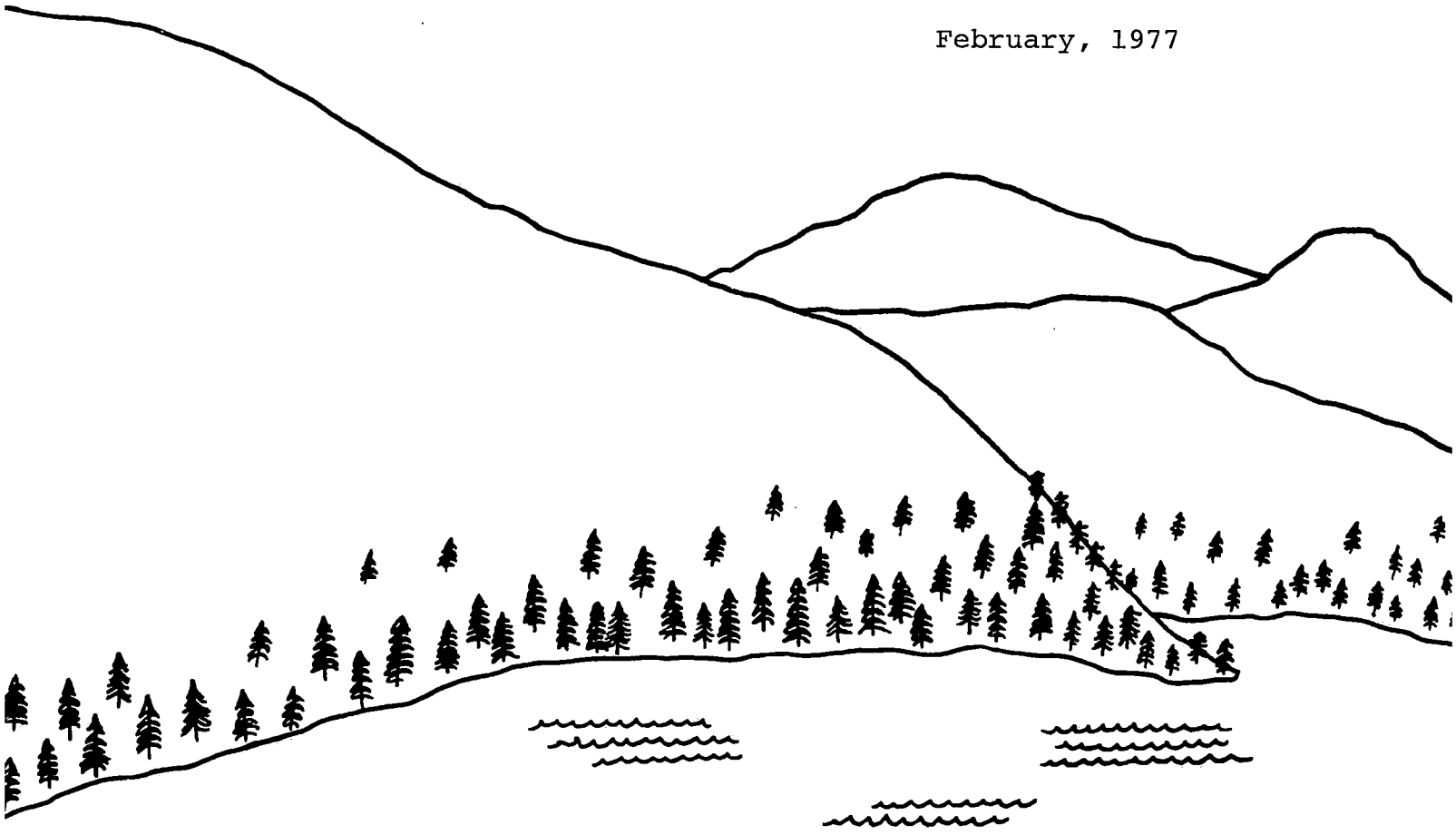
Clarkson College

Environmental Engineering

Acid Precipitation and the Salmon River System, Tug Hill, New York

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by

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Final Report of study conducted for the Temporary State Commission on Tug Hill.

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I. Introduction

Acid Precipitation. With the increasing emphasis in America today on the development and utilization of old and new energy resources, there must also be an increasing awareness of the potential environmental impact of energy production. Possibly one of the most serious consequences of this country's tremendous utilization could be the acidification of land and water in the northeastern United States as a result of the emission, transport, oxidation and hydrolysis, and deposition of sulfur oxides and nitrogen oxides, which are produced in the consumption of fossil fuels. While an awareness of the potential problem of acid precipitation exists, it is a very complex phenomenon and many of the basic questions related to it do not yet have definitive answers. Such questions as, "What and where are the major sources of acid rain? What are the components of acid rain and how is it formed and transported through the environment? How severe is the acid rain problem in New York State and on what basis can its severity be predicted? What is the impact of this problem on aquatic and terrestrial ecosystems? How might the problem be solved assuming it exists?" are the subject of much current research; however, a great deal more remains to be done. It is hoped that the results of this project contribute in some way to increasing our knowledge of the acid precipitation phenomenon.

From a historical basis, knowledge of the problem of acid precipitation in Scandinavia and interest in atmospheric contributions to aquatic nutrient cycles led to some documentation of low pH rainfall in the northeastern United States and eastern Canada.

Precipitation chemistry has been monitored in various locations in the northeast (Herman and Gorham (1957); Fisher, et al. (1968); Pearson and Fisher (1971); Likens (1972); Niles and Babcock (1975); Hornbeck, et al. (1976)), and results indicate that current pH values for precipitation in these areas generally fall within the range of 3 to 5. The precipitation in the northeast has, therefore, been found to be considerably more acidic than elsewhere in the United States (Junge (1958); Junge and Werby (1958); Richardson and Merva (1976)).

The potential environmental effects of the apparently man-made acid precipitation problems are numerous and far-reaching. Most of these problems are complex and not as yet completely understood; therefore, much work remains to be done on predicting and quantifying the effect. Possible environmental impacts of this phenomenon have been well documented elsewhere (Dochinger and Seliga (eds.)(1976); Hendrey and Wright (1976)); however, they can be summarized as follows:

1) acidification of surface waters and the subsequent detrimental effects on virtually all aquatic organisms,

2) increased teaching of nutrients and metal cations from terrestrial ecosystems,

3) decreased plant productivity,

4) increased soil acidity and subsequent reduction in buffering capability of the soil,

5) damage to man-made structures from the weathering of concrete and increased corrosion of metal, and

6) potential health effects on man.

The Salmon River Project. Acid precipitation and its subsequent detrimental effects on aquatic systems have to a certain

extent been documented. The Cornell University group has obtained a great deal of precipitation chemistry data in the Finger Lakes region (Likens (1972)) and in the Hubbard Brook Experimental Forest, New Hampshire (Fisher, et al. (1968); Likens, et al. (1970)), thus well documenting the acid precipitation severity in those areas. They have also conducted a general survey of the acidification of lakes in the Adirondack Park (Schofield (1977); Likens (1976)) and found that slightly over half of the 214 higher elevation lakes surveyed had pH less than 5. The New York State Department of Conservation has also been quite interested in the problem of acid precipitation and its effects as evidenced by their efforts to establish a statewide precipitation monitoring network and their preliminary studies in liming some Adirondack acid lakes (Buffington (1976)). Consistent with the state and national concern for the effects of acid precipitation, the Temporary State Commission on Tug Hill recommended instituting a "program to measure the acidity of Tug Hill precipitation and integrate this program with an adequately funded state "acid rain" research program to determine acid precipitation patterns throughout the state, the composition and sources of the acid, and the effects of acidity on plant and animal life" (Tug Hill Commission (1976)).

The high annual precipitation of the Tug Hill region, in conjunction with its key location in the state (down wind of Lake Ontario and potential pollution sources in the midwest and upwind of the Adirondack mountains and the Mohawk River Valley) and the delicate ecology of its vast aquatic and terrestrial resources, make it a very important study area for the "acid rain" problem. Furthermore, very little work has been conducted in New York State

on the effect of atmospheric inputs to flowing waters. The Salmon River system would be an especially good location for research efforts on this aspect of the overall problem. Besides the high annual precipitation on Tug Hill, its basic geological features (sedimentary sandstone, siltstones, and shale bedrocks overlain by glacial till of widely varying characteristics) make it representative of much of New York State with the exception of the Adirondack region (Jerome (1975)). Also, most of Tug Hill's 3879 miles of mapped streams (Tug Hill Commission (1976)) are virtually unpolluted with respect to local man-made municipal or industrial discharges, allowing the effects of acid rain to be more easily detected. Finally, the Salmon River in Oswego County is the proposed site of the New York Great Lakes Salmonid Hatchery (Macloed and Palmer (1975)). Preliminary estimates expect utilization of the eastern Lake Ontario fishery by more than 100,000 fishermen annually and a direct expenditure by these fisherman of more than $8 million annually. State and local tax revenues are expected to increase by more than $950,000 as a result of this venture. As a result the well-being of the water quality of the Salmon River system and all the streams on Tug Hill in the Lake Ontario basin is of tremendous economic as well as aesthetic importance.

In accordance with the desires of the people of Tug Hill to protect their unique environment and for the above-mentioned reasons, the Tug Hill Commission has supported a one-year study by the Clarkson College environmental engineering group to investigate the question of acid rain and its relationship to the Salmon River. The goals of this project are listed below. This manuscript

represents a report of the findings of this study.

Goals of Project. The objectives of this study were as follows:

1) To monitor the precipitation in the Salmon River watershed and to relate its chemistry to the existing acid rain data in New York State,

2) To obtain a baseline evaluation of the physical and chemical characteristics of the Salmon River which are pertinent to the acid rain problem,

3) To observe the short-term effects, if any, of an acid rain event on the chemistry (especially the pH) of the river,

4) To study the quantity and diversity of the macro-invertebrate community of the river with respect to the water quality of the river.

While the investigation reported herein addressed itself to all of the above objectives, the restrictions on manpower, resources, and time did not permit as detailed an evaluation of the above objectives as is deemed necessary. Nevertheless, it is felt that as an initial and preliminary effort this project provides a very good, and heretofore unavailable, baseline on the precipitation and water chemistry of the Salmon River area.

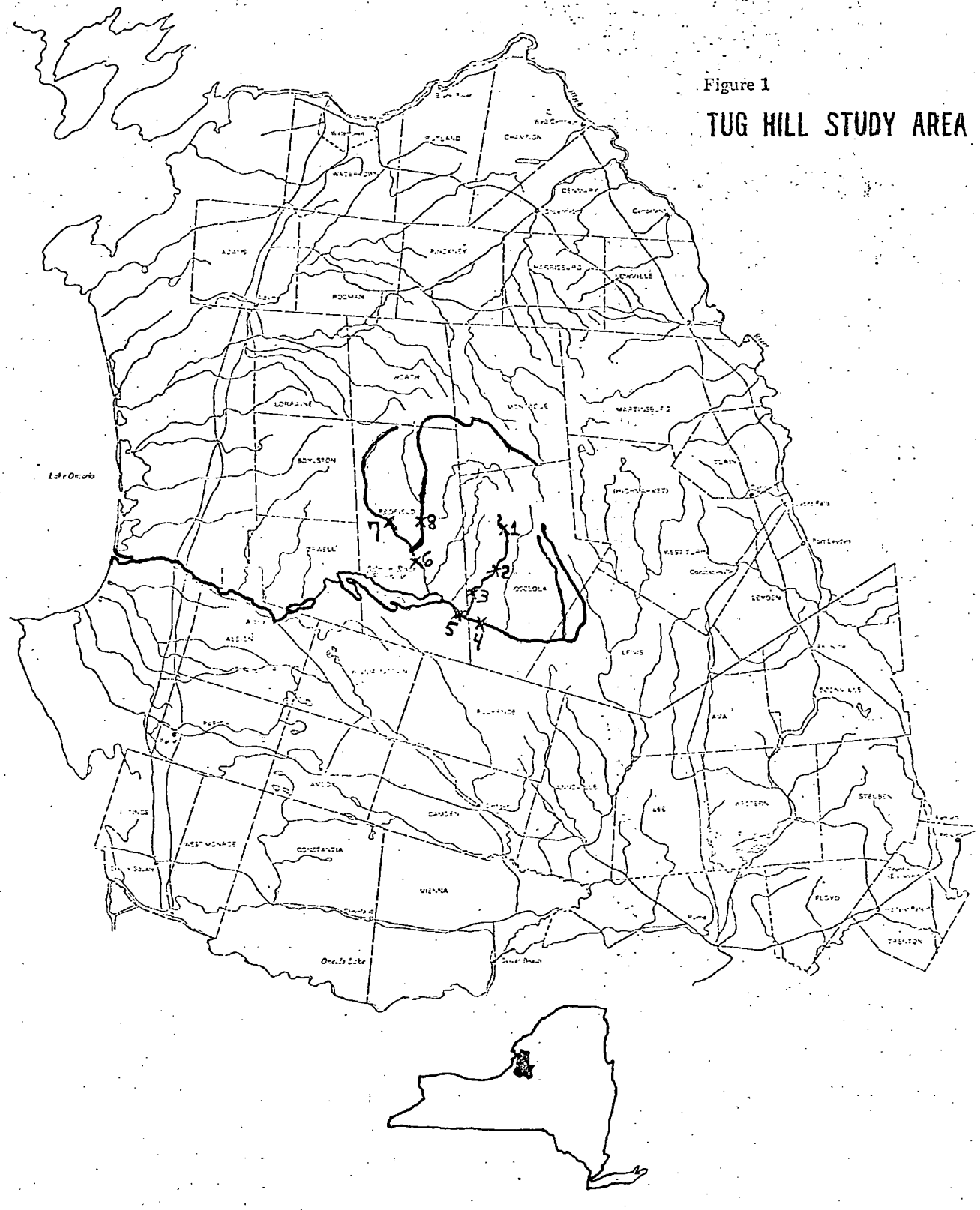
II. Experimental Methods and Procedures

The Study Area. The Salmon River is located in north-central New York in an area known as the Tug Hill Region (Figure 1). Tug Hill, as defined by the New York State Legislature in creating the Temporary State Commission on Tug Hill (Tug Hill Commission (1976)), contains some 1,285,000 acres and is made up of 39 towns in parts of Jefferson, Lewis, Oneida, and Oswego Counties. Its wilderness "core" (about 2000 feet above sea level) is the source of 11 major river systems - the Salmon River among them - which drain into four major watersheds in New York State (Black River, Oneida River, Mohawk River, and Eastern Lake Ontario). This alone is good reason for concern over the water quality in this region. Additional interest in the Salmon River system, which drains into Lake Ontario, stems from its proposed use for a large state-operated salmon hatchery.

In accordance with the objective of concentrating on the Salmon River water quality eight sampling sights in the watershed were selected (Figure 1), the first five of which received the most concentrated attention. Because of the large size of the Salmon River watershed (~40,000 ha.), it was felt that more meaningful and comparative data could be obtained by concentrating our efforts on a small sub-drainage area within the Salmon River system. The Prince Brook, a tributary of the East Branch of the Salmon River containing first and second order streams, was chosen because of its fairly well-defined drainage area, accessability of sampling sites, proximity to our mobile laboratory base, and the sparseness of population influence on its water quality.

Figure 1

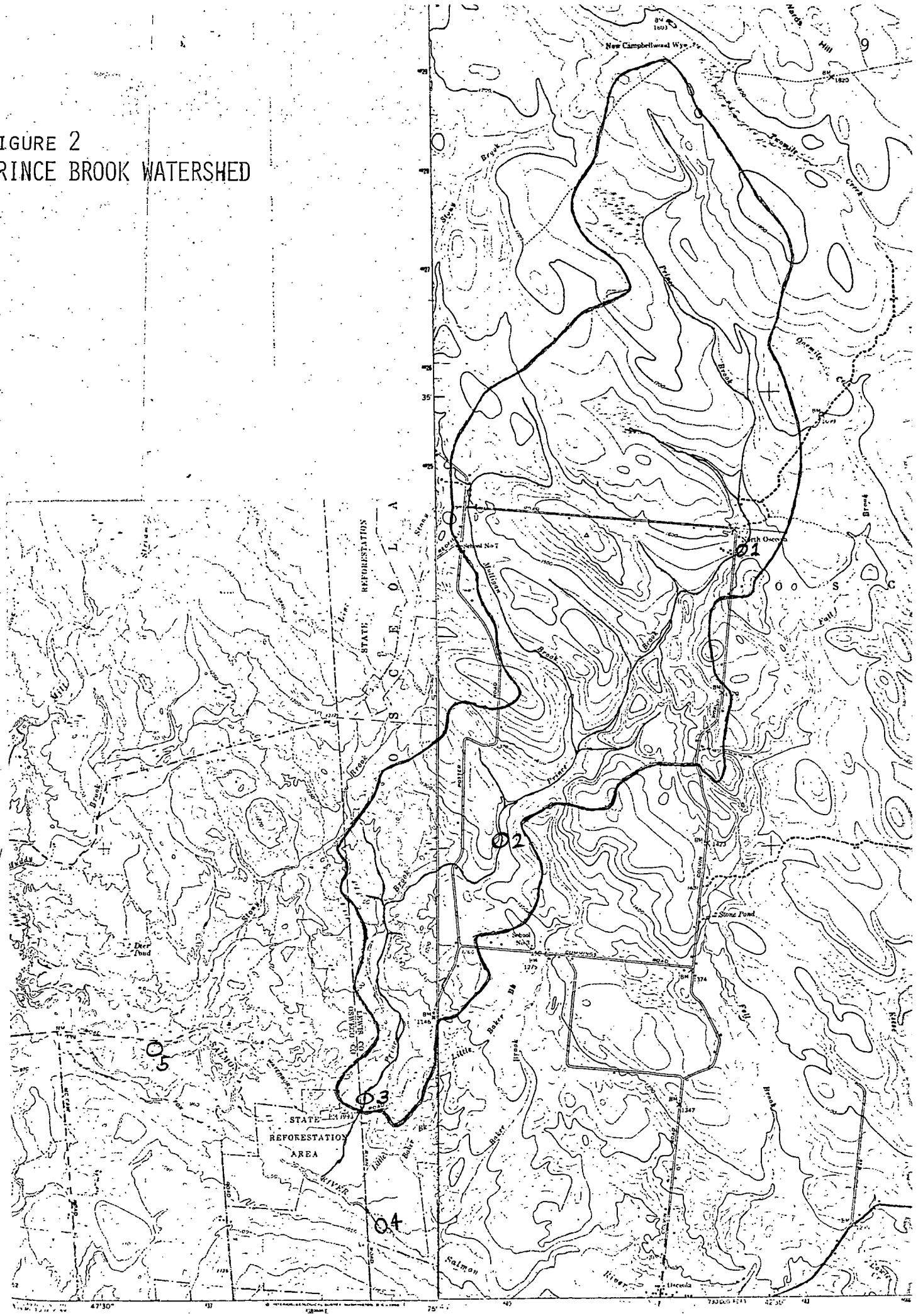
TUG HILL STUDY AREA



Furthermore, the Prince Brook was one of 26 stream sections on Tug Hill proposed for classification as "unique stream area" by the Tug Hill Commission (1976). The five sites chosen for more intensive study are shown in Figure 2, which contains an outline of the Prince Brook watershed (2235 ha.)(8.62 sq. miles)). Sites 1, 2 and 3 are on the Prince Brook and sites 4 and 5 are on the East Branch of Salmon. One other interesting feature of the Prince Brook area is that the majority of soils in the watershed is either of the Colosse cobbly loam fine sand series or the Empeyville stony loam series (Jerome (1975)). Both of these soil types are moderately to excessively drained, are moderately coarse textured, occupy areas with 3-15% slopes, generally extend 4 to 10 feet to bedrock and tend to be quite strongly acidic (ranging in pH from 4.5-6.0 in the upper 3 feet). In fact three soil samples we collected randomly in the Prince Brook watershed on 9/25/76 had pH values of 2.9, 4.5, and 4.6.

Precipitation Sampling. Precipitation was collected on a bulk basis (wet and dry fallout) in a clearing near our laboratory. Unless otherwise indicated the samples represented a composite of all precipitation falling between collection dates. This form of collection was the only feasible method due to travel restrictions to and from the study area. For rain a bulk collection device similar to that used by Likens (1972) was employed. This device prevents evaporation loss as well as extensive exchange of gases between the sample and the atmosphere. A large open-top 20 gallon plastic bucket was employed to collect bulk snow samples. Rain samples were analyzed immediately on site after collection for pH and acidity. The remainder of the sample was then stored

FIGURE 2
PRINCE BROOK WATERSHED



in a polyethylene bottle at 4°C for no more than one week prior to the other analyses, which included $SO_4^{=}$, NO_3^{-}, Ca^{++}, and total hardness. Snow samples were allowed to melt at room temperature prior to pH and acidity analysis, and were then stored in the same manner as the rain.

While it was not possible for us to accurately measure the quantity of precipitation in the Prince Brook watershed, we obtained estimates by consulting the New York State Climetological Data (NOAA (1975-76)) reports for the appropriate dates. The precipitation quantities we used for making loading estimates and weighted averages were based on an average of the amounts reported for the Lowville and Boonville stations, which somewhat bracket the Tug Hill wilderness core.

Stream Sampling. Sixteen sampling trips were made to the study area during the period of Nov. 1975 - Oct. 1976, with the heaviest concentration of trips during the spring and summer of 1976. An attempt was made to obtain a water chemistry sample from sites 1-5 during every excursion; however, deep snow during the winter and early spring prevented access to certain sites at that time. Sites 6-8 were sampled three times during the study period. The same parameters as measured for precipitation samples were analyzed for the stream samples: pH, acidity, and alkalinity on site, and $SO_4^{=}$, NO_3-N, Ca^{++}, and total hardness within one week of collection.

Beginning in June an attempt was made to measure the discharge of the Prince Brook at site 3 in order to estimate the relationship between atmospheric inputs of important ions to the watershed and the stream export of these parameters. The stream

velocity and cross-section were measured at the same time that chemistry samples were collected. While this procedure cannot provide the accuracy of a continuously-recording gaging station, it did allow us to estimate the ratio between input and discharge during the period from June - October.

To analyze the macroinvertebrate community in sites 1-4 an attempt was made to install multiplate artificial substrate samplers (with cinder blocks anchored in the bottom). This method of sampling insects proved to be ineffectual in our study system because of the rapid currents. Despite several installation attempts all but one sampler were dislodged and carried downstream. We therefore resorted to collecting insects on a quantitative basis by using a Hess type sampler (Usinger (1963)) (constructed in our lab) on sampling trips during the growing season. Macroinvertebrates collected by this method were separated at the species level, identified to the genus level, and counted to obtain a species diversity index. Usinger (1963), Pennak (1953), Betten (1934), Stone (1955), Johannsen (1969), and Ross (1972) were used for identification. The Shannon-Weaver index (Cook (1976)) $\bar{d} = - \Sigma \frac{Ni}{N} \log_2 \frac{Ni}{N}$ was used for calculation of species diversity.

Analytical Methods. The analytical techniques used for the determination of pH, acidity, alkalinity, sulfate, calcium and total hardness are detailed in Standard Methods for the Analysis of Water and Wastewater (A.P.H.A. (1975)). The Cadmium reduction method (U.S.E.P.A. (1974)) was used for spectrophotometric determination of nitrate-nitrogen. In the case of potentiometric titrations for acidity and alkalinity, 0.01N titrants were used on

100-200 ml samples. Sulfate was measured using the turbidimetric method with a Hach turbidimeter, Model 1860. The limit of detectability for this test was approximately 0.1 mg/l $SO_4^{=}$. Calcium and total hardness were analyzed by the EDTA titration method using high accuracy 10 ml vurets. The lower limit of detectability for calcium was 0.2 mg/l.

III. Results and Discussion

Acid Precipitation Chemistry. The chemistry of the bulk precipitation on Tug Hill was found to be very similar to that determined on precipitation in other areas of the northeast. Table I contains a summary of the amount of precipitation collected and the parameters monitored for the study period. Seasonal variation of pH, sulfate and nitrate concentrations in the rain samples is presented in Figure 3. The precipitation-weighted averages for pH, SO_4 and NO_3-N for the study period were 4.16, 0.11 meq/l and 0.038 meq/l, respectively. A mean annual pH of 4.16 compares favorably with data reported for other stations in the northeastern U.S. During the period from 1964-1974 the mean annual pH of precipitation collected at Hubbard Brook Experimental Forest, New Hampshire varied from 4.03 to 4.21 (Likens (1976)). According to the most recent pH contour maps (1972-73) prepared by Cogbill (1975), the precipitation pH at Tug Hill should be 4.40. Certainly the precipitation on Tug Hill is at least as acidic as one might expect.

The mineral acid nature of the rain is confirmed by the high mean annual sulfate and nitrate concentrations in the samples collected. During the period of Sept. 1972 to Aug. 1973 the average weighted sulfate and nitrate for three sites in New York and Hubbard Brook, N.H. was 0.098 meq/l and 0.044 meq/l, respectively (Cogbill and Likens (1974)). These are very similar to the values reported above for Tug Hill.

Even more important than the hydrogen ion concentration in the rain is the annual loading of acid on a given area, since this value takes into consideration the amount of precipitation. The

Table I

Bulk Precipitation Chemistry for Salmon River Area (1975-1976)

Collection Period	Precipitation Form	Precipitation Amount (cm)	pH	Total Acidity (meq/l)	$SO_4^=$ (mg/l as $SO_4^=$)	NO_3-N (mg/l as N)	Ca^{++} (mg/l as Ca^{++})
11/8 - 11/22/75	Rain	8.41	4.30	0.10	2.70	0.90	-
11/22 - 12/6/75	Rain	5.8	4.24	0.23	2.55	0.31	-
12/6/75 - 1/21/76*	Snow	11.86	5.99	0.08	7.00	0.43	-
1/21 - 2/6/76	Snow	10.95	3.98	0.31	4.95	0.93	-
2/6 - 3/5/76	Snow	14.96	3.92	0.18	6.20	1.16	-
3/5 - 3/27/76**	Snow/Rain	8.83	3.98	0.10	4.15	0.72	-
3/27 - 4/15/76	Rain	6.15	4.55	0.076	2.90	0.42	-
4/15 - 5/24/76	Rain	18.42	5.07	0.12	5.0	0.04	<0.2
5/24 - 6/19/76	Rain	6.10	3.79	0.22	8.65	0.66	1.24
6/19 - 6/30/76	Rain	8.76	4.24	0.11	2.90	0.30	<0.2
6/30 - 7/18/76	Rain	7.57	4.04	0.13	2.75	0.17	<0.2
7/18 - 8/25/76	Rain	12.7	3.93	0.27	10.7	0.61	2.40
8/25 - 9/11/76	Rain	5.66	4.16	0.10	3.0	0.30	0.80
9/11 - 9/25/76***	Rain	4.90	3.80	0.12	4.15	0.30	2.40
9/25 - 10/9/76	Rain	10.67	6.13	0.17	7.0	0.34	6.40
10/9/76****	Rain	1.6	4.51	0.10	1.3	0.03	<0.2

* This snow sample was collected with a shovel from side of road. Snow bucket was not in place until 1/21/76.

** Mixture of snow and rain collected in snow bucket.

*** Rain collector was vandalized during this period. Chemistry represents sample collected during rainfall of 0.4 cm on 9/25/76.

**** This sample represents rain collected during storm on 10/9/76 only.

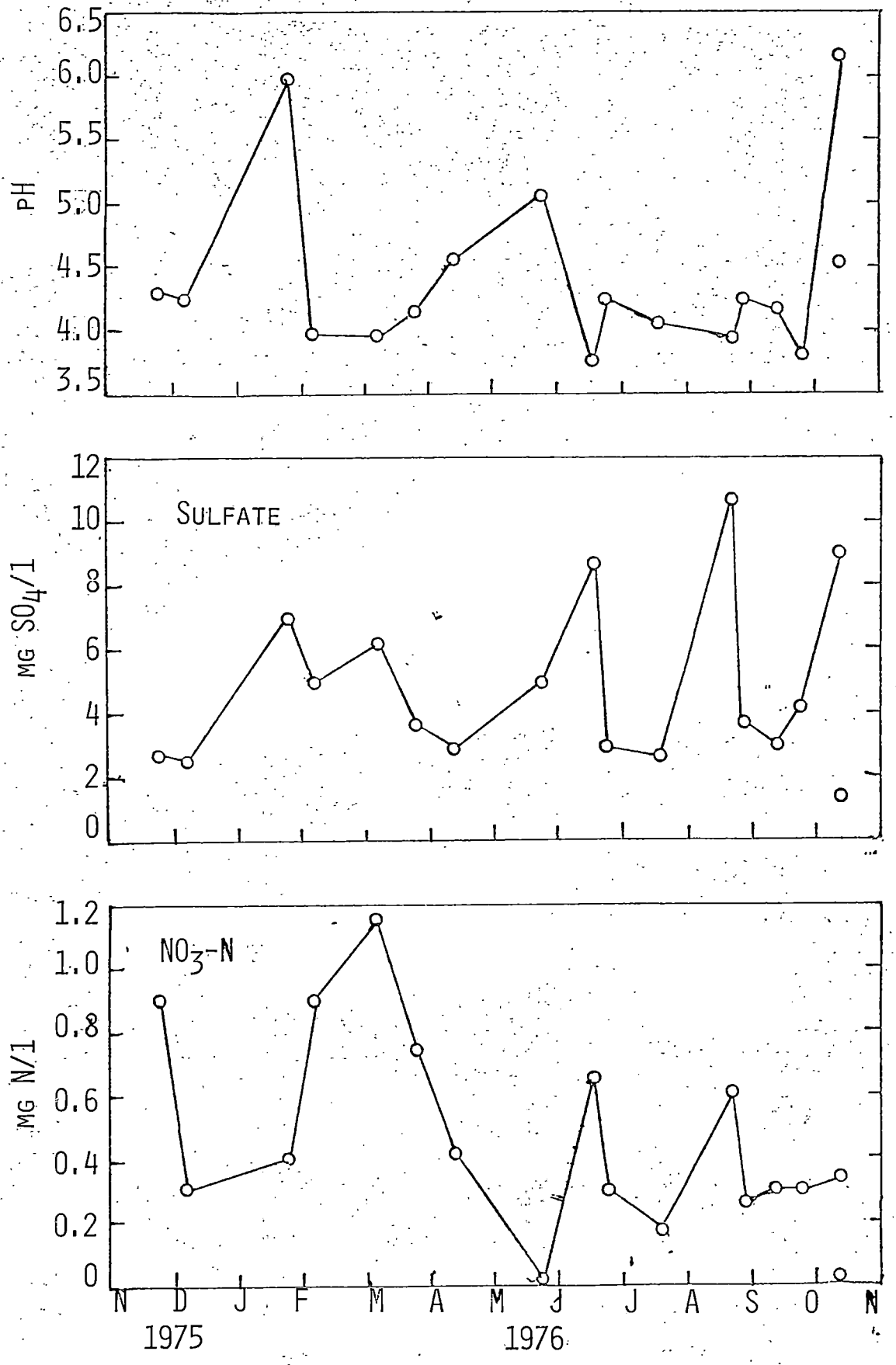


FIGURE 3. pH, SULFATE, AND NITRATE CONCENTRATION IN BULK PRECIPITATION ON PRINCE BROOK WATERSHED DURING 1975-76.

estimated precipitation amount on the Prince Brook watershed during the study period was 141 cm (almost 56 inches) and this led to a deposition of 980 eq/ha (397 eq/acre) of free hydrogen ions. Between 1969 and 1974 the annual H^+ deposition on Hubbard Brook varied from about 900-1120 eq/ha (Likens (1976)). It appears that the higher quantity of precipitation on Tug Hill makes up for the slightly higher pH values.

It is difficult to note seasonal variations in rainfall acidity based on only one year of data. This task is further complicated by the fact that the values measured represented both wet and dry fallout. The presence of dry fallout probably explains the lack of correlation between pH and sulfate and nitrate concentrations in our samples (Figure 3), especially during the dryer summer months. There are, however, some observations which can be made from the graphs in Figure 3. Aside from the two unusually high values near pH 6, the pH in the fallout seems relatively constant at around 4.0 with the exception of higher values in the spring. The higher pH values in April and May might be the result of dilution by closely spaced events, the second of which washes out very little sulfuric or nitric acid. A recent study at Lake George demonstrated the sulfuric acid washout theory (Stensland (1976)). Using a sequential sampler the sulfate concentration in rainfall was found to decrease from 9.33 mg SO_4/l to 0.60 mg SO_4/l over a three hour period, while pH increased from 3.1 to 5.2 during the same interval.

The two unusually high pH readings can also be explained. The first snow sample (1/21/76) was not really a composite sample but was collected with a snow shovel from the side of a dirt road.

Two factors could have contributed to the 5.99 pH reading. First, road dirt could have neutralized the sample. Second, acid is known to migrate down through a snow pack thus concentrating at the deeper levels (Oden (1976)). The second high pH value (9/25-10/9/76) is undoubtedly the result of neutralization by large quantities of dry fallout. Note the unusually high calcium concentration (6.4 mg/l) in this sample. Also, a wet precipitation sample collected during an individual event on 10/9/76 (disconnected points on Figure 3) had a much lower pH and calcium concentration than the composite.

With regard to sulfate concentration in the precipitation there appears to be little noticeable seasonal variation with some high values in the summer, perhaps due to SO_4 in dry fallout. The nitrate concentrations do tend to be somewhat higher during the winter months. This phenomenon was also noted by Niles and Babcock (1975) and may be the result of increased usage of heating oil and gas during the colder months.

Salmon River Stream Survey. One of the objectives of this study was to obtain a reliable baseline on the water quality of the streams of the Salmon River system with regard to the acid rain problem. The results of this reasonably extensive survey are presented in Table II. In general it appears that these streams have not yet suffered extensive damage from acid deposition. The pH rarely fell below 6.5 for grab samples at any of the sites and alkalinity was generally between 0.2-0.5 meq/l.

The best way to visualize the relatively good water quality of the Salmon River at this time is to compare it to a system that has apparently been affected by acid rain - the Hubbard Brook

TABLE II

Average Concentration for Selected Parameters in the Eight Sampling Sites on Salmon River, Nov. 1975-Oct. 1976

Site	1				2				3				4			
Time Period	Nov.-Feb.	Mar.-May	June-Oct.	Year Ave.	Nov.-Feb.	Mar.-May	June-Oct.	Year Ave.	Nov.-Feb.	Mar.-May	June-Oct.	Year Ave.	Nov.-Feb.	Mar.-May	June-Oct.	Year Ave.
pH	6.33	6.75	6.77	6.65	6.79	7.36	7.13	7.00	6.73	7.14	6.94	6.92	7.08	6.98	7.33	7.12
Alkalinity (meq/l)	0.2	0.17	0.27	0.225	0.37	0.23	0.36	0.349	0.39	0.25	0.45	0.367	0.43	0.29	0.54	0.429
Acidity (meq/l)	0.09	0.06	0.07	0.07	0.05	0.04	0.04	0.043	0.05	0.03	0.06	0.047	0.05	0.03	0.05	0.043
$SO_4^=$ (mg/l as SO_4)	8.4	5.56	5.52	6.01	8.57	7.0	5.73	6.82	7.94	5.49	5.98	6.34	7.20	5.89	5.28	5.96
NO_3-N (mg/l as N)	0.57	0.59	0.28	0.43	0.42	0.38	0.31	0.35	0.54	0.62	0.33	0.48	0.39	0.65	0.33	0.45
Ca^{++} (mg/l as Ca^{++})	2.70	4.70	6.93	5.48	3.07	6.00	7.68	5.96	4.65	5.88	8.93	6.77	3.93	7.10	10.16	7.58
otal Hardness (meq/l)	0.278	0.430	0.573	0.476	0.290	0.420	0.605	0.479	0.395	0.464	0.617	0.507	0.357	0.550	0.688	0.559
Site	5				6*				7*				8*			
pH	7.18	7.18	6.97	7.09	7.3	-	6.25	6.51	7.57	7.25	7.36	7.37	6.45	-	6.66	6.54
Alkalinity (meq/l)	0.43	0.30	0.54	0.423	0.50	-	0.33	0.42	0.30	0.26	0.50	0.35	0.84	-	0.42	0.63
Acidity (meq/l	0.07	0.03	0.06	0.049	0.07	-	0.07	0.07	0.06	0.03	0.06	0.05	0.07	-	0.13	0.10
$SO_4^=$ (mg/l as SO_4)	7.51	6.13	5.38	6.26	6.8	-	3.26	5.03	5.38	6.0	3.45	4.94	7.0	-	3.0	5.0
NO_3-N (mg/l as N)	0.51	0.79	0.33	0.54	0.14	-	0.17	0.16	0.16	0.19	0.15	0.17	0.17	-	0.14	0.16
Ca^{++} (mg/l as Ca)	5.00	6.40	10.16	7.34	2.80	-	6.8	4.8	3.20	6.0	7.6	5.60	3.40	-	8.40	7.4
otal Hardness (meq/l)	0.448	0.492	0.728	0.564	0.290	-	0.580	0.43	0.270	0.460	0.520	0.417	0.250	-	0.680	0.465

*Values represent only one sample collection for each season

watershed, New Hampshire. Table III is a comparison of the range of yearly average concentrations for selected parameters in sites 1-5 with data reported for the Hubbard Brook area. Several interesting comparisons can be made, generally indicating that the Salmon River is in better condition with respect to acid inputs. The pH, alkalinity and calcium concentrations for Tug Hill are all significantly higher than for the Hubbard Brook streams. Since the acid inputs are similar, one would suspect that the terrestrial system on Tug Hill is providing more neutralization of the atmospheric inputs than the Hubbard Brook system. Kramer (1976), using equilibrium calculations and empirical comparisons, proposed two methods for classifying a water body as to its stability relative to acid rain inputs. The first method is based on the rock/soil type in the given watershed. Generally, if a watershed is composed of calcerous rock and soil, the water body will have a pH $\geq$ 8 and alkalinity $\geq$ 2 meq/l and will have an essentially infinite H^+ ion assimilation capacity. The next category is for fine-grained non-calcarous soil and sediments with pH between 6 and 7 and alkalinity from 0.2 meq/l to 1 meq/l. Systems of this type can be altered by acid precipitation; however, the length of time or the amount of acid input required is difficult to estimate. Based on the stream chemistry the Salmon River seems to fall into this category. With regard to the sediment/soil type the Tug Hill study area seems to be composed mainly of sandstone and shale; however, there is an appreciable amount of calcium in the streams indicating that perhaps the lower sediment horizons may be calcerous. A detailed mineralogy and groundwater study in the area would be necessary to verify this postulate. Finally, the Hubbard Brook area seems to

Table III

Comparison of Selected Parameters Between Salmon River and Hubbard Brook

	Tug Hill[a]	Hubbard Brook[b]
pH	6.65-7.12	4.2-6.2[c]
Alkalinity (meq/l)	0.23-0.43	0.002-0.03[d]
$SO_4^=$ (mg SO_4/l)	6.0-6.8	5.9-6.4
NO_3^--N (mg N/l)	0.43-0.54	0.16-0.29
Ca^{++} (mg Ca/l)	5.5-7.5	1.27-1.82

[a] Range of average concentrations in sites 1-5 for 1975-76

[b] From Fisher, et al. (1968) and Likens, et al. (1970). Range of yearly weighted average concentrations in stream water from watersheds 4 and 6 for 1964-68

[c] Range of individual readings

[d] meq/l of HCO_3^-

fall into the final category, which is a system with non-calcerous rock outcrop that is definitely altered by acid rain ($4<pH<7$; $Alk \leq 0.1$ meq/l).

Another useful indicator of a system's pH stability put forth by Kramer (1976) is the calcite saturation index (CSI). The CSI is defined by:

$$CSI = p(Ca^{++}) + p(Alk) - pH + pK$$

where $p(x) = -\log(x)$, $pK = +2$, (Ca^{++}) = mole/l, (Alk) = eq/l and (H^{+}) = eq/l. It indicates the degree of saturation of a water body with respect to $CaCO_3$ and thus can be a measure of the water's ability to withstand acid inputs. If CSI = 0 the water body is saturated with respect to $CaCO_3$. If the water is supersaturated, CSI < 0, and if undersaturated, CSI > 0. A water body with CSI $\leq$ 3 should be generally stable to acid precipitation while systems with CSI from 4-6 are unstable systems. The CSI for sites 1 and 3 on the Prince Brook (using yearly averages) are 2.86 and 2.28, respectively. Based on the Hubbard Brook data in Table III, the CSI's for this system would range from about 4.6-8. By both criteria the Salmon River is in much better condition than Hubbard Brook, but may be somewhat susceptible to acid rain inputs.

Although the data are scarce, there is some basis for a long-term comparison of pH and alkalinity in the Salmon River system. This can be accomplished by comparing our data (although not exactly the same sites) with that obtained during the 1939 Biological Survey by the New York State Conservation Department (1940). They found in June, 1939 that pH in various sites on the river from the East Branch near Osceola to the mouth ranged from

7.0-8.6, while methyl-orange alkalinity for the same sample set was between 0.5-0.7 meq/l. Our summer average pH values for each site ranged from 6.25-7.36 and the alkalinities for the same time period varied from 0.27 meq/l to 0.54 meq/l. If comparison of these data is valid there has been some decrease, although minor, in these important parameters over the past 40 years. Needless to say the prior data base is very meager and any comparisons are tenuous at best; however, this comparison does point to a need for maintaining some kind of surveillance of this system to note future changes.

Prince Brook Water Quality. The more extensive study of sites 1-3 on the Prince Brook brought out some interesting and important observations on the effects of acid precipitation on lotic systems. The data for sites 1-3 are shown graphically as a function of time in Figures 4 and 5. Based on this intermittent sampling schedule there does not appear to be any noticeable seasonal variation in pH for the Prince Brook. This is consistent with the 9 years of monthly averages that Hornbeck, et al. (1976) reported for Hubbard Brook. There does, however, appear to be a detectable pH difference between sites 1 and 3 on the Prince Brook during the spring high flow period. (Site 2 was inaccessible from December until May.) One would expect the smaller upstream stations to show a larger response to acid inputs than downstream sites, and the large fraction of streamflow derived from snowmelt (rather than deep groundwater seepage) at this time explains the increased acid inputs.

While the pH in Prince Brook did not respond a great deal to the heavy spring snowmelt runoff (March-May), there was a

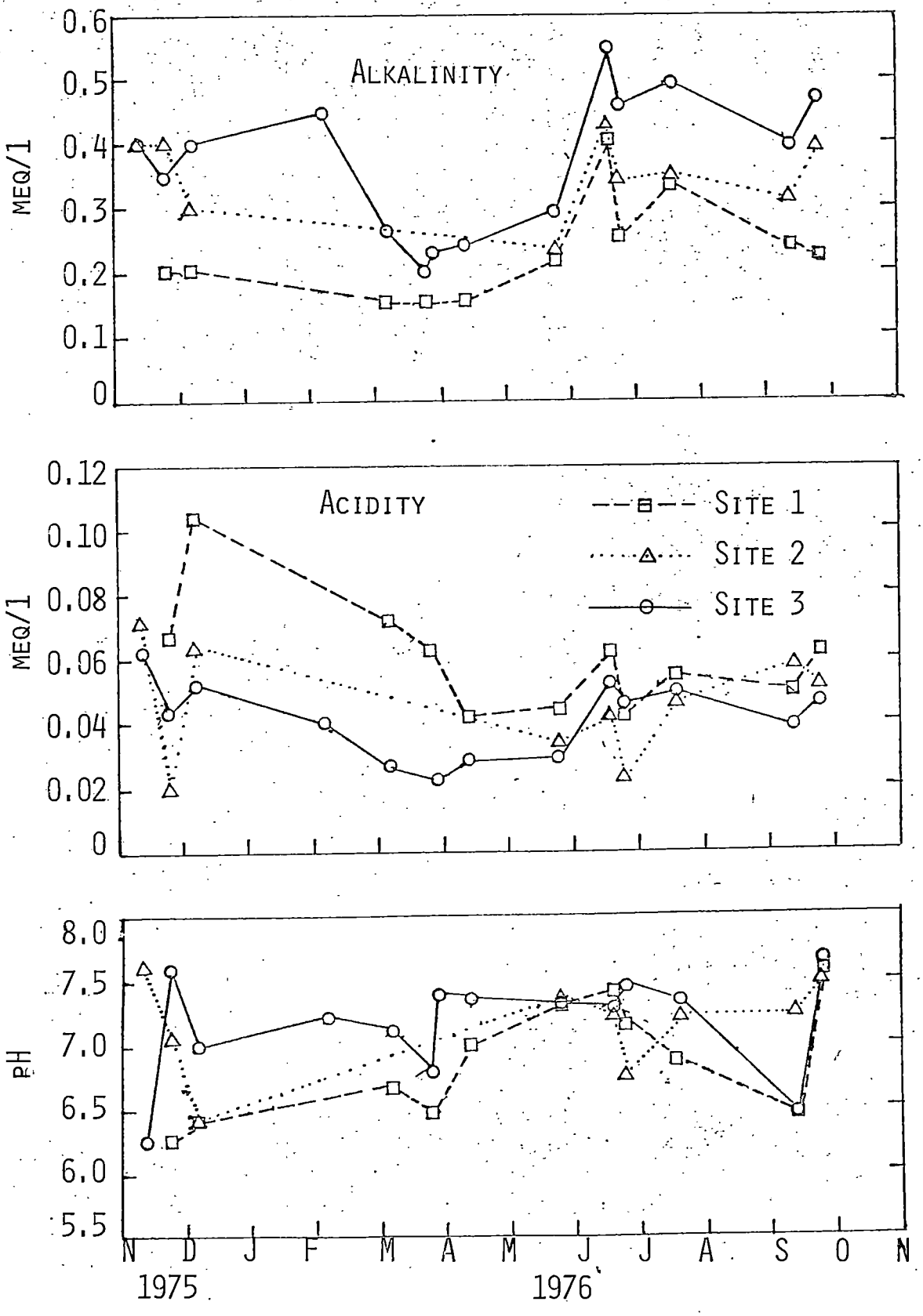


FIGURE 4. ALKALINITY, ACIDITY AND pH AT THREE SITES IN PRINCE BROOK DURING 1975-76 SAMPLING PERIOD.

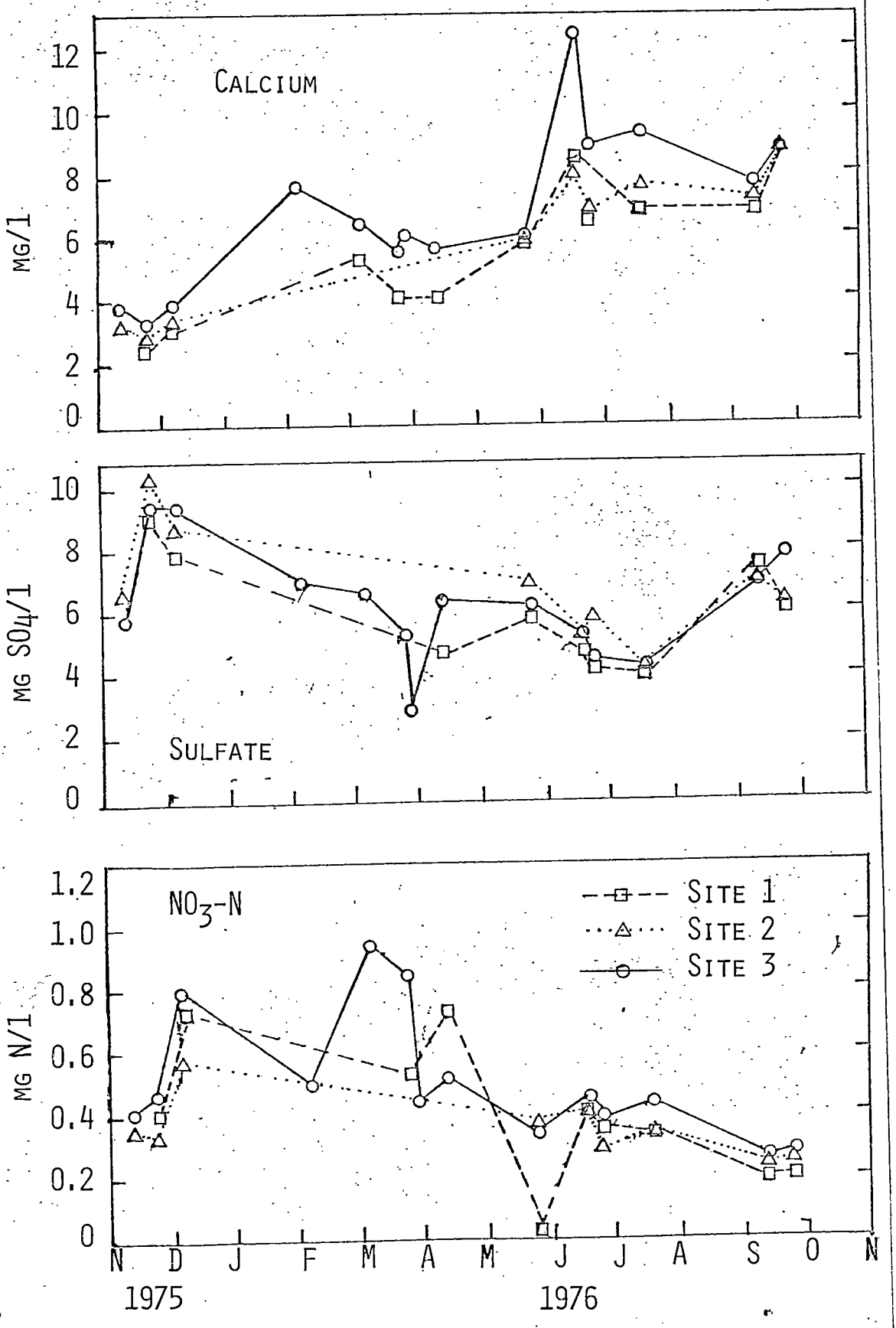


FIGURE 5. CALCIUM, SULFATE AND NITRATE CONCENTRATION AT THREE SITES IN PRINCE BROOK DURING 1975-76 SAMPLING PERIOD.

noticeable decrease in alkalinity at site 3 during this period. The large response of alkalinity in comparison to pH is not surprising in that the carbonate system has a relatively high buffer intensity in the pH range of 6-7. One would, therefore, not expect to see a large pH change per unit decrease in alkalinity. The more sensitive alkalinity fluctuation indicates that the stream is being "diluted" by lower alkalinity (higher acid) runoff during the spring, possibly due to a higher fraction of overland runoff from frozen ground or to the high contributions from acid snow melt. At any rate the stream system seems to be most stressed with regard to pH during the spring and should perhaps be most closely monitored at this time.

The seasonal variation of the base-associated cation calcium (Figure 5) confirms the findings for alkalinity. The stream calcium concentrations are lower in the winter and spring than in the low flow summer period when one would expect a larger relative contribution to the streamflow from deeper groundwater. Also, like alkalinity, the calcium concentration at site 3 appears to be consistently higher than that at site 1.

With regard to the acid anions sulfate did not exhibit a great deal of seasonal or site variation. As noticed by Fisher, et al. (1968) at Hubbard Brook, the Prince Brook exhibited a slight increase in sulfate concentration in the fall and a slight decrease in the spring. While sulfate is not completely conservative with respect to passage through land-water ecosystems, it is probably more conservative than nitrate and would, therefore, be a better tracer of atmospheric impact on stream water quality. The fall sulfate peak in the stream may, in fact, be a lag, damped

response to the high summer sulfate fallout.

Nitrate, on the other hand, is required in relatively large amounts by land and water vegetation, indicated by the lower concentration in the stream during the growing season. As noted earlier the Prince Brook NO_3-N levels are not only higher than in Hubbard Brook but they do not approach zero during the summer as in Hubbard Brook. This probably indicates that the soil is richer in the Prince Brook watershed. The amount of nitrate lost from the watershed annually (as compared to the inputs) should be carefully watched as this may indicate a change in vegetation structure and productivity.

Prince Brook Mineral Budgets. While these initial mineral budgets for the Prince Brook are admittedly crude, they are very useful in evaluating the condition of the watershed. The results of the input-output mass balance for sulfate, nitrate and calcium are presented in Table IV. The virtual balance between input sulfate and stream export suggests a simple sulfate cycle where this anion passes through the watershed with comparatively little net uptake by or contribution from the terrestrial portions. This is not to say that sulfur does not interact with the soil and vegetation; however, it appears to be in a state of dynamic equilibrium. This particular mineral budget should be carefully watched, since as Reuss (1975) points out if the loading is greater than the capacity of the ecosystem to utilize or store sulfur, than leaching could take place and the bases lost along with the sulfate will leave a more acid soil.

As expected and as found at Hubbard Brook (Fisher, et al. (1968)), there is a net gain of nitrate in the Prince Brook

TABLE IV

Mineral Budgets for Prince Brook
During Period of 6/19/76-10/9/76

Constituent	Precipitation Input (kg/ha)	Stream Discharge (kg/ha)	Net gain (+) or loss (-) in Watershed (kg/ha)
Sulfate	29.4	29.5	-0.1
Nitrate-N	1.85	1.61	0.24
Calcium	11.5	41.8	-30.3

	Precipitation Input (cm)	Stream Discharge* (cm)
Water	50.3	48.8

* Obtain by dividing total discharge (cm^3) by Watershed area (cm^2).

watershed. This difference in nitrate input versus stream discharge is generally considered to be the result of uptake and storage of nitrogen by the forest flora. The loss of nitrate from the ecosystem by denitrification is another possible occurrence. If the vegetation productivity in the Prince Brook watershed is being affected by acid precipitation, then a good indicator might be a decrease in the net gain of nitrate by the ecosystem.

Unlike sulfate and nitrate, the material balance on calcium for the watershed indicated a large loss from the system. This same trend was observed at Hubbard Brook (Likens, et al. (1970)) with especially high calcium losses observed in the deforested watershed no. 2. The excess stream calcium is obviously being contributed by the terrestrial portion of the ecosystem. This mobilization of calcium can occur either by 1) cation exchange of active Ca^{++} in the soil matrix, 2) chemical weathering of minerals, 3) decomposition of organic matter in and on the soil, and 4) erosion of calcium-bearing soil and subsequent dissolution in the streams. It has been proposed and demonstrated (Overrein (1972)) that increasingly acid precipitation will cause increased leaching (due to the first two mechanisms above) of calcium and other metallic cations from the soil, thus decreasing its fertility. While this may be occurring at Prince Brook, a much more detailed study must be done to partition the contribution of the various mechanisms listed above to the calcium loss.

The calcium and other hardness ion loss from the soil is somewhat indicative of the acidification of the soil. These mobilized hardness ions in the groundwater appear to be associated with either bicarbonate, sulfate or nitrate anions; and, the near

balance between the year's average total hardness concentration (0.507 meq/l) at site 3 and the sum of the alkalinity, sulfate and nitrate concentrations (0.533 meq/l) at the same site supports this premise. The soil therefore appears to be neutralizing the acid precipitation input through the dissolution of carbonates and the exchange of hardness ions for hydrogen ions. The process of neutralizing the acid inputs leaves a more acidic soil, and the extent and rate of damage depends on the amount of acid precipitation that penetrates the soil, the time span of penetration, and the neutralizing capacity of the soil.

Prince Brook Response to Transient Conditions. Unlike lakes, streams tend to exhibit a much more pronounced response to individual precipitation events. The magnitude of the response depends on the intensity and duration of the event and the size and characteristics of the watershed. It was felt that transient drops in pH of the Prince Brook may occur during or shortly after very intense rainfalls. At this time much of the acid precipitation input might reach the stream via overland runoff and, thus, not be as neutralized as subsurface flow. The concern over this phenomenon is that the acid precipitation impact on the biota of the stream may very well be the cumulative effect of several short-term dips in pH rather than a chronic, slightly depressed pH level.

In order to test the above hypothesis an effort was made to be on site during several events in order to monitor the short-term chemical fluctuations of the Prince Brook. Also, a portable, recording pH meter was installed at site 3 to continuously monitor this parameter while no one was on site. Although a good deal of

difficulty was encountered in keeping the instrument functional, we did obtain one pH - time profile during a short, intense storm. The time variation of pH at site 3 for this event is shown in Figure 6. A significant drop of two pH units, although short-lived, was recorded.

On-site sample collection was performed for two other less intense events. On 9/11/76 a pH drop from 7.4 to 6.46 was observed at site 3 and on 10/9 a decrease from 6.75 to 6.2 was measured at the same site. It appears that only occasionally does a severe pH dip occur in Prince Brook. Further study is required to determine if these occurrences warrant concern.

Macroinvertebrate Community. The number and diversity of aquatic insects observed in the Salmon River from the end of May through October were used as biological indicators of the general water quality of the stream. It was felt that attempting to correlate short-term insect succession to event-produced water quality changes was not only beyond the scope of our resources but would probably not be fruitful because the pH changes were so subtle. We, therefore, collected quantitative samples periodically during the main growing season with the intent of comparing species diversity with generally accepted values for indication of water quality. Also, of prime interest was to compare the species found with literature values for their pH tolerance. In this way we can perhaps gain some insights into the current stream pH effect on these organisms. Finally, and probably most significantly, there will be a list of species found during the 1976 season. The future disappearance of known low pH intolerant species could indicate a deterioration of the stream water quality with

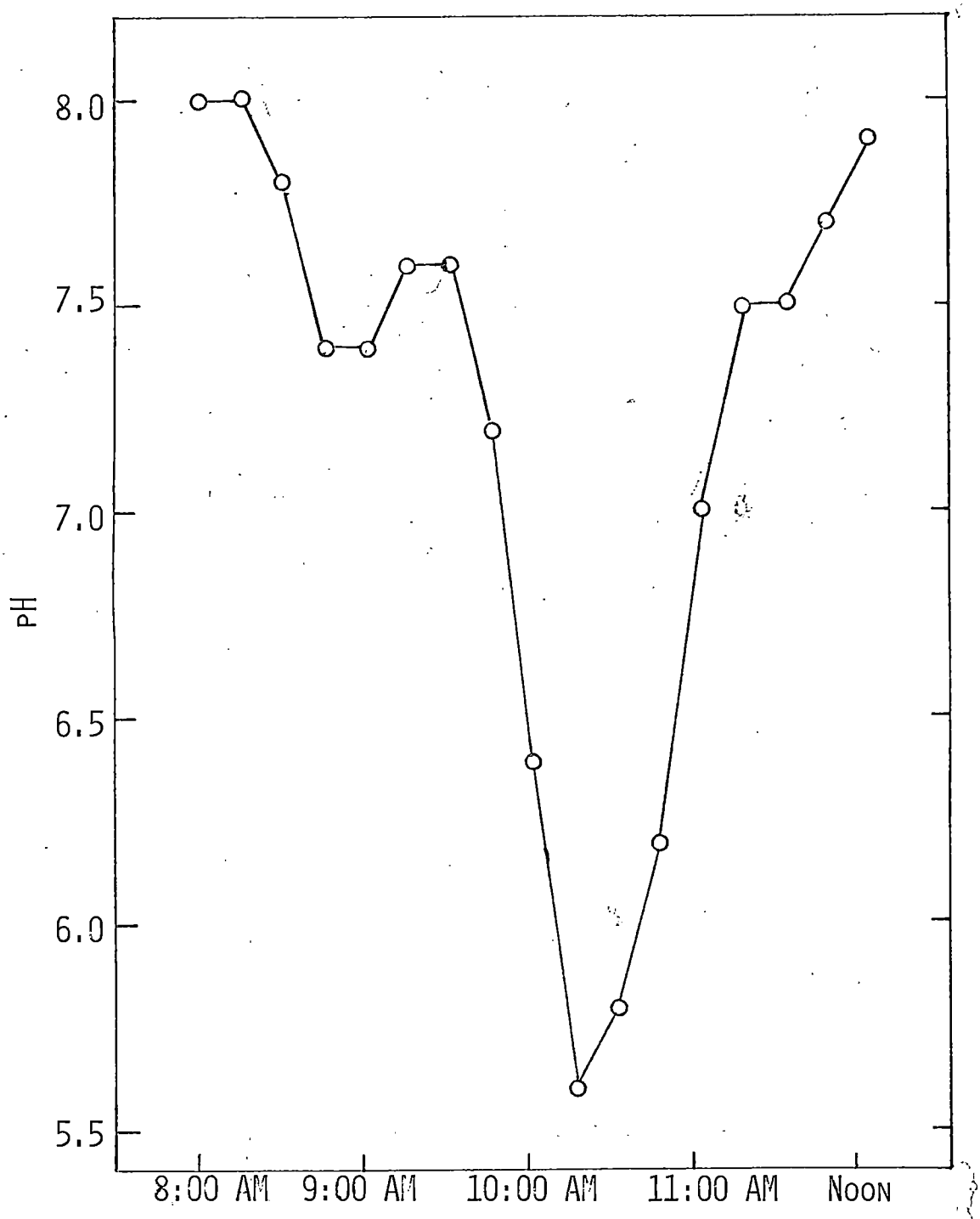


FIGURE 6. PLOT OF CONTINUOUSLY RECORDED pH AT SITE 3 IN PRINCE BROOK DURING STORM ON 7/21/76.

respect to that parameter.

With respect to species diversity, unpolluted streams are reported to have a Shannon-Weaver Index greater than 3. On the other hand, heavily polluted waters would consistently have index values less than about 1.5 (Cook (1976); Wilhm (1970); Simpson, et al. (1974); Wilhm and Dorris (1968)). A complete record of each sample collected from the Salmon River System and the calculated species diversity for each sample is presented in Appendix A. The majority of diversity indices were greater than 3 and virtually all indices were greater than 2.5. The arithmetic mean of the site 3 samples (most heavily studied site) for the entire study period was 2.88 ± 0.46. These values seem to indicate a relatively unpolluted stream with a diverse and healthy invertebrate community.

In comparing the insects found in the Salmon River with pH tolerances reported in the literature, data from the following laboratory studies was used: Bell and Nebeker (1969); Bell (1971); and Gaufin (1973). Of the species tested in these three studies, in general, Ephemeroptera (mayflies) ($3.32 < TL_m^{96} < 6.35$) and Plecoptera (stoneflies) ($3.25 < TL_m^{96} < 5.33$) proved to be the most sensitive to low pH while Trichoptera (Caddis flies) ($1.5 < TL_m^{96} < 3.34$) appeared to be the most tolerant. We found a healthy representation from all of these orders and especially high numbers of mayflies. This alone seems to support the conclusion that the Salmon River community is not being severly stressed by the current pH regime. Also, the fact that we found both 1st and 5th instars of Megaloptera (Dobson flies) and Odonata (dragon flies) suggests that there has been no long term effect or serious acid shocks in the past 3 to 5 years, since organisms from these

orders have 3 to 5 year life cycles.

Since we were unable to identify many of our organisms to the species level, the best that could be done was to compare individual pH tolerances at the genus level. Table VI presents the results of available laboratory low pH tolerance studies for organisms of the same genus as we identified in the Salmon River. If different species of the same genus are comparable, then the Salmon River supports aquatic insects with a TL_m^{96} range of 1.5-6.18. The only test species completely identified in our study was Ephemerella doddsi, which had a TL_m^{96} of 5.13. As is obvious from Table VI, its long term pH tolerance threshold would no doubt be somewhat higher, making it a sensitive test organism for the Salmon River.

Based on the comparisons between Appendix A and Table VI, there appears to be a relatively large number of low pH intolerant taxa in the Salmon River, especially in the mayfly group. The future persistance of these organisms in the Salmon River would be indicative of the watershed's ability to neutralize the effects of acid rain inputs.

TABLE VI

Effect of Laboratory Exposure to low pH on the Survival of Selected Aquatic Insects

Test Species	Mean pH Value*		
	TL_m 96 hour	TL_m 30 day	TL_m 90 day
EPHEMEROPTERA			
Ephemerella doddsi (Needham)[a]	5.13	-	-
Ephemerella grandis (Eaton)[a]	-	5.8 (48day)	-
Ephemerella subuaria (McDunnough)[b]	4.65	5.38	-
Stenonema rubrum (McDunnough)[b]	3.32	-	-
Leptophlebia sp.[a]	5.21	-	-
Heptagenia sp.[a]	6.18	-	-
PLECOPTERA			
Acroneuria pacifica (Banks)[a]			5.8
Acroneuria lycorias (Newman)[b]	3.32	3.85	-
TRICHOPTERA			
Brachycentrus Occidentalis (Banks)[a]	-	-	4.3
Hydropsyche sp.[a]	3.34	-	-
Brachycentrus americanus (Banks)[b]	1.5	2.45	-
Hydropsyche betteni (Ross)[b]	3.15	3.38	-
DIPTERA			
Similium vittatum (Zetterstadt)[a]	3.64	-	-

*TL_m indicates the pH value at which 50% of the test species died after the given exposure time

[a]species tested by Gaufin (1973)

[b]species tested by Bell and Nebeker (1969) and Bell (1970)

IV. Conclusions

1. The precipitation on Tug Hill appears to be at least as acidic as the rest of the northeastern United States and in many cases the annual hydrogen ion loading will be higher because of the quantity of precipitation in this area.
2. Based on this study, the chemical and biological water quality of the streams in the Salmon River watershed is quite good, and is capable of maintaining a diverse and productive macro-invertebrate community. The system does not appear to have been severely affected by acid rain to date and appears to be in no immediate danger; however, based on alkalinity data and mineral budgets the system may experience long term deterioration due to continued high acid inputs.
3. Some short-term, event-associated decreases in stream pH were observed, but it is unlikely that these occurrences have cumulatively affected the biota. Probably the most severe environmental stresses on the Salmon River system take place during the early spring high runoff period.

V. Recommendations

1. A permanent precipitation monitoring station should be established in the central core of Tug Hill to continuously determine amount and chemistry of precipitation. An attempt should be made to use a collection device which can separate wet and dry fallout.
2. Continued monitoring and study of the Prince Brook watershed (as a model stream for Tug Hill) is recommended in order to detect any deterioration in water quality or aquatic insect community. A gaging station should be established on the Prince Brook so that accurate mineral budgets can be determined.
3. The key to predicting the long term fate of the Salmon River with respect to acid rain inputs is to understand and evaluate the susceptibility of the soil/vegetation part of the watershed and to evaluate its capacity to neutralize acid inputs. A careful survey of the soil/rock chemistry of the Prince Brook watershed will aid in this evaluation. Laboratory studies (perhaps column studies) should be performed on these soils to estimate the effect of acid input on their chemical properties and to estimate their ability to reduce acid loads to the stream. The results of these studies could serve as a base-line for noting future deterioration of the soils in this watershed and for comparing these soils with other areas in the state.
4. Laboratory studies should be conducted on aquatic insects isolated from Prince Brook to compare their acid tolerance with that of identical species isolated from streams not

receiving acid inputs. This study will indicate whether the Prince Brook insects have become more acclimated to low pH conditions and will perhaps be an early warning of a chronically stressed community.

5. New York State needs to establish a study site for experimental research on the effect of acid precipitation on lotic systems. This experimental watershed would be very useful in obtaining the field data necessary to develop predictive mathematical models of the response of stream watersheds to acid rain. The Salmon River system would be an ideal site for such an experimental station.
6. Because the quality of the Salmon River system with regard to acid inputs is good at this time, no immediate restorative measures are recommended. It is strongly suggested, however, that the people of Tug Hill do everything in their power to prevent local disturbance to these precious ecosystems and continue to work to reduce outside influences like the acid precipitation phenomenon.

APPENDIX A

Macroinvertebrates (org./ft^2) in Samples Collected from Various Sites in the Salmon River System

DATE	5/24/76					6/19/76			
SITE	1	3	5	6	7	1	3	4	5
EPHEMEROPTERA									
Ephemeridea									
Ephemera sp. (Linnaeus)			1		4		10	10	12
Potamanthus sp. (Pictet)									
Heptageniidae									
Cinygmula sp. (McDunnough)							1		
Heptagenia sp. (Walsh)			3			3	1	2	14
Iron sp. (Traver)		5						2	
Stenonema sp. (Traver)	5	1					3		3
Baetidae									
Amelutus sp. (Eaton)		1							
Baetis sp. (Leach)	1	4	38				10	1	12
Baetodes sp. (Needham & Murphy)									
Ephemerella Bicolor sp.								1	5
Ephemerella doddsi (Needham)	4	3		1				1	4
Ephemerella Walkeria sp.						3			5
Habrophelebia sp. (Ulmer)	1								
Leptohyphes sp. (Eaton)							1	12	6
Leptophlebia sp. (Westwood)									
PLECOPTERA									
Leuctrinae									
Leuctra sp. (Stephens)									
Chloroperlidae									
Alloperla sp. (Banks)									
Hastaperla sp. (Ricker)	1	1	14		20		7	2	3
Acroneurinae									
Acroneuria ruralis (Pictet)		2	1					2	
Atoperla sp. (Banks)									
Taeniopteryginae									
Brachyptera sp. (Newport)									
Perlidae									
Neophasgano capitata (Lestage)							1	1	2
Paragentina sp. (Klapalek)								2	
Perlesta placida									
Peltoperlidae									
Peltoperla sp.									
ODONATA									
Gomphidae									
Hagenius sp. (Selys)									
Lanthus sp. (Needham)	1					1		1	
Cordulegastridae									
Cordulegaster sp. (Leach)	1								
MEGALOPTERA									
Sialidae									
Sialis sp.								1	
Corydalidae									
Chaulodes sp.			1				1	1	

DATE	5/24/76					6/19/76			
SITE	1	3	5	6	7	1	3	4	5
TRICHOPTERA									
Rhyacophilidae									
Glossosoma sp. (Curtis)								3	
Rhyacophila sp. (Pictet)									
Philopotamidae									
Dolophilodes sp. (Ulmer)			2				9	33	
Hydroptilidae									
Ochrotrichia sp. (Mosely)									
Brachycentridae									
Brachycentrus (sp. (Curtis)	1		10				1	2	
Micrasema sp. (McLachlan)								1	
Hydropsychidae									
Diplectrona sp. (Westwood)	2								
Hydropsyche sp. (Pictet)		5	12	1			1	10	11
Pycnopsyche sp.	4					3			
COLEOPTERA									
Haliplidae									
Haliplus sp. (Latreille)			2			7	3	1	
Psephenidae									
Ectoparia sp. (LeConte)									
Eubrianax sp. (Kiesenwetter)			1		11				
DIPTERA									
Tipulidae									
Antocha sp.			7			1	2		
Hexatoma sp.			3					2	
Heleidae									
Palpomyia sp. (Meigen)			1						
Tendipedidae (Chironomidae)									
Chironomus sp. (Meigen)	1		15			2	3	7	4
Pentaneura sp. (Philippi)							1	1	1
Simuliidae									
Simulium sp. (Latreille)								1	
Stratiomyinae									
Eulalia sp. (Meigen)									
Blepharoceridae									
Blepharocera sp.									
HYDRACARNIA									
Mites									
Unidentifiable		6							
TOTAL	22	28	101	2	25	20	55	100	82
DIVERSITY	3.11	2.97	3.15	2.0	.86	2.53	3.51	3.52	3.25

DATE	6/30/76				7/18/76							
SITE	1	3	4	5	1A	1B	1C	4A	4B	6A	6B	7
EPHEMEROPTERA												
Ephemeridea												
Ephemera sp. (Linnaeus)					1							
Potamanthus sp. (Pictet)	2	14	37	75			1		8	1	8	3
Heptageniidae												
Cinygmula sp. (McDunnough)												
Heptagenia sp. (Walsh)	13	7	3	5		1	4		7	1	13	8
Iron sp. (Traver)		6	10	2					1		2	
Stenonema sp. (Traver)		1					1					
Baetidae												
Amelutus sp. (Eaton)	2											
Baetis sp. (Leach)		31	42	7			2		16	1	27	11
Baetodes sp. (Needham & Murphy)												
Ephemerella Bicolor sp.	1	2		4						1		6
Ephemerella doddsi (Needham)		7	7	3			2		3		1	1
Ephemerella Walkeria sp.	2		8								18	
Habrophelebia sp. (Ulmer)			1								3	
Leptohyphes sp. (Eaton)	2	1	7	3					1		3	
Leptophlebia sp. (Westwood)			2									
PLECOPTERA												
Leuctrinae												
Leuctra sp. (Stephens)						2						
Chloroperlidae												
Alloperla sp. (Banks)		7							4			1
Hastaperla sp. (Ricker)	7	6	21	3	2		3		5	2	4	2
Acroneurinae												
Acroneuria ruralis (Pictet)		1	5				4		2		1	
Atoperla sp. (Banks)	1											
Taeniopteryginae												
Brachyptera sp. (Newport)												
Perlidae												
Neophasgano capitata (Lestage)		2	1	2					1		1	3
Paragentina sp. (Klapalek)	2	1							1			
Perlesta placida			2						1		1	
Peltoperlidae												
Peltoperla sp.			1						1			
ODONATA												
Gomphidae												
Hagenius sp. (Selys)	1											
Lanthus sp. (Needham)	8				2	4						
Cordulegastridae												
Cordulegaster sp. (Leach)	2					2						
MEGALOPTERA												
Sialidae												
Sialis sp.												1
Corydalidae												
Chaulodes sp.								1				1

DATE	6/30/76				7/18/76							
SITE	1	3	4	5	1A	1B	1C	4A	4B	6A	6B	7
TRICHOPTERA												
Rhyacophilidae												
Glossosoma sp. (Curtis)									2			
Rhyacophila sp. (Pictet)			5									
Philopotamidae												
Dolophilodes sp. (Ulmer)		29	21	12			2		1		5	
Hydroptilidae												
Ochrotrichia sp. (Mosely)	1											
Brachycentridae												
Brachycentrus (sp. (Curtis)		1	4						25			1
Micrasema sp. (McLachlan)			1	1					1			
Hydropsychidae												
Diplectrona sp. (Westwood)											1	
Hydropsyche sp. (Pictet)	1	18	8	1			1		14	1	9	5
Pycnopsyche sp.			1	4								
COLEOPTERA												
Haliplidae												
Haliplus sp. (Latreille)	5	3	1	2		2	5		3		6	2
Psephenidae												
Ectoparia sp. (LeConte)												
Eubrianax sp. (Kiesenwetter)							2			1	2	
DIPTERA												
Tipulidae												
Antocha sp.		2		1	1	1	5		1			5
Hexatoma sp.	8								4			2
Heleidae												
Palpomyia sp. (Meigen)							1		2			1
Tendipedidae (Chironomidae)												
Chironomus sp. (Meigen)		3		8	2				12	8	25	7
Pentaneura sp. (Philippi)	3			2		1	1		3	5	2	5
Simuliidae												
Simulium sp. (Latreille)												
Stratiomyinae												
Eulalia sp. (Meigen)									2			
Blepharoceridae												
Blepharocera sp.												
HYDRACARNIA												
Mites												
Unidentifiable	4											
TOTAL	65	143	188	135	10	13	35		121	21	132	65
DIVERSITY	3.68	3.26	3.54	2.60	2.52	2.62	3.64		3.80	2.54	3.48	3.75

DATE	7/19/76							8/18/76			
SITE	3A	3B	3C	3D	1A	1B	1C	3B	3C	3D	3E
EPHEMEROPTERA											
Ephemeridea											
Ephemera sp. (Linnaeus)											
Potamanthus sp. (Pictet)	2	3	1	2		1	2	1			3
Heptageniidae											
Cinygmula sp. (McDunnough)											
Heptagenia sp. (Walsh)	1	4	4	7	1	2	2	8			5
Iron sp. (Traver)		2								3	
Stenonema sp. (Traver)		1	1			1		3	1	1	2
Baetidae											
Amelutus sp. (Eaton)											
Baetis sp. (Leach)	23	42	15	38		24		8	40	43	42
Baetodes sp. (Needham & Murphy)											
Ephemerella Bicolor sp.					3			1			1
Ephemerella doddsi (Needham)	5	10		1					1		
Ephemerella Walkeria sp.											
Habrophelebia sp. (Ulmer)		2									
Leptohyphes sp. (Eaton)											
Leptophlebia sp. (Westwood)											
PLECOPTERA											
Leuctrinae											
Leuctra sp. (Stephens)				16							
Chloroperlidae											
Alloperla sp. (Banks)		6						1		22	
Hastaperla sp. (Ricker)	4	8	2	4	3	1	1	1			
Acroneurinae											
Acroneuria ruralis (Pictet)	8		3		1	2		3	7	1	5
Atoperla sp. (Banks)											
Taeniopteryginae											
Brachyptera sp. (Newport)											
Perlidae											
Neophasgano capitata (Lestage)				1				1		1	
Paragentina sp. (Klapalek)						5					
Perlesta placida											
Peltoperlidae											
Peltoperla sp.											
ODONATA											
Gomphidae											
Hagenius sp. (Selys)											
Lanthus sp. (Needham)											
Cordulegastridae											
Cordulegaster sp. (Leach)											
MEGALOPTERA											
Sialidae											
Sialis sp.											
Corydalidae											
Chaulodes sp.											

DATE	7/19/76							8/18/76			
SITE	3A	3B	3C	3D	1A	1B	1C	3B	3C	3D	3E
TRICHOPTERA											
Rhyacophilidae											
Glossosoma sp. (Curtis)		4			1	5	1		18		
Rhyacophila sp. (Pictet)	1	1				1					
Philopotamidae											
Dolophilodes sp. (Ulmer)		6		5		23	2	1	1	8	2
Hydroptilidae											
Ochrotrichia sp. (Mosely)											
Brachycentridae											
Brachycentrus (sp. (Curtis)	1	4		3				1	5		5
Micrasema sp. (McLachlan)		1									
Hydropsychidae											
Diplectrona sp. (Westwood)											
Hydropsyche sp. (Pictet)	1	3		9		7					4
Pycnopsyche sp.							9				
COLEOPTERA											
Haliplidae											
Haliplus sp. (Latreille)	3	3	1		17	9	1	2	5	3	2
Psephenidae											
Ectoparia sp. (LeConte)											
Eubrianax sp. (Kiesenwetter)				2	2		3				
DIPTERA											
Tipulidae											
Antocha sp.		2	1	1	6	4		1	7	1	5
Hexatoma sp.					2			1	2		
Heleidae											
Palpomyia sp. (Meigen)				1	1					2	
Tendipedidae (Chironomidae)											
Chironomus sp. (Meigen)	8	11	4	6	3	1	2	3	16	12	16
Pentaneura sp. (Philippi)	1	3			1		1	1	4	1	6
Simuliidae											
Simulium sp. (Latreille)				1							
Stratiomyinae											
Eulalia sp. (Meigen)		1						1			
Blepharoceridae											
Blepharocera sp.		1									
HYDRACARNIA											
Mites			3					3			
Unidentifiable				2	2						
TOTAL	58	118	35	99	43	84	24	41	106	98	98
DIVERSITY	2.61	3.42	2.61	2.90	2.98	3.0	2.86	3.67	2.79	2.43	2.83

	DATE	8/18/76		9/25/76			
	SITE	4A	4B	3A	3B	3C	3D
EPHEMEROPTERA							
Ephemeridea							
Ephemera sp. (Linnaeus)							
Potamanthus sp. (Pictet)		26			1		
Heptageniidae							
Cinygmula sp. (McDunnough)							
Heptagenia sp. (Walsh)		1	6	1	3		4
Iron sp. (Traver)		3					
Stenonema sp. (Traver)		1	6				
Baetidae							
Amelutus sp. (Eaton)							
Baetis sp. (Leach)		36	7	4	9		
Baetodes sp. (Needham & Murphy)		1					
Ephemerella Bicolor sp.		2					
Ephemerella doddsi (Needham)		2					
Ephemerella Walkeria sp.			2				
Habrophelebia sp. (Ulmer)							
Leptohyphes sp. (Eaton)							
Leptophlebia sp. (Westwood)					1		
PLECOPTERA							
Leuctrinae							
Leuctra sp. (Stephens)							
Chloroperlidae							
Alloperla sp. (Banks)		5		2			4
Hastaperla sp. (Ricker)		4					
Acroneurinae							
Acroneuria ruralis (Pictet)		1			2		
Atoperla sp. (Banks)							
Taeniopteryginae							
Brachyptera sp. (Newport)		3	1				
Perlidae							
Neophasgano capitata (Lestage)		3	4				
Paragentina sp. (Klapalek)							
Perlesta placida		2					
Peltoperlidae							
Peltoperla sp.							
ODONATA							
Gomphidae							
Hagenius sp. (Selys)							
Lanthus sp. (Needham)							
Cordulegastridae							
Cordulegaster sp. (Leach)							
MEGALOPTERA							
Sialidae							
Sialis sp.							
Corydalidae							
Chaulodes sp.							

DATE	8/18/76		9/25/76			
SITE	4A	4B	3A	3B	3C	3D
TRICHOPTERA						
Rhyacophilidae						
Glossosoma sp. (Curtis)	11		2			
Rhyacophila sp. (Pictet)		2	2			
Philopotamidae						
Dolophilodes sp. (Ulmer)	7		2	3		
Hydroptilidae						
Ochrotrichia sp. (Mosely)						
Brachycentridae						
Brachycentrus (sp. (Curtis)	17	7	10	39		14
Micrasema sp. (McLachlan)	1					
Hydropsychidae						
Diplectrona sp. (Westwood)						
Hydropsyche sp. (Pictet)	14	2	11	21		20
Pycnopsyche sp.						
COLEOPTERA						
Haliplidae						
Haliplus sp. (Latreille)	7	3	6	3		1
Psephenidae						
Ectoparia sp. (LeConte)						
Eubrianax sp. (Kiesenwetter)						
DIPTERA						
Tipulidae						
Antocha sp.	1	2	6	1	2	3
Hexatoma sp.	4	2	2			
Heleidae						
Palpomyia sp. (Meigen)						
Tendipedidae (Chironomidae)						
Chironomus sp. (Meigen)	12	9	3			
Pentaneura sp. (Philippi)	4	3	1			
Simuliidae						
Simulium sp. (Latreille)	3					
Stratiomyinae						
Eulalia sp. (Meigen)						
Blepharoceridae						
Blepharocera sp.						
HYDRACARNIA						
Mites						
Unidentifiable						
TOTAL	166	57	52	83	2	46
DIVERSITY	3.74	3.34	3.05	2.24	0	2.03

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