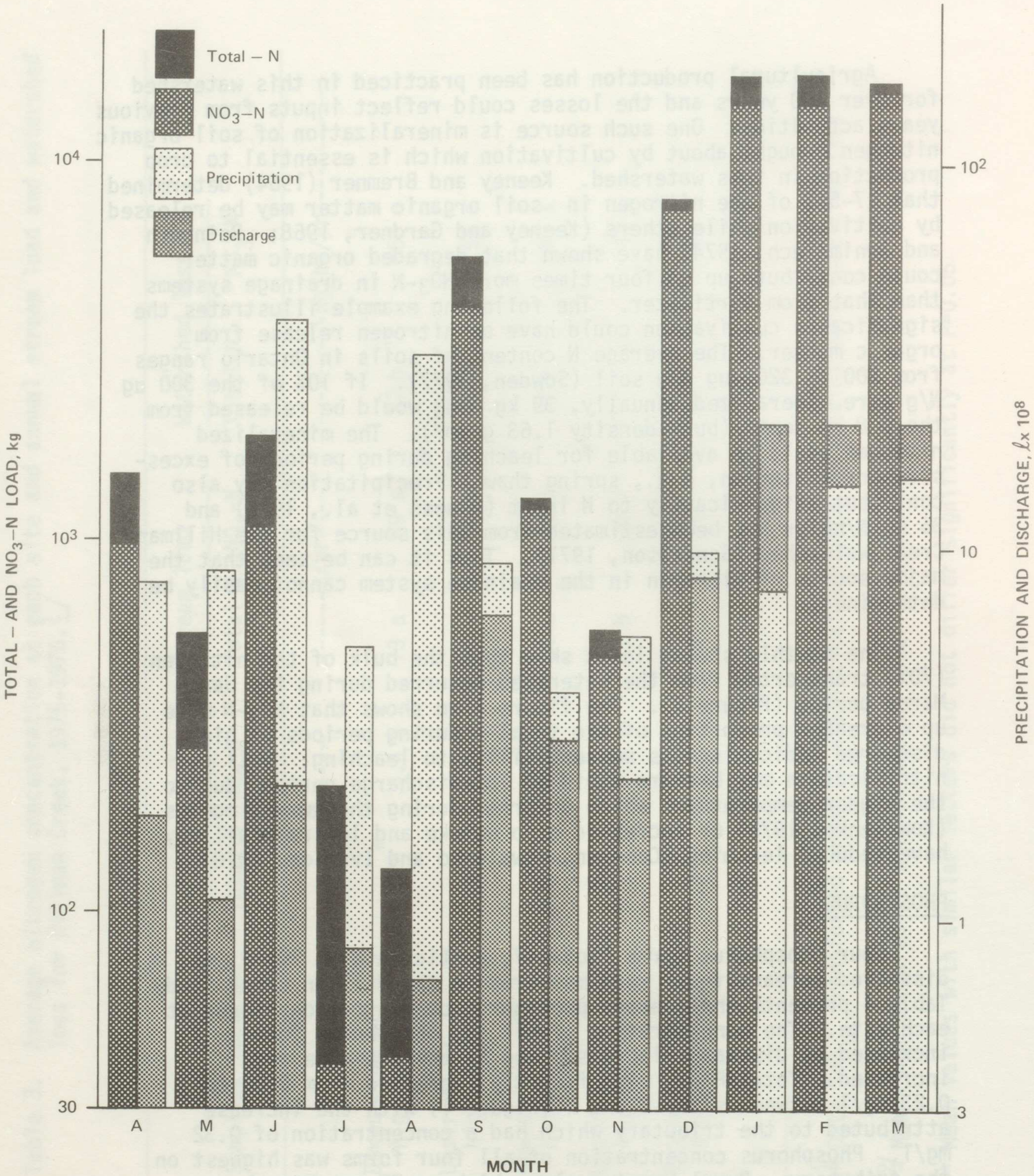


Figure 3. Monthly total–and NO_3–N load, precipitation, and discharge at the site downstream of highway 3 on Hillman Creek.

Table 4. Average concentration of various phosphorus forms at selected sites in Hillman Creek, 1975-1976[1/]

Sampling location	Total-P	Particulate-P	DU-P[2/]	PO_4-P
	-----------------------	mg/l	-----------------------	
Downstream of highway 3	0.24 a*	0.09 a	0.036 a	0.115 a
Upstream of highway 3	0.23 a	0.09 a	0.034 ab	0.113 a
Downstream of highway 77	0.09 b	0.05 b	0.020 bc	0.032 b
Upstream of highway 77	0.07 c	<0.03 b	<0.012 c	<0.023 c
Tributary between hwy 3 and 77[3/]	0.32	0.09	0.042	0.204

1/ Data $\log_{10}$ transformed prior to statistical analysis to provide more sensitive test

2/ Dissolved unreactive-P (DU-P)

3/ Means not compared in t-test due to insufficient data

* Mean values with similar letters did not differ significantly at P = 0.05

was not increased. The predominantly agricultural area at the site upstream of highway 77 had consistently low phosphorus concentrations with 60% of the samples at or below the detection limit of 0.015 mg/l (Appendix table 1-4).

The annual stream load of phosphorus increased with area but the increase was not proportional to the area drained as reflected by the different unit area losses for total-P and PO_4-P at each site (Table 5). Unit area loss of total-P increased from 0.96 to 2.57 kg/ha from the site upstream of highway 77 (site D) to the site downstream of highway 3 (site A). Orthophosphate loss increased similarly but loss of particulate-P and dissolved unreactive-P were similar between sites. Particulate-P was the major form lost from the total watershed (69% of total-P lost, Table 6) but from the concentration data (Table 4) and unit area loss calculations, PO_4-P appeared to be the species entering the creek in disproportionate quantities to the drainage area.

Rural septic systems in some agronomic watersheds have been shown to contribute significantly to measured phosphorus losses (Jones, Smeck, and Wilding, 1977). In this study the location of sampling sites permitted a partial separation of inputs from rural housing and agricultural areas. Magdoff et al. (1974) indicated that orthophosphate accounts for 85% of the total-P in domestic septic influent, thus, if septic systems significantly contribute phosphorus to the Hillman Creek this may be reflected in the proportion of PO_4-P to total-P. Table 6 expresses the three forms of phosphorus (particulate-P, dissolved unreactive-P, and PO_4-P) as a percent of total-P. As noted PO_4-P from the area drained by the tributary, which had a housing density of 33 houses/km^2, made up 53% of the total-P discharged while orthophosphate at the other sites comprised 29% of the total-P. The higher proportion of PO_4-P on the tributary relative to the rest of the watershed suggests domestic input from rural housing in this area. Particulate-P accounted for 62% of the total-P at the more agricultural sites in the watershed (site D) and the absence of an increase in the proportion of PO_4-P at sites downstream of rural housing areas on the main branch (e.g.,site C) of the creek may be due to dilution from upstream areas. Housing density along highway 77 was similar to that for the agricultural areas consequently the amount of PO_4-P contributed by this area may be masked by the agricultural input.

Geldreich (1967) developed relationships between populations of biological indicator organisms in the water to differentiate between pollution in streams from domestic and animal sources. In this study water samples for biological indicator organisms were collected at each site at the same time as nutrient samples and the

Table 5. Annual stream load and watershed loss of phosphorus for Hillman Creek, 1975-1976[1].

Sampling Location	Stream load Total-P	Particulate-P	DU-P [2]	PO_4-P	Watershed loss Total-P	Particulate-P	DU-P [2]	PO_4-P
	---kg/yr---				---kg/ha/yr---			
Downstream of highway 3	3332 a*	2295 a	146 ab	932 a	2.57 a	1.77 a	0.112 a	0.72 a
Upstream of highway 3	2510 a	1380 a	253 a	885 a	2.00 a	1.10 a	0.202 a	0.71 a
Downstream of highway 77	584 b	360 b	80 b	153 b	1.62 ab	1.00 a	0.221 a	0.42 ab
Upstream of highway 77	237 c	< 146 c	<35 b	<61 c	0.96 b	<0.59 a	< 0.142 a	<0.25 b
Tributary between hwy 3 and 77	850	339	66	451	1.55	0.62	0.12	0.82

[1] Data $\log_{10}$ transformed prior to statistical analysis to provide more sensitive test

[2] Dissolved unreactive-P (DU-P)

* Mean values with similar letters did not differ significantly at P = 0.05

Table 6. Forms of phosphorus transported by Hillman Creek expressed as a percentage of total phosphorus.

Sampling location	Total-P	Particulate-P	DU-P [1/]	PO_4-P
	kg/yr	%		
Downstream of highway 3	3332	68.8	4.4	28.0
Upstream of highway 3	2510	55.0	10.1	35.3
Downstream of highway 77	584	61.6	13.7	26.2
Upstream of highway 77	237	61.6	14.8	25.5
Tributary between hwy 3 and 77	850	39.9	8.4	53.0

[1/] Dissolved unreactive - P (DU-P)

geometric means for total and fecal coliform and fecal streptococci bacteria are presented in table 7. The average numbers of biological indicator organisms were significantly increased at the site downstream of highway 77 (site C) and on the tributary (site E), areas of intensive rural housing, and where total-P and PO_4-P were increased (Table 5). According to Geldreich (1972) fecal coliform to fecal streptococci (FC/FS) ratios >4.0 at septic outfalls indicate domestic input whereas ratios <0.7 indicate an animal origin. From his studies agricultural areas not influenced by domestic systems consistently had a FC/FS ratio <0.7. In this study the agricultural area upstream of highway 77 (site D) had a FC/FS ratio of 0.3 whereas sampling sites downstream of rural housing areas, e.g., sites C and E, had FC/FS ratios from 1.5 to 2.4 (Table 7). The FC/FS ratio downstream of rural areas would be expected to be <4.0 due to dilution and/or organism dieoff in the stream (Geldreich, 1972) since samples were not taken at septic outfalls. In the absence of septic contamination of the creek all sites would be expected to have FC/FS ratios <0.7.

As demonstrated by the biological data and the increase in phosphorus concentration in Hillman Creek around areas of rural housing, domestic input is suggested. It was of interest to estimate the quantity of phosphorus contributed by the three rural housing and two agricultural areas in this watershed from the stream load data at the selected sites. These results, presented in table 8, are only estimates since the quantity and proportion of phosphorus discharged to the creek would vary annually. Unit area losses of all phosphorus forms did not differ between the two land uses (Table 8). Total-P loss was 2.23 and 2.86 ± 8.14 kg/ha while PO_4-P loss was 0.58 and 0.83 ± 0.27 kg/ha for the respective agricultural and rural housing land uses (Table 8). The large standard error for total-P and particulate-P is due to the suspended solids load from the area around highway 3 which was greater than that from the other sites (11 vs <1 t soil/ha). This resulted in unit losses of 19 and 21 kg/ha total-P and particulate-P. It is evident that the area around highway 3 had a higher erosion potential than the other areas which masked the contribution of total-P from rural housing.

The proportion of the total PO_4-P load discharged from the study area attributable to rural housing was estimated from the sum of the stream loads at the appropriate sites presented in table 5. If it is assumed that all of the PO_4-P from the rural housing areas [PO_4-P load from (C-D) + E + (A-B)] arose from housing then 63% of the annual PO_4-P load at site A originated from this source. Obviously not all of the PO_4-P load in these areas originated solely from housing since agriculture was interspersed throughout the area. Assuming agriculture contributed 0.58 kg PO_4-P/ha (Table 8) to the load from the rural housing areas then PO_4-P from rural housing,

Table 7. Geometric means for numbers of biological indicator organisms at selected sites in Hillman Creek, 1975-1976.

Sampling location	Indicator organism			
	Total coliform	Fecal coliform	Fecal streptococci	FC/FS
	---Colonies/100 ml---			
Downstream of highway 3	14130 ab*	1866 a	912 a	2.0
Upstream of highway 3	20510 a	1837 a	780 a	2.4
Downstream of highway 77	9354 b	1099 a	484 a	2.3
Upstream of highway 77	288 c	65 b	247 b	0.3
Tributary between hwy 3 and 77[1/]	21580	2679	1766	1.5

[1/] Means not compared in t-test due to insufficient data

* Mean values with similar letters did not differ significantly at P = 0.05

Table 8. Annual phosphorus loss from agricultural and rural housing subwatersheds in Hillman Creek, 1975-1976.

Land Use	Stream Load				Subwatershed Loss			
	Total-P	Particulate-P	DU-P	PO_4-P	Total-P	Particulate-P	DU-P	PO_4-P
	kg/yr				kg/ha			
Agriculture 1/	1313	827	143	342	2.23	1.41	0.24	0.58
Rural housing 2/	2019	1468	111	590	2.86	2.08	0.16	0.83
Standard error	413	375	41	202	8.14	9.63	0.18	0.27

1/ {Load at D + [B-(C+E)]}/(246.2 + 342.1 ha)

2/ [Load at (A-B) + (C-D) + E] /(115.3 + 549.4 + 42.3 ha) corrected for agriculture, would comprise 27% of the total PO_4-P load discharged at site A. The actual contribution from rural housing probably lies between 27 and 63% of the total PO_4-P load discharged from the study area since the percentage of the housing area in agriculture and road allowances was not accurately determined. From these figures it was estimated that the average daily contribution of PO_4-P from each of the 298 houses in the study area was between 2 and 5 g PO_4-P/house/day. The actual amount of PO_4-P contributed by each house would depend upon the proximity of the house to the creek, the condition of the septic field, the number of people and the quantity of water discharged per house.

For the agricultural area, 61% of the watershed (2070 ha) received 63 kg P/ha in 1975 (Frank and Ripley, 1977). Assuming this amount (63 kg/ha) was uniformly applied to the two agricultural subwatersheds in this study (588.3 ha total) and that all of the phosphorus lost from the agricultural areas originated from fertilizer application then the amounts of total-P and PO_4-P found in the creek would represent 3.5 and 0.92% respectively of that applied. It is quite apparent from these results that a large part of the phosphorus lost from the agricultural portion of the watershed occurred as particulate-P (Table 6). The loss of soluble phosphorus (PO_4-P) from the agricultural portion of the watershed (0.58 kg/ha) was in the range reported for other agricultural watersheds ($<$ 0.02 - 1 kg/ha, Olness et al., 1974) and does not appear to be excessive. It was estimated that the actual amount of PO_4-P contributed by the agricultural area represented 37 to 73% of the total PO_4-P discharged.

From the foregoing results it was shown that housing in rural areas may contribute as much orthophosphate to drainage systems as agriculture. However, there is a need to better quantify the inputs from rural housing before remedial measures in the agricultural sector will be effective. It appears that measures to reduce erosion from agricultural land may reduce agriculture's contribution to the total phosphorus load since particulate-P appeared to be the dominant species from this source but a reduction in the particulate-P load without controlling inputs from rural housing would result in an increase in the proportion of orthophosphate discharged.

The monthly distribution of phosphorus forms transported by Hillman Creek at the site downstream of highway 3 (site A) is presented in figure 4. The PO_4-P made up the bulk of the phosphorus transported during the low discharge period but a greater proportion of particulate-P was transported during high discharge. The proportion of DU-P decreased as discharge increased. Most of the PO_4-P (63-80%) and the particulate-P (84-93%) was transported during the spring runoff.

SOLUBLE CATIONS

The average soluble cation concentrations found at each site are presented in table 9. Except for Ca the concentration of the soluble cations increased as the area drained increased. The concentration of Ca decreased from 124 to 112 mg/l as drainage area increased. Calcium may have originated from a point source such as a limed field near the source of the creek. Rural housing around highway 3 had no significant effect on the soluble cation concentration but the Na concentration was significantly increased at the site downstream of highway 77 (site C) possibly by rural housing. Septic outfalls increased Na, K, and PO_4-P concentration in an agronomic watershed (Jones, Smeck, and Wilding, 1977) thus the higher concentrations of Na around highway 77 provides further evidence of septic contamination of the creek. The tributary had the highest concentrations of Mg, Na and K but not Ca.

The annual stream load and watershed loss for the soluble cations are displayed in table 10. The stream load of soluble cations increased proportionately to area drained except activities around highway 77 increased Ca, and Mg load but not the Na and K load. Rural housing around highway 3 had no significant effect on the soluble cation load and the increases noted arose from inputs on the tributary and from the area upstream of highway 3 (site B). The increased soluble cation loads along highway 77 could have been due to road salting during the winter months but there is no direct evidence for this.

The quantity of Na (43-77 kg/ha) and K (42-61 kg/ha) removed from the watershed was not significantly different at any of the sampling locations thus these cations were probably derived from geologic weathering. Precipitation added 12 kg K/ha annually (Sanderson, 1977) and may have contributed significantly to K loss from the watershed. More Ca and Mg was removed from the watershed near the source of the stream (898 and 103 kg/ha respectively,site D) than downstream (605 and 100 kg/ha resp., site A), and the decrease in Ca concentration with an increase in drainage area suggests a point source. Excluding the drainage area of the tributary, the drainage area between the highways (342 ha) is of the same extent as the total drainage area (361 ha) for the site downstream of highway 77 (site C) thus similar quantities of Ca removal would be expected if geologic weathering were responsible. Soil loss of Ca and Mg for these respective areas was 509 and 109 kg/ha and 1062 and 134 kg/ha. The quantity of Ca and Mg removed from the watershed at the site downstream of highway 3 (605 and 100 kg/ha resp) was of the same order as that removed by the tributary (406 and 74 kg/ha resp) but only half of that removed upstream of highway 77 (898 and 103 kg/ha resp). The source may arise from the 8-16 ha

Figure 4. Monthly total–P, particulate–P, dissolved unreactive–P, and PO_4–P load, precipitation and discharge at the site downstream of highway 3 on Hillman Creek.

Table 9. Average concentration of salts at various sites in Hillman Creek, 1975-1976.[1]

Sampling location	Ca	Mg	Na	K
	mg/l			
Downstream of highway 3	112 b*	16 a	13 a	7.4 a
Upstream of highway 3	112 b	16 a	12 a	6.9 a
Downstream of highway 77	117 ab	13 b	7 b	4.7 b
Upstream of highway 77	124 a	14 b	5 c	4.6 b
Tributary between highway 3 and 77[2]	106	18	16	10.5

[1] Data $\log_{10}$ transformed prior to statistical analysis to provide more sensitive test

[2] Means not compared in t-test due to insufficient data

* Mean values with similar letters did not differ significantly at P=0.05

Table 10. Annual stream load and watershed loss of salts for Hillman Creek, 1975-1976.[1/]

Sampling location	Stream load				Watershed loss			
	Ca	Mg	Na	K	Ca	Mg	Na	K
	t/yr				kg/ha/yr			
Downstream of highway 3	784 a*	129 a	99 a	71 a	605 b	100 b	77 a	55 a
Upstream of highway 3	783 a	127 a	94 a	68 a	625 b	101 b	75 a	55 a
Downstream of highway 77	384 b	48 b	28 b	22 b	1062 a	134 a	76 a	61 a
Upstream of highway 77	221 b	25 b	11 b	10 b	898 ab	103 b	43 a	42 a
Tributary between hwy 3 and 77 [2/]	225	41	38	26	406	74	69	47

[1/] Data $\log_{10}$ transformed before statistical analysis to provide more sensitive test

[2/] Means not compared in t-test due to insufficient data

* Mean values with similar letters did not differ significantly at P = 0.05

beyond the site upstream of highway 77 (site D) which was limed during the year. In the total watershed 44 ha received 185 tonnes of limestone. Adsorption of Ca or Mg by the suspended solids or precipitation as the carbonate as it is transported down the stream do not appear to be responsible for the decreasing losses towards the lower end of the watershed since neither Ca nor Mg were correlated with suspended solids. As with the nutrients and suspended solids most of the soluble cations were removed during the spring thaw (Figure 5).

METALS

The average metal concentrations, and annual stream load and watershed loss are recorded in table 11. Low concentrations of Pb, Cr and Cd were found at all sites (11, 2, and 0.6 ug/l respectively). The concentrations reported were derived from unfiltered water and reflect soluble and extractable sediment bound metal. The concentration of Cu, Zn, and Fe was not significantly increased by the land use at any of the sites thus these metals probably originated from geologic weathering. A considerable amount of Cu and Zn (80 and 256 g/ha/yr input) could have arose from precipitation (Sanderson, 1977). Aerial transport of suspended soil may in part be responsible for the high precipitation load of these metals. The concentration of Cu, and Zn at all sites in Hillman Creek did not exceed the Ontario permissable level of these metals for irrigation water (Anonymous, 1967).

Stream load increased proportionately to the area drained (Table 11). Except for the site downstream of highway 77 the losses of Cu, Zn, and Fe from the watershed were similar at each site supporting the conclusion that the metals were derived from geologic weathering. Suspended solids and Cu and Fe concentration and load were correlated positively which suggests these elements were transported on the suspended solids. Suspended solids was not correlated with Zn load and concentration indicating transport as the soluble species. The monthly distribution of Cu, Zn, and Fe load are presented in figures 6 and 7. The load of these elements increased as discharge increased with the greater part of these elements transported during the spring thaw.

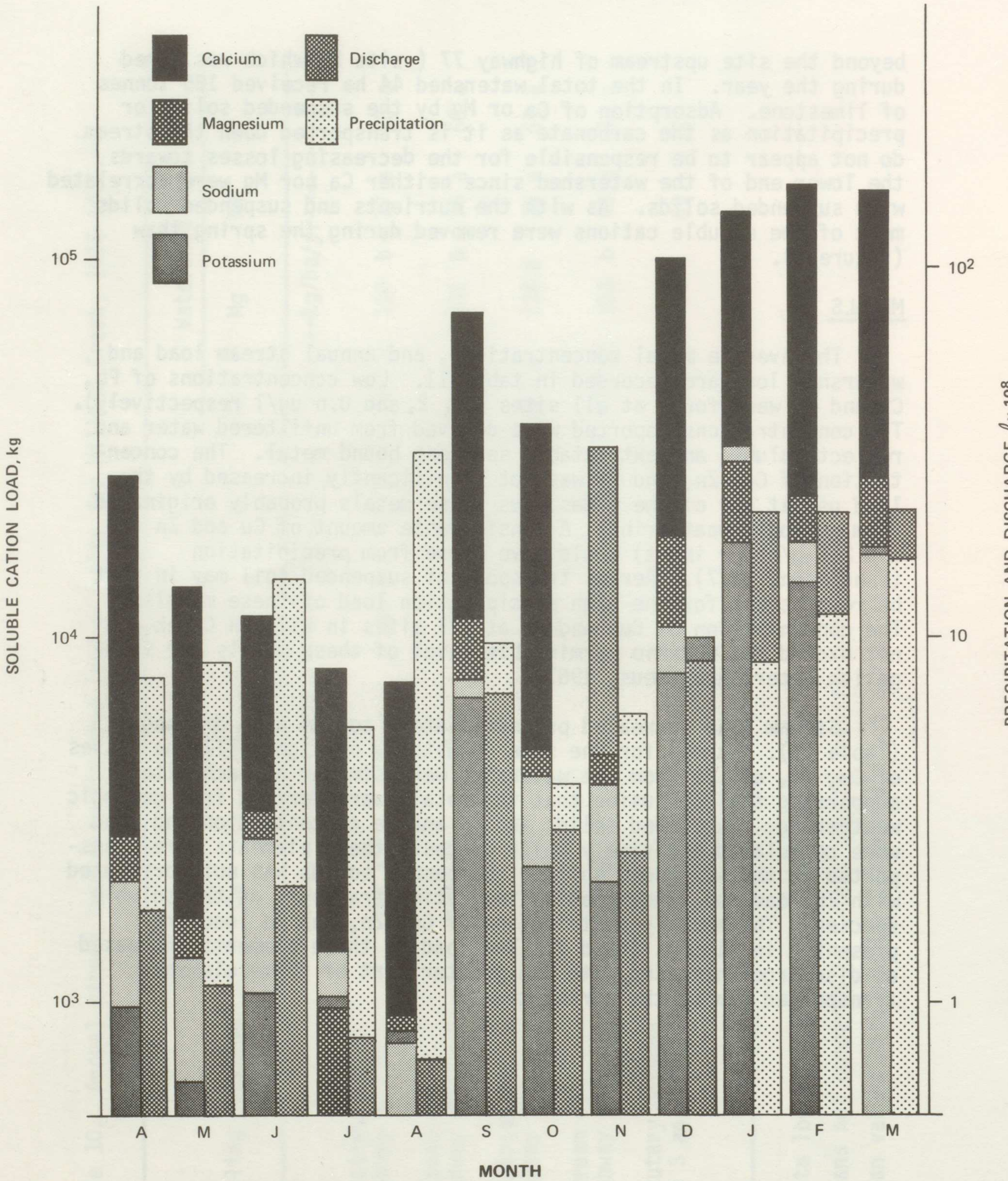


Figure 5. Monthly soluble cation load, precipitation, and discharge at the site downstream of highway 3 on Hillman Creek.

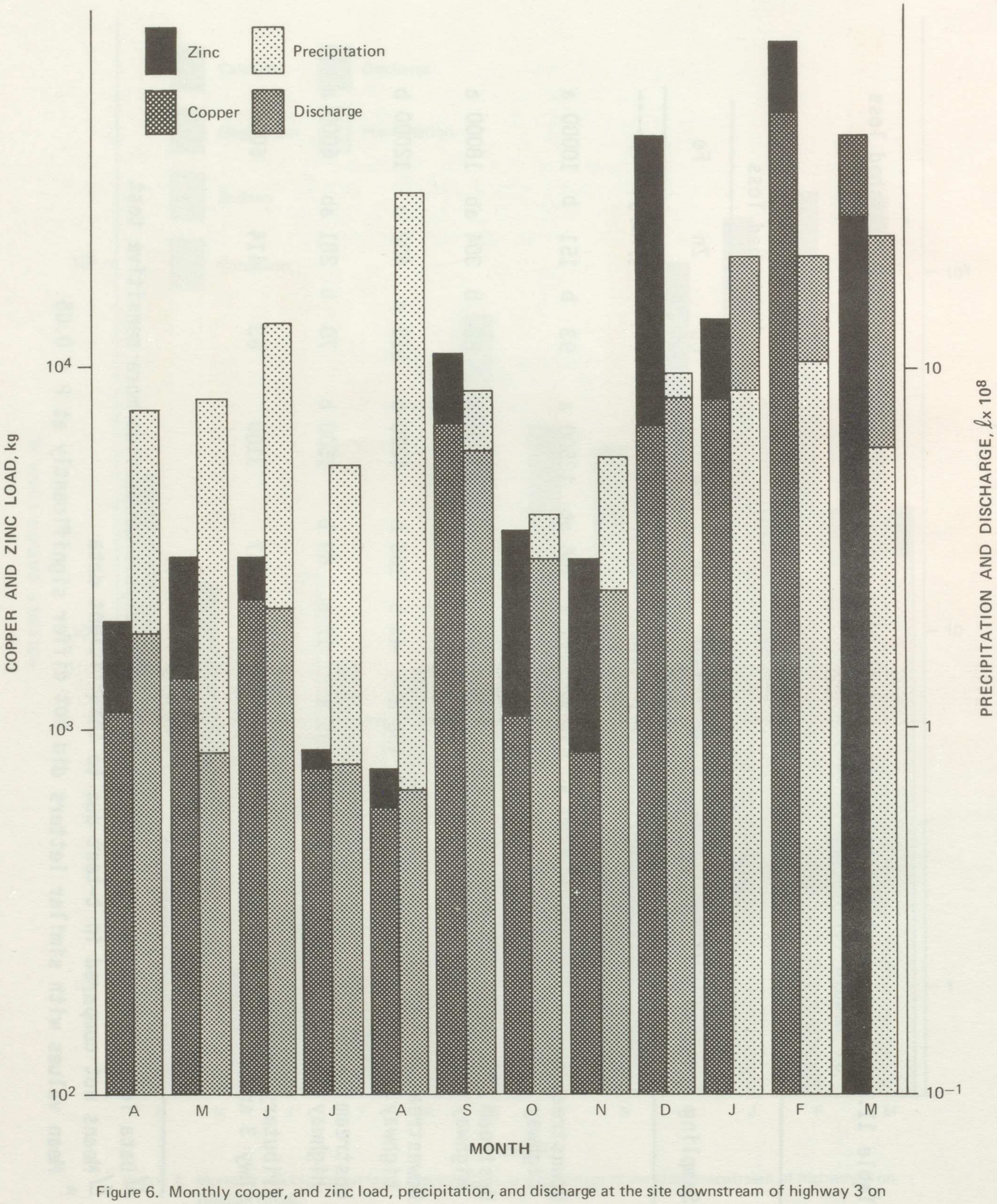


Figure 6. Monthly cooper, and zinc load, precipitation, and discharge at the site downstream of highway 3 on Hillman Creek.

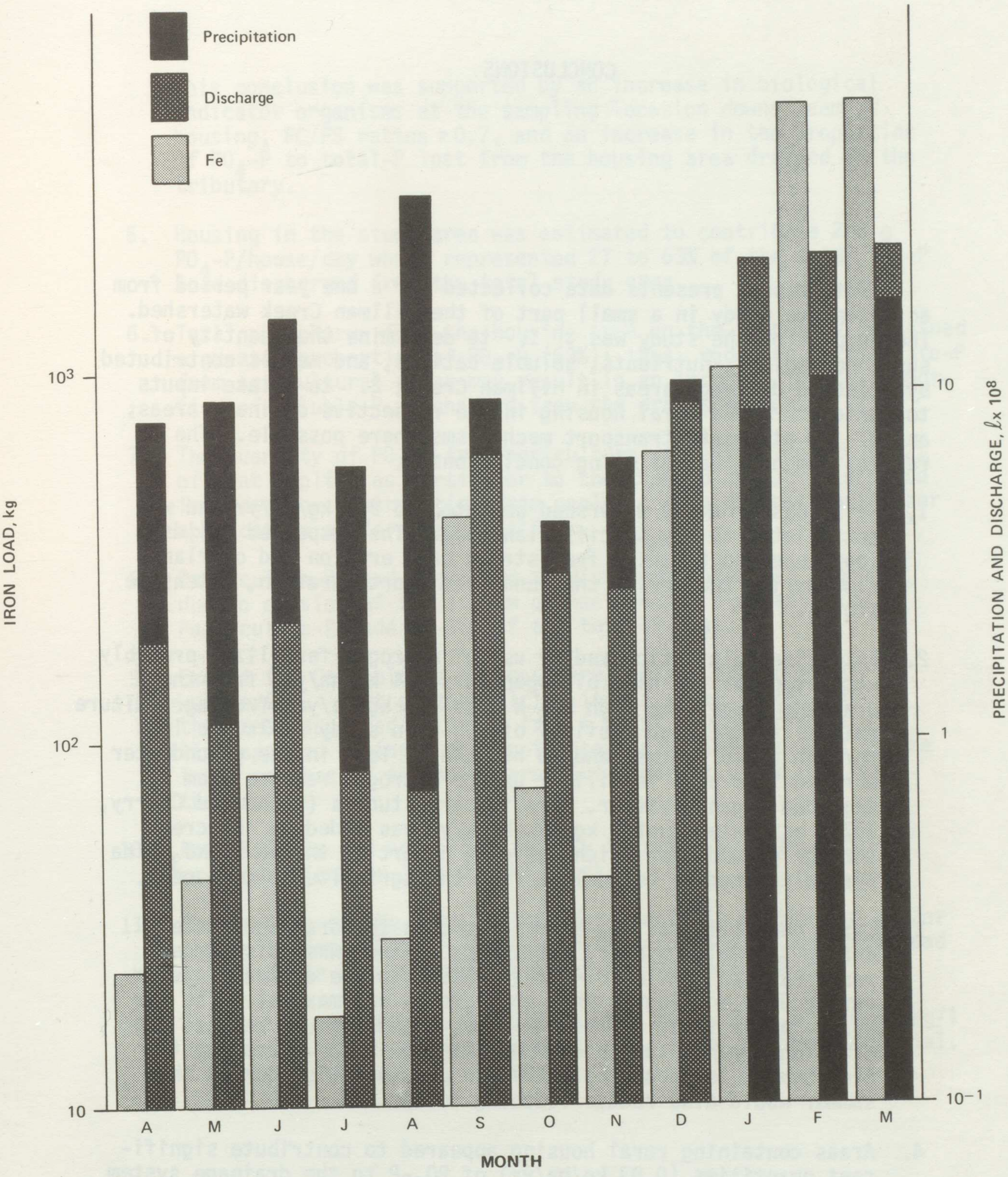


Figure 7. Monthly iron load, precipitation, and discharge at the site downstream of highway 3 on Hillman Creek.

CONCLUSIONS

This report presents data collected for a one year period from an intensive study in a small part of the Hillman Creek watershed. The purpose of the study was : 1. to determine the quantity of suspended solids, nutrients, soluble cations, and metals contributed by selected drainage areas in Hillman Creek; 2. to relate inputs to agriculture and rural housing in the respective drainage areas; and 3. to elucidate transport mechanisms where possible. The results suggest the following conclusions:

1. Soil loss from the watershed amounted to 943 kg/ha/yr and was not related to any specific land use. The suspended solids load appeared to arise from stream bank erosion and overland flow during the spring thaw and from short duration, intensive storms.

2. Intensive cultivation and/or use of nitrogen fertilizer probably accounted for the high nitrogen loss (54 kg/ha/yr) from the drainage area. The high NO_3-N loss (48 kg/ha/yr) from agriculture relates to the high mobility of NO_3-N in sandy soils, to loss through field drains, and to high NO_3-N load in the groundwater derived from past fertilizer use or nitrogen release from degraded organic matter. Preliminary studies (Frind and Cherry, 1977) estimated that 7 kg NO_3-N/ha/yr was added to the creek through groundwater which would be a part of the 48 kg NO_3-N/ha /yr calculated as being lost from the agricultural component.

3. Large quantities of NO_3-N were found in the drainage system during the fall, winter, and spring periods when discharge was greatest. Little NO_3-N was present in the drainage system during July and August when crop growth was maximal. The low NO_3-N levels found during the summer months could reflect efficient crop uptake or denitrification in the stream at the high summer temperatures. The low precipitation during the summer would also reduce leaching losses.

4. Areas containing rural housing appeared to contribute significant quantities (0.83 kg/ha/yr) of PO_4-P to the drainage system compared to the more agricultural areas (0.58 kg/ha/yr).

This conclusion was supported by an increase in biological indicator organisms at the sampling location downstream of housing, FC/FS ratios > 0.7, and an increase in the proportion of PO_4-P to total-P lost from the housing area drained by the tributary.

5. Housing in the study area was estimated to contribute 2-5 g PO_4-P/house/day which represented 27 to 63% of the total PO_4-P load discharged from the total study area.

6. Total phosphorus from the housing area on the tributary contained a greater proportion of PO_4-P (53%); thus, reducing particulate-P from agricultural areas may result in an increase in the proportion of soluble-P discharged from the drainage area.

7. The quantity of PO_4-P from agriculture was equivalent to 0.92% of that applied as fertilizer to the cropped area. This value includes the contribution from geologic origin, past fertilizer application and/or precipitation.

8. Particulate-P load increased as discharge increased probably due to erosion of the stream channel and/or overland flow. Particulate-P made up 68% of the total-P lost.

9. Except for Ca, soluble cations were derived from geologic weathering. Part of the calcium in the upper reaches of the creek appeared to arise from a point source, probably lime applied during the cropping season. Lime was used in the lower reaches of the study area but apparently did not reach the creek.

10. Road salting did not significantly increase soluble cation concentrations or load in the creek.

11. The Cu, Zn, and Fe were derived from geologic weathering and/or precipitation. Copper and Fe were transported by the suspended solids while Zn was transported as the soluble species.

12. The Cr, Cd, and Pb concentrations were below 2, 0.6, and 11 ug/l respectively and appeared to be derived from weathered material.

RECOMMENDATIONS

STUDY CONSTRAINTS

The results, although limited in time, provided a first estimate of the magnitude of pollutants contributed by a drainage system from an agricultural area interspersed with housing. Greater confidence on the discharge and loading values would have occurred had time permitted more adequate site instrumentation at the initiation of the study, however, the results were comparable to those reported for other agricultural watersheds and to losses calculated from data collected by the Ontario Ministry of the Environment at their site encompassing the study area. Areas of major interest for delineation of inputs were defined as the sampling season progressed and sufficient samples were collected for statistical comparisons. The sources of inputs on the tributary were very ill defined and it was determined near the conclusion of the study that at least six sampling sites were required to delineate sources. Major gauging installations would have been required at these sites to prepare them for monitoring. At least one year would be required to characterize the study area, i.e., select appropriate sampling sites, assess periods where sampling frequency needed intensification, properly instrument and gauge the stream, and become acquainted with the hydrology of the study area. A further three to five years would be required to determine seasonal variations and improve the loading estimates.

These results were derived from a watershed representing a form of agriculture, i.e., extensive cultivation and culture of crops with high fertilizer demand, which has a high potential for high nutrient inputs to the drainage system. The parameter loads within this watershed were within the range of that calculated for other agricultural watersheds but may appear high in relation to other land uses in other watersheds e.g., forestry. Thus an assessment should be made before remedial measures are implemented to put the loading values from this and similar watersheds into perspective with the total load from all sources entering the Great Lakes system to determine their overall significance.

REMEDIAL MEASURES

All of the inputs measured in the study area with the possible exception of Ca arose from a diffuse source. Thus remedial measures need to be applied over the whole watershed to reduce the many small inputs. Suspended solids were derived from stream bank erosion and overland flow which occurred during the spring thaw when localized flooding was prevalent along the course of the creek. Some areas within the watershed appeared to be more susceptible to erosion than others, e.g. the area around highway 3. Ice flow during spring breakup effectively scours the channel, thus grass covered waterways would not be sufficient to prevent erosion but may slow the rate. The stream channel is not sufficient to contain the volume of water leaving the watershed during this period. The most effective means of reducing the suspended solids load would be to widen the stream channel to contain the maximum amount of flow and to concrete the waterway but this may not be economically feasible. Suspended solids derived from field runoff may be reduced by encouraging more extensive contour practices during fall cover crop establishment and by maintaining grass covered waterways in depressions. Permanent grass covered waterways would not be economical in this watershed where the average farm size is 17 ha but a management practice encouraging cultivation of fall wheat and spring crops in drainage depressions and early establishment of grass waterways in the depressions after harvest should be investigated.

The source of nitrogen could not be related to fertilizer application or release from degrading organic matter brought about by cultivation but was probably a composite of both sources. Preliminary studies (Frind and Cherry, 1977) showed that groundwater concentrations of NO_3-N are significantly increased and that 13 kg N/ha is stored in the shallow groundwater. Tile drainage, the sandy soils, and the culture of crops with a high fertilizer and cultivation requirement have contributed to the high nitrogen loss from the watershed. More efficient use of nitrogen fertilizer i.e., more frequent application of smaller amounts based on crop growth and development may reduce fertilizer inputs but may not be economical or significantly reduce the overall load. Slow release fertilizers may reduce leaching but the impact of any remedial measure will not be felt for a number of years due to the large amount of N in the groundwater and organic matter.

Phosphorus appeared to be derived equally from rural housing and agriculture. Phosphorus mobility from fertilizer application from agriculture was low since 3.5% of that applied to the cropped area (assuming all phosphorus arose from fertilizer application) was lost to the creek. A large amount of P originated on the tributary which had a high housing density (33 houses/km^2). There exists a need to better quantify the contribution of P from rural housing septic systems since estimates from this study suggests they may be significant. The use of slow release phosphate fertilizers and applications based on soil test results, crop growth, and development may reduce PO_4-P loss from agriculture. Much of the phosphorus (62%) from the more agricultural areas was of a particulate nature which could be reduced with the suspended solids load, however some studies indicate that the proportion of soluble-P may increase if input from domestic systems are not included in remedial measures.

Soluble cations and metals were derived from geologic sources and/or precipitation which could be reduced with the suspended solids load. Calcium near the source of the Hillman Creek may have arisen from the use of limestone. Regulating lime application to fields near the creek where erosion from flooding is likely or where fields are tiled may control losses but an evaluation should be made on the importance of Ca as a pollutant.

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APPENDIX I

SITE SAMPLING DATES AND PARAMETER CONCENTRATIONS

Table I-1. Sampling date, discharge and concentration of selected parameters at the site downstream of highway 3 on Hillman Creek, 1975-1976.

Date	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
11/4	0.090	7	9.3	6.2	0.052	0.007	0.029	0.023	118	16	12	4.5	5	9	155
17/4	0.050	10	9.7	5.4	0.062	0.027	0.000	0.043	119	16	12	5.1	4	16	145
21/4	0.070	1	8.8	5.2	0.084	0.000	0.071	0.061	118	16	12	6.0	7	7	97
29/4	0.064	6	8.1	4.2	0.118	0.018	0.012	0.088	112	15	12	6.9	10	15	136
7/5	0.040	5	5.6	4.3	0.135	0.038	0.082	0.015	115	16	13	6.2	15	9	136
14/5	0.030	15	4.8	2.7	0.188	0.093	0.009	0.086	120	15	12	4.9	19	88	262
20/5	0.040	24	5.6	2.9	0.292	0.079	0.115	0.098	121	15	12	6.8	8	10	453
27/5	0.052	59	4.6	2.1	0.212	0.058	0.000	0.175	124	15	12	4.4	11	19	571
2/6	0.052	17	3.8	2.1	0.215	0.028	0.009	0.178	124	14	21	3.5	14	17	232
6/6	0.100	53	9.9	6.0	0.715	0.275	0.040	0.400	124	16	11	5.8	14	24	680
13/6	0.070	15	7.1	2.6	0.240	0.044	0.015	0.081	124	15	11	5.7	11	11	291
17/6	0.090	26	12.0	5.7	0.325	0.149	0.051	0.125	123	16	10	8.0	7	11	389
25/6	0.130	40	10.7	6.8	0.300	0.076	0.066	0.158	100	14	14	1.2	10	11	320
27/6	0.052	2	6.1	2.7	0.335	0.183	0.034	0.118	114	14	13	7.2	12	7	117
21/7	0.030	2	2.5	0.5	0.328	0.035	0.087	0.206	97	12	16	12.6	10	11	135
5/8	0.030	9	1.6	0.5	0.204	0.057	0.038	0.109	102	12	11	11.2	4	6	245
26/8	0.021	42	3.1	0.8	0.288	0.110	0.031	0.157	118	15	12	13.2	16	20	630

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DUP)

Table I-1 (Continued)

Date	Discharge	SS[1/]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2/]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
5/9	0.290	30	9.7	9.5	0.183	0.024	0.000	0.198	120	18	13	10.1	21	22	700
12/9	0.370	31	9.9	10.3	0.194	0.057	0.012	0.125	115	17	10	12.1	5	15	640
25/9	0.070	8	5.9	4.5	0.143	0.005	0.018	0.120	120	17	14	7.8	3	11	330
21/10	0.109	5	4.3	4.2	0.163	0.015	0.040	0.108	128	18	14	8.4	4	13	250
4/11	0.100	12	2.4	1.8	0.162	0.012	0.052	0.098	123	17	13	8.4	4	10	170
18/11	0.090	12	2.5	2.2	0.176	0.039	0.033	0.104	122	17	18	9.3	3	14	170
9/12	0.152	9	6.5	6.2	0.184	0.037	0.044	0.103	128	23	14	9.2	5	15	380
16/12	0.430	44	11.9	10.9	0.220	0.126	0.024	0.070	120	23	10	10.7	9	36	980
30/12	0.350	21	9.1	9.1	0.304	0.082	0.117	0.105	108	19	15	7.0	9	90	600
15/1	0.140	7	7.3	6.6	0.159	0.042	0.024	0.093	108	20	12	6.0	3	10	260
27/1	1.400	21	8.4	7.1	0.221	0.069	0.013	0.139	72	13	16	8.5	4	6	540
17/2	1.400	325	8.7	8.7	0.850	0.773	0.000	0.081	67	11	7	6.5	22	42	3050
24/2	0.320	135	9.0	13.3	0.115	0.035	0.016	0.064	112	20	11	6.0	34	28	710
5/3	1.450	252	7.5	7.1	0.390	0.319	0.000	0.080	65	11	7	7.5	19	4	2750
10/3	0.192	29	8.5	9.1	0.090	0.036	0.000	0.073	110	18	11	7.5	5	74	470

1/ Suspended Solids (SS)

2/ Dissolved unreactive-P (DUP)

Table I-2. Sampling date, discharge and concentration of selected parameters at the site upstream of highway 3 on Hillman Creek, 1975-1976.

Date	Discharge	SS[1/]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2/]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
11/4	0.089	8	10.0	5.9	0.070	0.031	0.006	0.033	117	16	11	4.1	9	9	145
17/4	0.054	8	9.9	4.4	0.053	0.000	0.007	0.050	118	15	12	4.7	68	31	184
21/4	0.072	1	8.4	5.0	0.087	0.026	0.000	0.063	117	16	12	5.5	9	8	106
29/4	0.066	10	8.1	3.3	0.130	0.035	0.010	0.085	115	14	12	5.4	10	5	145
7/5	0.045	5	6.0	4.1	0.119	0.014	0.019	0.086	116	16	12	5.9	18	9	184
14/5	0.036	4	4.9	2.8	0.176	0.049	0.044	0.083	119	15	11	4.4	7	9	155
20/5	0.045	3	5.5	2.0	0.232	0.026	0.062	0.144	121	15	11	5.8	6	9	281
27/5	0.056	14	4.6	2.0	0.276	0.138	0.000	0.165	125	14	11	3.8	10	22	290
2/6	0.056	2	4.2	2.3	0.223	0.025	0.025	0.173	125	14	11	4.2	16	29	314
6/6	0.098	19	10.0	6.9	0.785	0.080	0.192	0.513	126	16	11	5.7	17	17	423
13/6	0.072	88	7.1	2.9	0.275	0.077	0.164	0.034	124	15	11	4.3	7	7	272
17/6	0.089	29	11.9	5.7	0.290	0.124	0.048	0.118	71	15	10	7.2	10	11	360
25/6	0.125	54	11.2	6.2	0.590	0.417	0.010	0.163	102	14	14	1.1	9	12	330
27/6	0.056	8	6.0	2.9	0.235	0.089	0.028	0.118	117	14	14	6.3	6	7	175
21/7	0.036	18	2.5	0.8	0.317	0.095	0.037	0.185	106	13	15	10.9	13	11	189
5/8	0.036	16	1.8	0.4	0.269	0.121	0.033	0.115	107	12	10	9.8	4	11	328
26/8	0.029	30	2.7	0.9	0.240	0.066	0.026	0.158	123	15	11	12.2	18	16	610

1/ Suspended Solids (SS)

2/ Dissolved unreactive-P (DUP)

Table I-2 (Continued)

Date	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	-----	-----	-----	-----	mg/l	-----	-----	-----	-----	-----	-----	-----	ug/l	-----
5/9	0.266	7	9.5	9.4	0.138	0.015	0.007	0.116	130	18	12	10.0	9	14	370
12/9	0.366	30	9.8	11.1	0.195	0.057	0.014	0.124	122	17	10	11.3	5	19	650
25/9	0.072	3	5.2	3.4	0.117	0.000	0.010	0.116	132	17	13	7.6	3	15	300
21/10	0.120	2	3.4	3.2	0.144	0.009	0.054	0.081	130	19	16	9.8	3	47	320
4/11	0.094	69	2.5	2.3	0.166	0.031	0.041	0.094	126	17	12	8.6	5	19	160
18/11	0.086	9	2.3	2.2	0.163	0.041	0.033	0.089	123	17	13	6.6	6	10	240
9/12	0.180	4	7.6	7.1	0.202	0.079	0.030	0.093	127	23	13	9.6	4	18	240
16/12	0.640	42	13.2	11.2	0.208	0.088	0.057	0.063	119	23	10	11.0	6	27	860
30/12	0.320	35	9.6	9.5	0.195	0.013	0.069	0.103	105	18	13	6.5	18	45	860
15/1	0.190	17	7.1	6.4	0.147	0.025	0.018	0.104	126	19	11	5.5	3	12	470
27/1	1.100	26	7.7	6.8	0.237	0.069	0.013	0.150	72	13	16	7.8	4	16	640
17/2	1.300	290	8.4	8.4	0.700	0.600	0.011	0.089	67	11	7	6.5	16	96	2600
24/2	0.315	35	9.3	12.9	0.081	0.036	0.002	0.043	111	19	11	6.0	25	30	690
27/2	0.240	5	9.0	8.4	0.089	0.027	0.022	0.040	114	19	9	5.3	-[3]	-	-
3/3	1.290	79	7.8	7.8	0.270	0.178	0.007	0.085	63	10	7	8.3	17	58	1780
5/3	1.250	208	7.9	7.2	0.335	0.206	0.055	0.074	66	11	7	7.3	20	42	3290
10/3	0.150	9	8.7	9.2	0.072	0.021	0.000	0.091	111	17	12	6.3	4	2	450

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DUP)

[3] Not determined (-)

Table I-3. Sampling date, discharge and concentration of selected parameters at the site downstream of highway 77 on Hillman Creek, 1975-1976.

Date	Discharge	SS[1/]	Total-N	NO_3-N	Total P	Part-P	DU-P[2/]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
11/4	0.060	10	9.8	5.0	0.031	0.000	0.027	<0.015	119	13	7	3.1	12	7	252
17/4	0.047	14	8.9	3.5	0.027	0.005	0.002	0.020	124	13	6	3.1	7	6	223
21/4	0.053	2	7.4	3.5	0.064	0.016	0.000	0.048	121	13	7	3.4	5	4	155
29/4	0.051	10	7.6	3.8	0.052	0.022	0.015	<0.015	121	13	7	3.9	5	6	213
7/5	0.044	8	5.6	3.5	0.025	0.000	0.000	0.075	108	13	6	3.0	11	6	194
14/5	0.040	4	5.5	3.6	0.026	0.005	0.006	<0.015	123	13	6	2.5	5	8	136
20/5	0.044	2	5.2	2.0	0.122	0.066	0.031	0.025	122	13	7	2.4	12	7	328
27/5	0.047	12	5.4	2.1	0.069	0.034	0.020	<0.015	130	13	5	1.9	8	100	298
2/6	0.047	23	3.8	2.6	0.115	0.060	0.040	<0.015	130	12	10	1.9	14	9	323
6/6	0.061	8	5.9	3.7	0.092	0.064	0.005	0.023	132	13	6	2.4	10	7	273
13/6	0.053	8	6.6	2.1	0.074	0.040	0.019	<0.015	131	13	6	1.7	10	7	223
17/6	0.060	15	10.6	4.4	0.072	0.035	0.022	<0.015	132	13	6	2.5	8	7	291
25/6	0.070	11	10.0	5.2	0.067	0.035	0.017	<0.015	116	12	8	5.7	10	8	185
27/6	0.047	2	6.1	2.2	0.077	0.029	0.013	0.035	123	12	7	4.3	18	7	165
21/7	0.040	0	2.0	1.0	0.110	0.049	0.000	0.063	116	12	6	5.1	6	10	189
5/8	0.040	10	2.3	0.8	0.114	0.036	0.039	0.039	116	11	6	6.9	5	9	275
26/8	0.038	8	3.1	1.2	0.122	0.027	0.000	0.103	131	15	9	7.7	13	14	340

1/ Suspended Solids (SS)
2/ Dissolved unreactive-P (DUP)

Table I-3. (continued)

Date	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
5/9	0.116	16	7.1	5.4	0.075	0.028	0.000	0.055	133	15	9	7.4	39	14	180
12/9	0.139	5	6.8	6.6	0.100	0.029	0.015	0.056	133	15	17	7.7	3	9	370
25/9	0.053	6	4.7	3.0	0.060	0.019	0.007	0.034	112	15	7	5.7	2	12	400
21/10	0.050	4	3.1	2.6	0.031	0.000	0.052	<0.015	133	16	7	6.2	2	9	330
4/11	0.048	16	2.3	2.1	0.049	0.007	0.027	<0.015	129	15	6	6.6	5	16	420
18/11	0.048	10	2.2	2.2	0.067	0.033	0.005	0.029	127	15	6	5.4	5	8	320
9/12	0.072	9	4.5	4.3	0.114	0.036	0.053	0.025	126	17	9	7.8	5	15	190
16/12	0.140	21	6.1	5.8	0.141	0.067	0.056	0.018	120	17	7	7.1	5	22	780
30/12	0.097	30	6.1	6.0	0.173	0.000	0.135	0.044	106	15	5	4.8	10	41	890
15/1	0.100	31	6.3	5.9	0.074	0.060	0.027	0.020	131	16	7	4.5	3	12	630
27/1	0.880	17	6.2	5.0	0.094	0.048	0.006	0.039	75	10	7	6.0	3	12	470
17/2	0.370	170	5.8	6.1	0.273	0.205	0.017	0.051	76	10	5	4.5	15	25	2240
24/2	0.087	35	6.7	8.8	0.054	0.032	0.004	0.018	118	15	8	4.5	36	680	620
27/2	0.078	11	6.6	6.5	0.051	0.001	0.015	0.035	115	17	8	4.8	—[3]	—	—
3/3	0.490	60	5.6	4.7	0.176	0.133	0.000	0.043	65	9	5	4.3	13	12	1500
5/3	0.500	69	5.7	4.0	0.380	0.330	0.017	0.033	62	9	5	5.0	17	48	2780
10/3	0.070	0	6.0	6.7	0.040	0.023	0.000	0.019	116	14	7	5.0	4	114	240

[1] Suspended solids (SS)

[2] Dissolved unreactive -P (DUP)

[3] Not determined (-)

Table I-4. Sampling date, discharge and concentration of selected parameters at the site upstream of highway 77 on Hillman Creek, 1975-1976.

Date	Discharge	SS[1/]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2/]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec	--------	--------	--------	--------	mg/l	--------	--------	--------	--------	--------	--------	--------	ug/l	--------
11/4	0.045	8	8.5	5.0	0.016	0.000	0.013	<0.015	121	13	5	3.1	22	2	435
17/4	0.038	6	10.0	3.9	0.017	0.000	0.000	<0.015	126	13	5	3.1	9	6	223
21/4	0.041	4	7.6	3.6	0.018	0.003	0.000	<0.015	124	13	5	3.4	6	3	165
29/4	0.040	2	7.2	2.1	0.018	0.001	0.002	<0.015	121	13	5	3.8	7	6	223
7/5	0.036	5	5.6	3.7	<0.015	0.000	0.000	<0.015	114	13	5	3.8	10	5	223
14/5	0.034	2	5.1	3.7	0.033	0.018	0.000	<0.015	125	13	5	2.5	6	8	204
20/5	0.036	1	5.9	1.7	0.065	0.043	0.007	<0.015	123	13	4	2.3	9	8	348
27/5	0.038	16	5.0	2.4	0.058	0.032	0.003	0.023	131	13	5	2.0	13	75	306
2/6	0.038	42	5.1	2.7	0.087	0.072	0.000	<0.015	130	12	6	1.4	6	9	530
6/6	0.046	26	8.7	3.1	0.069	0.054	0.000	0.019	129	13	5	2.4	9	9	488
13/6	0.041	9	7.2	2.3	0.044	0.029	0.000	<0.015	133	13	5	2.5	7	7	282
17/6	0.045	13	10.5	4.4	0.068	0.022	0.011	0.035	131	13	5	2.1	23	7	289
25/6	0.051	32	8.8	4.6	0.051	0.016	0.010	0.025	119	12	7	5.1	19	7	185
27/6	0.038	5	6.0	1.8	0.050	0.019	0.016	<0.015	127	12	6	3.7	6	7	185
21/7	0.034	0	3.5	1.3	0.025	0.010	0.000	0.028	116	11	5	5.3	5	5	135
5/8	0.034	0	2.9	1.1	0.036	0.021	0.000	<0.015	118	11	5	7.1	4	8	243
26/8	0.033	42	3.4	1.9	0.055	0.028	0.004	0.025	132	15	6	7.4	14	10	340

[1/] Suspended solids (SS)

[2/] Dissolved unreactive-P (DUP)

Table I-4 (Continued).

Date	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec	mg/l											ug/l		
5/9	0.077	44	7.3	5.3	0.036	0.002	0.000	0.049	136	15	6	7.0	9	21	230
12/9	0.090	2	7.5	6.1	0.071	0.019	0.012	0.040	137	15	6	8.0	5	77	340
25/9	0.041	5	4.8	3.1	0.034	0.009	0.006	0.019	142	15	6	6.5	2	9	240
21/10	0.042	12	2.7	3.0	0.030	0.003	0.012	<0.015	135	16	5	7.5	3	23	330
4/11	0.039	0	2.3	2.2	0.052	0.027	0.010	<0.015	130	15	5	6.3	4	11	420
18/11	0.033	14	2.9	2.5	0.071	0.049	0.007	<0.015	128	15	5	5.3	2	10	330
9/12	0.048	1	4.6	4.4	0.094	0.033	0.046	<0.015	126	16	6	5.5	4	8	190
16/12	0.072	12	8.5	6.5	0.103	0.042	0.046	<0.015	120	17	6	6.8	6	13	370
30/12	0.040	71	6.5	6.3	0.200	0.091	0.094	<0.015	110	15	5	4.5	7	106	870
17/2	0.260	147	7.2	7.2	0.320	0.224	0.047	0.049	99	10	5	4.8	8	30	2310
24/2	0.091	10	6.2	8.7	0.089	0.015	0.015	0.059	121	15	7	4.8	6	22	250
5/3	0.295	2	6.1	5.8	0.173	0.121	0.014	0.038	91	12	5	5.5	15	18	1110
10/3	0.072	0	6.7	6.9	0.040	0.025	0.000	<0.015	119	14	6	5.0	8	173	170

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DUP)

Table I-5. Sampling date, discharge and concentration of selected parameters on the Hillman Creek tributary between highways 3 and 77, 1975-1976.

Date	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec	mg/l											ug/l		
5/8	0.010	12	1.5	0.2	0.435	0.080	0.060	0.295	118	14	20	11.6	4	16	480
26/8	0.013	32	5.0	1.4	0.612	0.108	0.054	0.450	132	18	24	24.6	8	19	770
5/9	0.019	16	10.4	10.6	0.187	0.000	0.021	0.193	129	20	15	11.0	7	30	260
12/9	0.102	20	10.7	11.7	0.177	0.000	0.012	0.198	119	19	11	12.8	5	14	300
25/9	0.021	1	5.6	3.9	0.209	0.000	0.019	0.250	126	18	21	9.8	4	13	210
21/10	0.013	6	4.2	3.9	0.290	0.203	0.079	0.203	123	19	19	13.2	5	14	350
4/11	0.011	20	2.9	2.3	0.459	0.348	0.040	0.348	115	17	20	11.5	3	14	240
18/11	0.010	12	2.7	2.4	0.363	0.225	0.102	0.225	122	18	21	8.4	2	13	260
9/12	0.036	50	8.1	7.2	0.371	0.193	0.037	0.193	127	25	18	11.0	4	21	230
16/12	0.180	19	12.6	10.7	0.173	0.088	0.040	0.088	116	24	12	10.4	7	41	570
30/12	0.041	57	8.2	7.0	0.704	0.295	0.117	0.295	87	19	26	13.0	9	26	730
15/1	0.011	19	9.2	7.3	0.324	0.195	0.040	0.250	116	20	19	9.0	8	19	510
27/1	0.520	8	8.8	7.0	0.249	0.250	0.022	0.195	68	13	21	9.8	9	120	260
17/2	0.518	150	7.7	7.6	0.348	0.128	0.000	0.128	63	11	8	7.3	12	28	1780
24/2	0.102	0	8.9	11.8	0.181	0.091	0.000	0.091	108	21	13	6.5	14	11	240
27/2	0.094	6	9.0	8.0	0.134	0.078	0.127	0.078	108	22	13	6.0	-[3]	-	-
3/3	0.540	59	7.0	6.3	0.235	0.109	0.000	0.109	59	11	7	8.3	11	200	1400
5/3	0.530	115	7.6	6.2	0.369	0.118	0.015	0.118	65	12	8	8.8	19	29	1780
10/3	0.060	7	8.5	8.9	0.246	0.168	0.010	0.168	104	18	14	6.5	3	4	360

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DU-P)

[3] Not determined(-)

Table II-1. Average monthly discharge and concentration of selected parameters at the site downstream of highway 3 on Hillman Creek, 1975-1976.

Month	Discharge	SS[1/]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2/]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
April	0.068	6	9.0	5.3	0.08	0.01	0.03	0.05	117	16	12	6	7	12	133
May	0.041	26	5.2	3.0	0.21	0.07	0.05	0.09	120	15	12	6	13	32	356
June	0.088	26	8.3	4.3	0.36	0.13	0.05	0.18	118	15	13	5	11	14	338
July	0.030	2	2.5	0.5	0.33	0.04	0.09	0.21	97	12	16	13	10	11	135
August	0.026	26	2.4	0.7	0.25	0.08	0.03	0.13	110	14	12	12	10	13	438
September	0.253	23	8.5	8.1	0.17	0.03	0.01	0.15	118	17	12	10	10	16	557
October	0.109	5	4.3	4.2	0.16	0.15	0.04	0.11	123	18	14	8	4	13	250
November	0.095	12	2.5	2.0	0.17	0.03	0.04	0.10	123	17	16	9	4	12	170
December	0.311	25	9.2	8.7	0.24	0.08	0.06	0.09	119	22	13	9	8	47	653
January	0.770	14	7.9	6.9	0.19	0.06	0.02	0.12	90	17	14	7	4	8	400
February	0.860	230	8.6	11.0	0.48	0.40	0.01	0.07	90	16	9	6	28	35	1880
March	0.821	141	8.0	8.1	0.24	0.18	0.00	0.08	88	15	9	8	12	39	1610

1/ Suspended solids (SS)

2/ Dissolved unreactive-P (DU-P)

Table II-2. Average monthly discharge and concentration of selected parameters at the site upstream of highway 3 on Hillman Creek, 1975-1976.

Month	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	mg/l											ug/l		
April	0.071	7	9.1	4.7	0.09	0.02	0.01	0.06	117	15	12	5	24	13	145
May	0.046	7	5.3	2.7	0.20	0.06	0.03	0.12	120	15	11	5	10	12	128
June	0.074	33	8.4	4.5	0.40	0.14	0.08	0.19	111	15	12	5	11	14	312
July	0.036	18	2.5	0.8	0.32	0.10	0.04	0.19	106	13	15	11	13	11	189
August	0.033	23	2.3	0.7	0.26	0.09	0.03	0.14	115	14	11	11	11	14	469
September	0.268	13	8.2	8.0	0.15	0.02	0.01	0.12	128	17	12	10	6	16	440
October	0.120	2	3.4	3.2	0.14	0.01	0.05	0.08	130	19	16	10	3	47	320
November	0.090	39	2.4	2.3	0.16	0.04	0.04	0.09	125	17	13	8	6	15	200
December	0.380	27	10.1	8.9	0.20	0.06	0.05	0.09	117	21	12	9	9	30	653
January	0.645	22	7.4	6.6	0.19	0.04	0.02	0.13	99	16	14	7	4	14	555
February	1.028	110	8.9	9.9	0.29	0.22	0.01	0.06	97	16	9	6	21	63	1645
March	0.897	99	8.1	8.1	0.23	0.14	0.02	0.08	80	13	9	7	14	34	1840

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DU-P)

Table II-3. Average monthly discharge and concentration of selected parameters at the site downstream of highway 77 on Hillman Creek, 1975-1976.

Month	Discharge	SS[1/]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2/]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.	----------	----------	----------	----------	mg/l	----------	----------	----------	----------	----------	----------	----------	----------	ug/l--
April	0.053	9	8.4	4.0	0.04	0.01	0.01	<0.03	121	13	7	4	7	6	211
May	0.044	7	5.4	2.8	0.06	0.03	0.01	<0.03	121	13	6	2	9	30	239
June	0.056	11	7.2	3.4	0.08	0.04	0.02	<0.02	127	13	7	3	12	8	243
July	0.040	0	2.0	1.0	0.11	0.05	0.00	0.06	116	12	6	5	6	10	189
August	0.039	9	2.7	1.0	0.12	0.03	0.02	0.07	124	13	8	7	9	12	308
September	0.103	9	6.2	5.0	0.08	0.03	0.01	0.03	126	15	11	7	15	12	317
October	0.050	4	3.1	2.6	0.03	0.00	0.05	<0.02	133	16	7	6	2	9	330
November	0.048	13	2.3	2.2	0.06	0.02	0.02	<0.02	128	15	6	6	5	12	370
December	0.102	20	5.6	5.4	0.14	0.03	0.08	0.03	117	16	7	7	7	26	620
January	0.445	24	6.3	5.5	0.08	0.04	0.01	0.03	103	13	7	5	3	12	550
February	0.178	72	6.4	7.1	0.13	0.08	0.01	0.04	103	14	7	5	26	353	1430
March	0.353	43	5.8	5.1	0.20	0.16	0.01	0.03	81	11	6	5	11	58	1507

1/ Suspended solids (SS)

2/ Dissolved unreactive -P (DU-P)

Table II-4. Average monthly discharge and concentration of selected parameters at the site upstream of highway 77 on Hillman Creek, 1975-1976.

Month	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec	mg/l											ug/l		
April	0.041	5	8.3	3.7	0.02	<0.01	<0.01	<0.02	123	13	5	3	11	4	262
May	0.036	6	5.4	2.9	0.04	0.02	<0.01	<0.02	123	13	5	3	10	24	270
June	0.043	21	7.7	3.2	0.06	0.04	<0.01	<0.02	128	13	6	3	12	8	327
July	0.034	0	3.5	1.3	0.03	0.01	0.00	0.03	116	11	5	5	5	5	135
August	0.034	21	3.2	1.5	0.05	0.02	<0.01	<0.02	125	13	6	7	9	9	292
September	0.069	17	6.5	4.8	0.05	0.01	<0.01	0.04	138	15	6	7	5	36	270
October	0.042	12	2.7	3.0	0.03	0.15	0.12	<0.02	135	16	5	8	3	23	330
November	0.036	7	2.6	2.4	0.06	0.04	<0.01	<0.02	129	15	5	6	3	11	375
December	0.053	28	6.5	5.7	0.13	0.06	0.06	<0.02	119	16	6	6	6	42	477
January						FROZEN									
February	0.176	79	6.7	8.0	0.20	0.12	0.03	0.05	110	13	6	5	7	26	1280
March	0.184	1	6.4	6.4	0.11	0.07	0.01	<0.03	105	13	6	5	12	96	640

[1] Suspended solids (SS)

[2] Dissolved unreactive -P (DU-P)

Table II-5. Average monthly discharge and concentration of selected parameters on the Hillman Creek tributary between highways 3 and 77, 1975-1976.

Month	Discharge	SS[1]	Total-N	NO_3-N	Total-P	Part-P	DU-P[2]	PO_4-P	Ca	Mg	Na	K	Cu	Zn	Fe
	m^3/sec.					mg/l								ug/l	
August	0.012	22	3.3	0.8	0.52	0.09	0.06	0.37	125	16	22	18	6	18	675
September	0.057	12	8.9	8.7	0.19	0.00	0.02	0.21	125	19	16	11	5	19	256
October	0.013	6	4.2	3.9	0.29	0.01	0.08	0.20	123	19	19	13	5	14	350
November	0.011	16	2.8	2.4	0.41	0.05	0.07	0.29	119	18	21	10	3	14	250
December	0.129	42	9.6	8.3	0.42	0.16	0.07	0.19	110	23	19	11	7	29	510
January	0.266	14	9.0	7.2	0.29	0.03	0.03	0.22	92	17	20	9	9	70	385
February	0.271	52	8.5	9.1	0.22	0.12	0.04	0.10	93	18	11	7	13	20	1010
March	0.377	60	7.7	7.1	0.28	0.14	<0.01	0.13	76	14	10	8	11	111	1180

1/ Suspended solids (SS)

2/ Dissolved unreactive -P(DU-P)

APPENDIX III

SITE PRECIPITATION AND MONTHLY LOAD OF SELECTED PARAMETERS

Table III-1 Monthly load of selected parameters and precipitation at the site downstream of highway 3 on Hillman Creek, 1975-1976.

Month	Precipitation	SS[1]	Total-N	NO_3-N	Ca	Mg	Na	K	Total-P	Part-P	DU-P[2]	PO_4-P	Cu	Zn	Fe
	cm	tonnes							kg						
April	5.9	1.0	1.6	0.95	21	2,8	2.1	1.0	14	2	5.0	9.2	1.2	2.0	24
May	6.3	3.1	0.6	0.32	13	1.7	1.3	0.6	23	7	5.5	10.8	1.4	2.9	41
June	10.6	6.4	1.9	1.05	25	3.2	2.7	1.0	80	28	11.9	40.1	2.4	3.0	79
July	4.1	0.2	0.2	0.04	8	1.0	1.3	1.0	26	3	7.0	16.6	0.8	0.9	11
August	23.2	1.5	0.2	0.04	7	0.9	0.8	0.8	16	5	2.1	8.8	0.6	0.8	28
September	6.6	17.9	6.0	5.95	74	11.0	7.3	6.9	117	25	4.9	96.8	7.0	11.0	400
October	3.0	1.5	1.3	1.23	37	5.3	4.1	2.5	48	4	11.7	31.5	1.1	3.7	73
November	4.4	3.0	0.6	0.49	30	4.2	3.8	2.2	42	6	10.6	24.8	0.9	2.9	42
December	7.4	24.7	8.3	7.87	97	17.9	10.4	7.5	204	79	51.7	73.7	6.9	44.0	615
January	5.8	40.7	17.1	14.55	155	28.1	32.2	17.1	444	137	28.9	278.0	8.1	13.1	1061
February	8.0	624.1	18.9	20.59	162	27.3	16.7	13.8	1537	1370	6.4	167.7	52.2	84.9	5634
March	12.1	496.8	16.7	16.13	155	26.0	16.4	16.5	781	629	0.0	174.1	38.2	26.8	5461

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DU-P)

Table III-2 Monthly load of selected parameters and precipitation at the site upstream of highway 3 on Hillman Creek, 1975-1976.

Month	Precipitation	SS[1]	Total-N	NO_3-N	Ca	Mg	Na	K	Total-P	Part-P	DUP[2]	PO_4-P	Cu	Zn	Fe
	cm	tonnes							kg						
April	5.9	1.2	1.7	0.87	21	2.8	2.1	0.9	16	5	1.0	10.2	3.7	2.2	26
May	6.3	0.9	0.6	0.33	15	1.8	1.4	0.6	25	8	3.5	15.1	1.3	1.6	29
June	10.6	7.8	2.0	1.06	23	3.2	2.6	1.0	96	36	16.9	43.2	2.3	2.9	70
July	4.1	1.7	0.2	0.08	10	1.3	1.4	1.1	31	9	3.6	17.8	1.3	1.0	18
August	23.2	1.9	0.2	0.05	10	1.2	0.9	0.9	22	8	2.2	11.7	0.9	1.2	40
September	6.6	11.3	5.6	5.88	77	10.6	6.7	6.3	101	22	6.7	73.1	3.8	10.2	309
October	3.0	0.6	1.1	1.03	42	6.1	5.1	3.2	46	3	17.4	26.0	1.0	15.1	103
November	4.4	9.4	0.6	0.53	29	4.0	2.9	1.8	38	8	8.7	21.4	1.3	3.4	46
December	7.4	34.6	11.5	10.26	118	22.0	11.5	9.7	207	70	57.1	80.4	9.2	31.2	776
January	5.8	47.9	14.7	13.01	153	26.6	29.6	14.5	434	107	49.8	277.6	7.5	29.8	1191
February	8.0	325.1	13.4	14.20	124	20.8	12.3	9.7	799	666	16.9	116.0	35.9	168.2	4507
March	12.1	324.3	19.0	18.25	161	26.1	17.5	18.6	695	438	69.5	192.7	34.3	113.9	5598

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DU-P)

Table III-3 Monthly load of selected parameters and precipitation at the site downstream of highway 77 on Hillman Creek, 1975-1976

Month	Precipitation	SS[1]	Total-N	NO_3-N	Ca	Mg	Na	K	Total-P	Part-P	DU-P[2]	PO_4-P	Cu	Zn	Fe
	cm	Tonnes							kg						
April	5.9	1.2	1.2	0.55	17	1.8	0.9	0.5	6	1	1.6	3.3	1.0	0.8	29
May	6.3	0.8	0.6	0.33	14	1.5	0.7	0.3	7	3	1.7	3.8	1.1	3.7	28
June	10.6	1.6	1.1	0.51	19	1.8	1.0	0.5	12	6	2.7	2.8	1.7	1.1	35
July	4.1	0.0	0.2	0.11	12	1.3	0.6	0.5	12	5	0.0	6.7	0.6	1.1	20
August	23.2	0.9	0.3	0.10	13	1.4	0.8	0.8	12	3	2.1	7.3	0.9	1.2	32
September	6.6	2.5	1.7	1.47	34	4.0	3.3	1.9	22	7	2.1	13.8	4.4	3.0	81
October	3.0	0.5	0.4	0.35	18	2.1	0.9	0.8	4	0	7.0	<2.0	0.3	1.2	44
November	4.4	1.6	0.3	0.27	16	1.9	0.7	0.7	7	3	2.0	<2.7	0.6	1.5	46
December	7.4	5.8	1.6	1.52	32	4.5	1.9	1.8	40	11	22.1	7.7	1.8	7.3	187
January	5.8	24.2	8.2	6.68	106	13.9	9.2	7.7	121	48	24.4	48.6	3.9	15.7	638
February	8.0	55.8	2.7	2.90	40	5.3	2.6	2.0	92	66	6.5	19.4	10.9	85.7	1106
March	12.1	57.1	5.4	4.26	63	8.8	4.9	4.4	249	207	7.6	34.7	13.5	33.8	1912

[1] Suspended solids (SS)

[2] Dissolved unreactive-P (DU-P)

Table III-4. Monthly load of selected parameters and precipitation at the site upstream of highway 77 on Hillman Creek, 1975-1976.

Month	Precipitation	SS[1]	Total-N	NO_3-N	Ca	Mg	Na	K	Total-P	Part-P	DU-P[2]	PO_4-P	Cu	Zn	Fe
	cm	tonnes							kg						
April	5.9	0.5	0.9	0.39	13	1.4	0.5	0.4	2	<1	0.4	<1.6	1.2	0.4	28
May	6.3	0.6	0.5	0.28	12	1.3	0.5	0.3	4	2	0.3	<1.6	0.9	2.4	26
June	10.6	2.4	0.9	0.36	14	1.4	0.6	0.3	7	4	0.7	<2.4	1.4	0.9	36
July	4.1	0.0	0.3	0.12	11	1.0	0.5	0.5	2	<1	0.0	2.5	0.5	0.5	12
August	23.2	1.9	0.3	0.13	11	1.2	0.5	0.7	4	2	0.1	<1.8	0.8	2.6	37
September	6.6	3.3	1.2	0.94	25	2.7	1.1	1.3	9	2	1.2	7.0	1.1	0.8	26
October	3.0	1.4	0.3	0.34	15	1.8	0.6	0.8	3	<1	1.3	<1.7	0.3	7.7	50
November	4.4	0.6	0.2	0.22	12	1.4	0.5	0.5	6	4	0.8	<1.4	0.3	1.0	35
December	7.4	3.4	1.0	0.83	17	2.3	0.8	0.8	18	7	8.3	<2.1	0.8	17.3	63
January	5.8					FROZEN									
February	8.0	47.3	2.9	3.22	44	4.8	2.3	2.0	110	72	16.4	21.9	3.2	11.9	754
March	12.1	0.8	2.8	2.96	47	6.1	2.6	2.7	72	50	5.5	<16.5	6.7	23.8	455

1/ Suspended solids (SS)

2/ Dissolved unreactive-P (DU-P)

Table III-5. Monthly load of selected parameters and precipitation on the Hillman Creek tributary between highways 3 and 77, 1975-1976.

Month	Precipitation	SS[1/]	Total-N	NO_3-N	Ca	Mg	Na	K	Total-P	Part-P	DUP[2/]	PO_4-P	Cu	Zn	Fe
	cm	tonnes							kg						
August	23.2	0.7	0.1	0.03	4	0.5	0.7	0.6	17	3	1.7	11.8	0.2	0.5	20
September	6.6	2.0	1.2	1.28	15	2.3	1.6	1.5	23	0	1.7	25.2	0.6	2.0	35
October	3.0	0.2	0.1	0.14	4	0.7	0.7	0.5	10	<1	<2.8	7.1	0.2	0.5	12
November	4.4	0.4	<0.1	0.06	3	0.5	0.6	0.3	11	2	1.9	7.9	<0.1	0.4	7
December	7.4	6.8	2.6	2.21	26	5.4	3.5	2.5	66	23	11.9	31.1	1.6	8.2	126
January	5.8	5.9	6.3	4.98	49	9.3	14.9	7.0	178	11	28.2	139.5	6.4	83.8	189
February	8.0	65.4	4.8	4.92	45	8.3	5.6	4.2	177	116	10.0	69.3	9.6	19.6	1186
March	12.1	83.2	7.4	6.45	65	11.9	7.9	8.5	301	176	7.6	117.4	14.5	110.4	1537

1/ Suspended solids (SS)

2/ Dissolved unreactive -P(DU-P)

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