

MORRISTOWN NATIONAL HISTORICAL PARK
WATERSHED STUDY
PHASE II

Aquatic Resources

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EXECUTIVE SUMMARY

Selected physical, chemical, and biological characteristics of the five major stream systems in Morristown National Historical Park, New Jersey, were monitored on a seasonal basis for one year. Surface waters were in ample supply and water quality ranged from very good to near excellent. Fecal coliforms and fecal streptococci counts indicated at this time little likelihood of any contamination of these streams by human excrement. The assemblages and numbers of stream dwelling invertebrates were typical for shallow, swiftly running, clean, woodland streams in this region. The algae, mainly diatoms, associated with the bottom substrate of these streams similarly indicated water of a high quality.

A continuing, in-house program to monitor selected water quality parameters in these streams was recommended. A periodic and more extensive chemical and biological survey by an outside agency was strongly suggested. A 10-year period was recommended in the event the monitoring program did not signal a need for an extensive survey at an earlier time.

Concentrations of total recoverable aluminum in the surface waters were found to be very low and to pose no threat at this time to the aquatic life in these streams. The relatively few soil samples that were analyzed did, however, reveal high soil concentrations of aluminum which could, given the proper circumstances, pose a threat to the viability of not only the forest trees but also the aquatic life. Further consideration to assessing the potential mobilization of soil aluminum and its transport to the streams was recommended.

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their proximity to human influences; concentrations of 2.46 to 4.96 mg/l characterized the more remote Primrose system, and values ranging from 9.42 to 24.85 mg/l were found in the other less remote systems. Ammonia nitrogen was extremely low and, with the exception of the Passaic River, nitrate nitrogen varied seasonally, ranging from a winter maximum of 1.002 mg/l in Indian Grave to a fall minimum of 0.005 mg/l in the Primrose system. Total phosphorus never exceeded 28 µg P/l in the Primrose system and 87 µg in the other streams, and soluble reactive phosphorus never exceed 11 µg P/l in the Primrose system and 17 µg in the other streams. Total recoverable aluminum varied from 0.022 to 0.103 mg/l in surface waters, whereas the concentration of exchangeable Al in the acidic soils of the Primrose system contained from 0.4 to 27.2 mg Al/100 g of soil.

Water quality was judged generally as good to near excellent on the basis of the chemical analyses and a "modified" water quality index. Fecal coliform and fecal streptococci counts indicated little likelihood of contamination from human excrement. Fecal coliform counts rarely exceeded 200 per 100 ml and then only for summer samples.

A recommendation for a minimal in-house program to monitor water temperature, dissolved oxygen, specific conductance, and the pH of surface waters is made. A more extensive chemical and biological survey by an outside agency every 10 years is strongly suggested. If possible, the apparently high fecal coliform counts reported for the West Branch of Primrose Brook should be investigated more thoroughly. Although the surface water aluminum concentrations do not constitute a hazard to the aquatic life at this time, more rigorous assessment of any potential threat of the high soil aluminum concentrations to the terrestrial flora is recommended.

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INTRODUCTION

A major part of Morristown National Historical Park exists in what was once a highly-rural area of western Morris County, New Jersey. This relatively small park is of great historical and ecological importance to the people of New Jersey and our nation. Unfortunately, this highly prized parkland no longer benefits from the low-intensity use that was once characteristic of the lands surrounding the park. A rapid suburbanization has taken place along its boundaries during the past few decades, and there appears to be little chance for any major curtailment. These changes in land use threaten the natural resources of this park.

The National Park Service has correctly recognized this threat to the integrity, preservation and public use of Morristown National Historical Park and has sought to establish background or baseline data on the natural resources within the park's boundary. In keeping with this recognized need, the Park Service contracted Associated Ecologists to conduct an evaluation of the park's aquatic resources. That study has been completed and a final report was submitted (Mele and Mele 1983).

One of the shortcomings in the study by Associated Ecologists was the benthic macroinvertebrate survey. The number of samples taken were too few, quantitative methods were not used and identification was rarely to genus. Benthic macroinvertebrates, especially the larval aquatic insects, are one of several groups found in lotic environments that have been used to classify streams (Persoone 1979; NCDNR 1986) and to monitor water quality (Hawkes 1979).

The objectives of this study were to:

1. establish, reconfirm or extend baseline data on selected parameters of water quality,
2. measure seasonal concentrations of aluminum in the stream waters and in the soil,
3. determine the seasonal fecal coliform/fecal streptococcus ratios in the major streams,
4. perform a comprehensive and quantitative survey of the benthic macroinvertebrates, and
5. identify the macrophytes and benthic algae associated with the park's streams.

The results of this study are meant to supplement and/or confirm the finding reported by Mele and Mele (1983). When taken together these two studies should provide:

1. a satisfactory inventory of aquatic resources,
2. knowledge of current water quality,
3. guidance in the establishment of suitable management practices, and
4. a workable in-house program for monitoring the status of the aquatic systems in the park.

METHODS

Samples were taken from two sites on the five major stream systems of the park (Fig. 1). All sites were within or in close proximity to the park boundary. Selection of the sampling sites was based on accessibility and coincidence with sites used in an earlier environmental study by Mele and Mele (1983). The sampling sites were East Branch (E_1 , E_2) and West Branch (W_1 , W_2) of Primrose Brook, Indian Grave (I_1 , I_2), Jersey Brook (J_1 , J_2) and the Passaic River (P_1 , P_2). Details of specific locations are given in Appendix A. Sites E_2 , W_1 , I_1 , J_2 , and P_1 correspond to sampling stations used in the Mele and Mele study (Fig. 1).

Physico-Chemical Measurements

Beginning in July 1986 and ending July 1987 selected physical and chemical characteristics of the five stream systems were measured on a seasonal basis (Table 1). Duplicate grab samples for chemical analysis were collected at each site in hydrochloric acid-washed and distilled water-rinsed one-liter Nalgene bottles. Each bottle was also rinsed once with stream water before collecting the sample. Samples were obtained from both sites of one stream in the morning hours, transported promptly to the laboratory in a cooler chest and analyzed that afternoon for tests requiring immediate measurement or preserved for subsequent analysis. Most analyses were performed in triplicate.

Water Temperature. Temperature of the stream water was measured by a thermistor probe incorporated in a Yellow Springs Instrument Dissolved Oxygen meter (YSI Model 57). The temperature was verified with a laboratory grade stem thermometer.

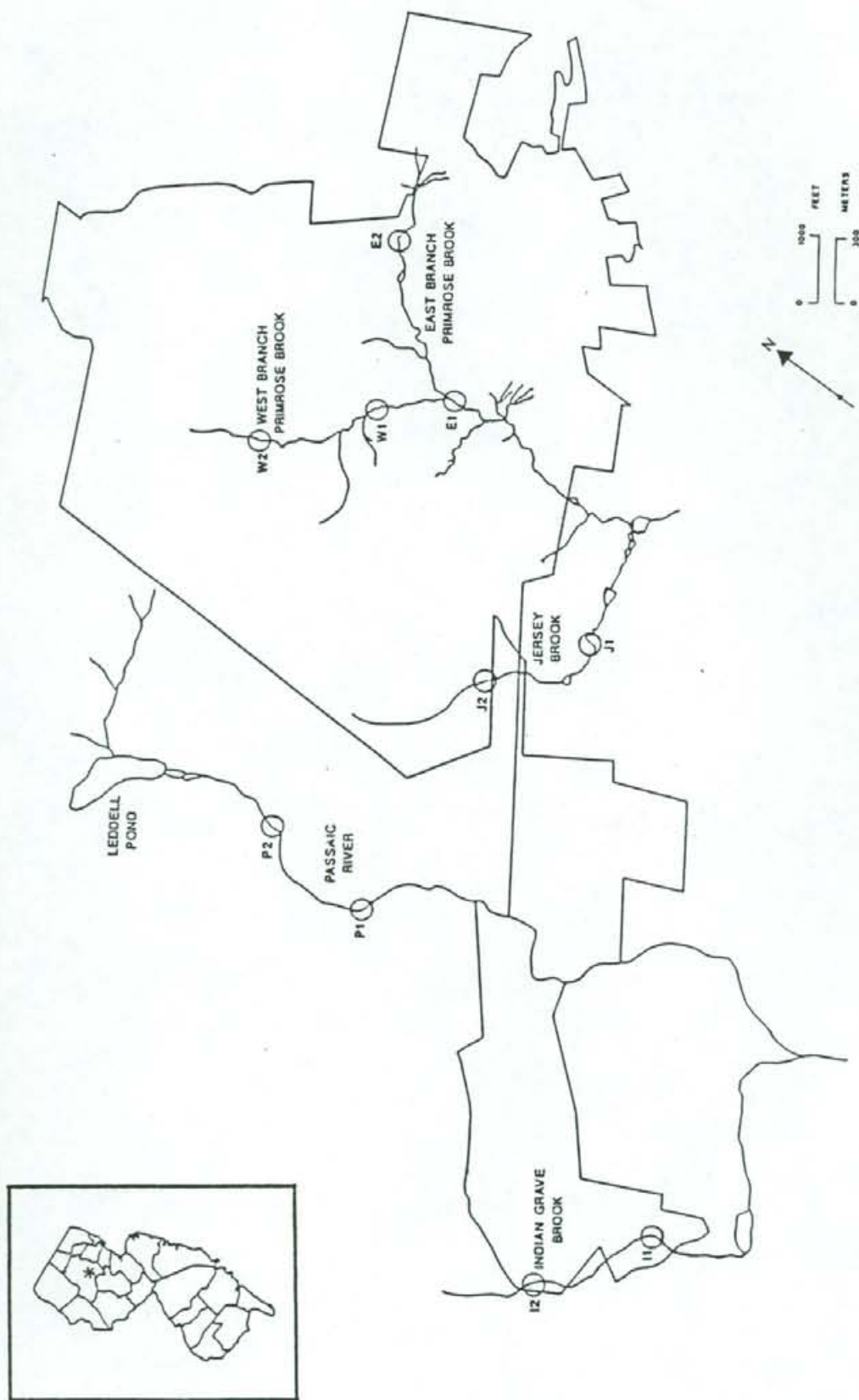


Fig. 1. Map of Morristown National Historical Park, Morris County, New Jersey, showing locations of sampling sites and approximate location of the park in the state.

Table 1. Sampling schedule for Morristown National Historical Park Watershed Study:
Phase II (1986-87).

Sample	Month of Study											
	J	A	S	O	N	D	J	F	M	A	M	J
A. Water Quality	*			*			*			*		*
B. Benthic Macro-invertebrates	*			*						*		
C. Benthic Algae	*			*						*		
D. Aquatic Macrophytes	*			*						*		

Water Velocity and Stream Discharge. Channel width, mean depth and water velocity were determined by establishing a transect across the channel at approximately the same location every time water samples were taken. A metal tape was strung across the stream, and water depth was estimated with a yard stick, and the integrated water velocity was measured using a Gurley Pigmy current meter at appropriate intervals. The cross-sectional area of the stream channel was calculated by multiplying stream width by mean depth, and the discharge was computed by multiplying the cross-sectional area by the arithmetic mean water velocity for the transect (Wetzel and Likens 1979).

Total Suspended Solids. A measured water sample of approximately one liter was vacuum filtered through a washed, oven dried, and preweighed glassfiber filter (Whatman GF/C; 2.5 cm diam.). Filters plus the residues were dried at 105°C for at least one hour, cooled in a desiccator, and reweighed.

Total Dissolved Solids. An estimate of total dissolved solids was made on-site using a direct reading Myron L. Delux "DS" meter, Model 532 T₂.

Specific Conductance. In situ conductivity was measured with a Yellow Springs Instrument Model 33 portable meter and probe. Readings are in micromhos/centimeter and are not temperature compensated.

Dissolved Oxygen. Concentration and percentage saturation of dissolved oxygen was measured in situ with a Yellow Springs Instrument Model 57 portable meter and probe. The instrument was calibrated in the laboratory before each sampling day using air-saturated distilled water and a laboratory grade stem thermometer.

Total Alkalinity. The alkalinity to pH 4.5 was measured in triplicate 100 ml samples using standard 0.02 N H_2SO_4 in a 10-ml microburet (Standard Methods 1980). Alkalinities are reported as equivalent mg CaCO_3 /l to pH 4.5.

pH. The pH of stream water was measured in situ using a Fisher Scientific Accumet portable pH meter (Model 640A). Relative accuracy and repeatability was given by the manufacturer as ± 0.01 pH units.

Chlorides. The mercuric nitrate method (Standard Methods 1980) to measure chloride concentrations using a microtitrator was routinely employed. A second method, mercuric thiocyanate (Florence and Farrar 1971), which is a spectrophotometric procedure (Beckman UV Spectrophotometer, Model 25), was used on water samples collected between October 1986 and July 1987. All analyses were done in triplicate and on samples that had been filtered through glassfiber filters (Whatman GF/C) and stored at 4°C.

Ammonia-Nitrogen. An Orion ammonia electrode (Model 95-12) was used with a Fisher Scientific Accumet combination pH/mV/ion meter (Model 825 MP) to measure concentrations of ammonia nitrogen directly in untreated water samples. All analyses were in triplicate and completed within 6 hours of collection. Lower limit of detection for the ion-selective electrode used was given as 0.01 ppm.

Nitrate-Nitrogen. Two independent techniques were utilized to measure the concentrations of nitrate nitrogen in stream water samples. The cadmium reduction method (Standard Methods 1980) determines the milligrams of oxidized N per liter (the sum of NO_3^- -N plus NO_2^- -N). The Brucine method (Standard Methods 1971) is recommended for the range of 0.1 -2 mg NO_3^- -N/l but is not regarded as

an acceptable technique by the US EPA. The NJ DEP, however, does accept the results from the Brucine method. A Beckman Model 25 spectrophotometer was used to measure color development in triplicate samples and standards for both methods used. Analyses were made on glassfiber filtered samples (Whatman GF/C) within 8 hours of collection.

Phosphorus. Concentrations of total (TP) and soluble reactive phosphorus (SRP) were measured by a slightly modified procedure of Strickland and Parsons (1968). Stream water samples, which had been frozen in the original Nalgene bottles within 4 hours of collection time, were rapidly thawed in an autoclave by a 3 minute exposure to 121°C and 1.1 kg cm² pressure just prior to analysis. Concentrations were read directly with a Beckman spectrophotometer (Model 25) and a 50 mm rectangular cell at 885 nm wavelength.

Triplicate 50 ml samples for TP were digested by the addition of acid-persulfate and autoclaving for 30 minutes at 121°C and 1.1 kg cm² pressure (Jeffries et al. 1979). Digested samples were rapidly cooled to room temperature in an ice bath and then filtered through a Whatman GF/C glassfiber filter to remove particulates. Two drops of phenolphthalein indicator solution were added to each flask and the pH adjusted first by adding 9 N NaOH until a pink color formed and then back titrating with 0.24 N HCl to dispel the pink color. Mixed reagent was then added and the phosphorus concentrations were read directly after a 5 minute color development time.

Concentrations of SRP were measured in triplicate 100 ml aliquots of thawed sample that had been filtered (Whatman GF/C). Concentrations were read directly 5 minutes after the addition of 10 ml of mixed reagent.

Aluminum. Duplicate water samples were collected at each site in 500 ml, acid rinsed, LPE Nalgene bottles. Samples were stored at 4°C until analyzed. Prior to analysis, samples were acidified with nitric acid and the concentration of total recoverable aluminum was determined using a Perkin-Elmer Model 503 flameless atomic absorption spectrophotometer equipped with an HGA-2100 graphite furnace unit. All measurements were made at 309.9 nm using standard operating parameters. EPA QA/QC samples (Trace Metals 1 and 2) were also measured at the time water samples were analyzed. All AA analyses were performed by Dr. Marc Sprenger, Department of Environmental Sciences, Rutgers University.

Surface soil samples were obtained from the forest floor in the immediate vicinities of Stations W1 and W2 on July 08, 1987 and Stations E1 and E2 on July 10, 1987. A composite sample was made at each site from random soil samples taken from depths of up to 15 cm (6 in.). Samples were placed in self-closing polyethylene collecting bags and stored in a freezer until December 04, 1987; the frozen samples were thawed and air-dried between December 04 and 07. Air-dried samples were mixed and homogenized by hand in a mortar and pestle.

The soil pH (in water and in 0.01 M CaCl_2), exchangeable aluminum (1M KCl), and extractible aluminum (1M KCl adjusted to pH 3.5 with acetic acid) were determined for the homogenized soil samples. The pH values were measured with a Fisher Accumet Model 825 MP pH meter equipped with glass electrodes following standard procedures. The methods to determine exchangeable and extractible aluminum concentrations in soils were obtained from Dr. P. Hsu, Department of Soils and Crops, Rutgers University (personal communication). To measure exchangeable aluminum, 10g of the homogenized soil sample plus 25 ml of a 1M KCl solution were introduced into a 50 ml centrifuge tube. The tube was hand shaken

for 15 minutes, centrifuged and the supernatant decanted. This was repeated three more times and the collected supernatant solution was made up to 100 ml with deionized, distilled water. The final solution was filtered through a Whatman GF/C glassfiber filter. To measure extractible aluminum, the procedure was repeated using a 1M KCl solution adjusted to pH 3.5 with acetic acid and the fourth (final) extraction left overnight. Final centrifugation and filtration of the 100 ml combined extract took place the next day.

Exchangeable and extractible aluminum concentrations in the extracts were determined on a Perkin-Elmer Model 603 atomic absorption spectrophotometer with a nitrous oxide acetylene flame.

Biological Measurements

Bacteria. Samples for bacterial analysis were collected at each site in duplicate, sterile 500 ml Nalgene bottles at the same time that samples for chemical analysis were taken. Fecal coliform and fecal streptococcus densities were determined by a membrane filter technique (Standard Methods 1985) using freshly collected stream water samples.

Fecal coliform bacteria were grown on commercially available mFC medium-impregnated nutrient pads in presterilized petri dishes (Nalgene, Cat. No. 704-0001) in a water bath at 44°C. Incubation time ranged from 22 to 24 hours. Densities of coliforms were recorded from appropriate volumes of filtered samples and were expressed as number of fecal coliforms per 100 ml.

Fecal streptococcus bacteria were grown on freshly prepared KF streptococcus agar at 35°C for 48 hours (Standard Methods 1985). Several sample volumes were filtered and incubated. Filters were placed directly on the agar in sterile petri dishes which were inverted during incubation. Streptococcus densities were expressed as number per 100 ml.

Benthic Algae and Aquatic Macrophytes. At the times macroinvertebrates were sampled, one or two small rocks were taken from the stream bed, placed in a bucket with stream water and returned to the laboratory. Several scrapings were made from each rock using a scalpel. Individual scrapings were placed in a drop of distilled water on a glass slide. A cover clip was added and the preparation was examined with a compound light microscope at 100x and 430x magnification. Algae observed in the rock scrapings were identified to genus.

No rooted aquatic macrophytes were observed at any of the sampling sites throughout this study. The aquatic moss, Fontinalis, was commonly observed growing on rock surfaces in swiftly running water.

Benthic Macroinvertebrates. Five samples using a Surber Square Foot Stream Bottom Sampler were taken in the summer, fall and spring at each site. Organisms dislodged from rocks, debris and the sediment within the square foot sampling area were swept into the collecting net by the stream's current. Organisms were hand collected from the net and from the small stones and debris (leaves, sediment, etc.) emptied from the collection net into a white enameled pan using forceps (Wetzel and Likens 1979). All organisms were immediately preserved in 80% ethyl alcohol and transported to the laboratory for subsequent identification and enumeration.

Whenever appropriate, several dip net samples and a random examination of rocks and debris were made at the collection site. Organisms collected in this manner were preserved in 80% ethyl alcohol but were kept separate from the Surber samples.

RESULTS

The results of this study are organized into five sections. This grouping is one of convenience and ease of presentation and is not to be interpreted as an absence of possible relationships between or among the physical, chemical and biological properties of these lotic ecosystems. The sections are:

- I. Physical and Chemical
- II. Concentrations of Aluminum
- III. Fecal Coliforms and Fecal Streptococci
- IV. Benthic Algae and Macrophytes
- V. Benthic Macroinvertebrates

I. Physical and Chemical

Water Velocity and Stream Discharge. Seasonal measurements of mean depth, stream channel width, mean water velocity and the calculated flow or discharge (Q) are summarized in Table 2 for both sites on all stream systems. Spring discharges were maximal and, in general, the fall '86 discharges were minimal and were similar to the summer '86 discharges. All summer '87 discharges,

Table 2. Stream transect data, water velocity, and discharge.

EAST PRIMROSE : E1

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.127	0.027	4.27	0.0148
FALL	0.154	0.047	4.57	0.0333
WINTER	-	-	-	-
SPRING '87	0.427	0.086	3.76	0.1387
SUMMER	0.401	0.047	3.12	0.0583

EAST PRIMROSE : E2

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.067	0.034	0.91	0.0021
FALL	0.069	0.044	0.86	0.0026
WINTER	-	-	-	-
SPRING '87	0.302	0.056	1.22	0.0206
SUMMER	0.157	0.042	0.91	0.0060

WEST PRIMROSE : W1

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.100	0.046	1.52	0.0073
FALL	0.081	0.052	1.83	0.0077
WINTER	0.208	0.073	2.24	0.0346
SPRING '87	0.243	0.112	3.28	0.0893
SUMMER	0.135	0.051	2.06	0.0142

WEST PRIMROSE : W2

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.086	0.042	1.12	0.0041
FALL	0.091	0.058	1.09	0.0057
WINTER	0.183	0.044	2.44	0.0196
SPRING '87	0.451	0.065	2.51	0.0732
SUMMER	0.211	0.026	2.51	0.0138

Table 2 (contd)

INDIAN GRAVE : I1

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.214	0.068	4.27	0.0620
FALL	0.152	0.059	4.27	0.0384
WINTER	0.249	0.138	4.88	0.1674
SPRING '87	0.334	0.153	5.18	0.2651
SUMMER	0.317	0.110	4.88	0.1703

INDIAN GRAVE : I2

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.258	0.095	2.51	0.0615
FALL	0.185	0.104	2.16	0.0416
WINTER	0.327	0.156	3.35	0.1713
SPRING '87	0.381	0.151	3.51	0.2019
SUMMER	0.270	0.124	3.15	0.1052

JERSEY BROOK : J1

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.157	0.054	1.68	0.0142
FALL	0.068	0.042	1.68	0.0048
WINTER	0.183	0.090	1.88	0.0310
SPRING '87	0.269	0.076	3.05	0.0623
SUMMER	0.222	0.060	1.22	0.0161

JERSEY BROOK : J2

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.140	0.037	1.27	0.0066
FALL	0.117	0.041	1.37	0.0066
WINTER	0.175	0.074	2.08	0.0270
SPRING '87	0.183	0.064	2.44	0.0285
SUMMER	0.095	0.054	1.07	0.0055

Table 2 (contd)

PASSAIC RIVER : P1

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.260	0.060	6.35	0.0991
FALL	0.165	0.085	5.89	0.0826
WINTER	0.315	0.131	7.62	0.3137
SPRING '87	0.400	0.129	8.38	0.4338
SUMMER	0.284	0.084	5.94	0.1417

PASSAIC RIVER : P2

TIME OF YEAR (1986-87)	MEAN VELOCITY (m/s)	MEAN DEPTH (m)	TOTAL WIDTH (m)	DISCHARGE (m ³ /s)
SUMMER '86	0.112	0.120	6.40	0.0861
FALL	0.078	0.144	5.94	0.0671
WINTER	0.336	0.144	5.33	0.2583
SPRING '87	0.306	0.153	7.92	0.3703
SUMMER	0.189	0.107	5.08	0.1029

however, exceeded summer '86 discharges except for Jersey Brook which showed little difference between the summers of '86 and '87. Precipitation was above average in July 1987.

All stream channels were narrow and shallow with swift currents flowing over a substrate of sand, gravel, and rock. No stream dried up during the period of July '86 to '87. The mean depths and discharges for Station 2 on East Primrose and Station 2 on Jersey Brook were small and very similar to one another. All other discharges were low to moderate and had the typical pattern of a small woodland stream in an elevated temperate zone.

There were several anomalous discharges recorded. For example, $Q_{(1)}$ should exceed or equal $Q_{(2)}$ barring any significant impoundment or diversion. $Q_{(1)}$ for Indian Grave was less than the $Q_{(2)}$ in the fall and winter of 1986 (Table 2). This same anomaly was observed in Jersey Brook in the fall of 1986 (Table 2). These apparent "errors" were small and might have simply been the result of inaccurate field data.

Water Temperature. The in situ seasonal water temperatures for all streams are given in Table 3. These temperatures were recorded some time between 10 am and 1 pm for both stations on the day of sampling. The expected seasonal pattern was observed; summer highs ranged from 23.0°C for the downstream station on the Passaic River to a summer low of 15.7°C for the upstream station on West Primrose (Table 3). Ice was never observed in these streams during the winter sampling period, but ice formation certainly could have occurred at some time during the colder months of the year.

Table 3. Water temperature (C).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	17.2	17.4	16.8	17.0	20.8	21.3	20.1	17.0	21.7	23.0
FALL	13.2	13.7	9.0	10.3	11.6	11.9	10.5	10.9	8.3	9.4
WINTER	-	-	4.2	4.9	3.0	3.3	5.5	6.0	3.7	3.9
SPRING	9.4	11.1	8.4	9.3	14.7	15.1	9.9	10.3	10.4	11.6
SUMMER '87	17.4	17.2	15.8	15.7	18.7	19.2	20.0	16.9	17.9	19.5

Table 4. Total suspended solids (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	2.85	5.35	3.40	6.50	2.95	2.20	1.85	4.05	0.90	0.50
FALL	1.50	2.80	0.36	0.55	1.05	0.40	1.45	1.30	0.70	1.20
WINTER	-	-	1.35	0.60	0.75	0.80	1.85	1.80	3.25	4.40
SPRING	2.60	2.70	3.30	2.70	2.95	3.45	2.75	4.30	1.70	2.00
SUMMER '87	5.00	7.67	4.25	4.20	7.17	5.92	9.00	9.51	2.35	0.87

Table 5. Total dissolved solids (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	56	39	61	48	67	68	80	75	58	62
FALL	58	44	68	53	74	75	74	67	88	95
WINTER	-	-	52	44	75	75	92	84	96	98
SPRING	44	32	44	39	66	66	82	84	72	75
SUMMER '87	56	39	58	45	59	61	78	84	64	68

Table 6. Specific conductivity (umhos/cm).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	99	65	105	80	120	125	125	130	105	115
FALL	85	65	90	70	108	110	100	100	90	125
WINTER	-	-	62	52	81	83	91	102	90	110
SPRING	61	45	57	51	108	109	111	115	110	112
SUMMER '87	95	65	85	79	105	105	93	140	115	122

Summer-time water temperatures were significantly cooler in the East and West Primrose than for other stream sites except Station 2 on Jersey Brook which had a thermal pattern similar to that of the Primrose system (Table 3). Station 1 on Jersey Brook was below a small impoundment on the Jarvis property, and Station 2 was above the impoundment in a heavily wooded area.

Total Suspended Solids. All of the TSS concentrations for these streams were low (Table 4). Values ranged from 0.40 mg/l for Station 2 on Indian Grave in fall '86 to 9.51 mg/l for Station 2 on Jersey Brook. TSS concentrations showed no obvious pattern, but they were lowest in fall '86 and highest in summer '87.

Total Dissolved Solids. The concentrations of TDS (Table 5) were lowest at Station 2 on East Primrose followed closely by Station 2 on West Primrose. Values for Station 1 on West Primrose were somewhat elevated, and concentrations at Station 1 on East Primrose tended to be intermediate to E2 and W1 concentrations. There was a significant increase in TDS from W2 to W1 for all seasons (Table 5).

TDS concentrations, which are reflective of the salt content of the stream water, were all low. Jersey Brook and Passaic River samples had the highest TDS concentrations. No reading, however, exceeded 98 mg/l which is well below the mean value of 142 mg/l total dissolved inorganic concentration reported for North American river waters (Wetzel 1983).

Specific Conductivity. The relationship of TDS concentrations among the five stream systems was confirmed by the specific conductivities (Table 6). Conductivity readings reflect the concentrations of ionizing salts in water.

Low conductivities were associated with E2 and W2. Somewhat greater conductivities were recorded at other locations. Values ranged from 45 to 125 umhos/cm.

The specific conductivity at W1 always exceeded the conductivity at W2 (Table 6). Station W2 was approximately 0.5 mile upstream from Station W1. Specific conductivities from Indian Grave, Jersey Brook and Passaic River either did not change significantly or decreased slightly as the waters moved downstream (i.e. from Sta. 2 to Sta. 1).

Dissolved Oxygen. Concentrations of dissolved oxygen were always close to air-saturation. In fact, the concentrations frequently were greater than 100% saturation which, although possible, would not likely be expected for these swift running, heavily forested streams (Table 7).

Concentrations ranged from 16.00 mg/l in the winter to 7.92 mg/l in the summer of 1987 (Table 8). There never appeared to be a significant deficit of dissolved oxygen in any of these streams at any time of the year.

Total Alkalinity. All alkalinity readings were classified as "methyl orange" alkalinities since water sample pH values never exceeded nor reached a pH of 8.3. All of the alkalinity, therefore, was probably due to the bicarbonate ion concentrations in the water sample. Readings ranged from 11.33 to 49.83 mg/l, and the lowest values were associated with E2 (Table 9). Higher alkalinities were characteristic of the Passaic River samples. As expected, springtime values were minimal for any one stream system.

Table 7. Dissolved oxygen (% sat).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	142	139	139	133	138	138	95	103	99	93
FALL	101	92	117	117	103	104	99	93	103	102
WINTER	-	-	108	105	117	119	112	111	109	120
SPRING	109	100	119	112	110	109	106	103	110	114
SUMMER '87	93	98	93	90	103	100	87	101	97	91

Table 8. Dissolved oxygen (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	13.5	13.28	13.06	12.94	12.45	12.27	8.62	9.91	8.66	7.98
FALL	10.5	9.56	13.62	13.07	11.34	11.48	11.05	10.54	12.11	11.68
WINTER	-	-	14.07	13.42	15.60	16.00	14.01	13.93	14.26	15.58
SPRING	12.3	11.18	14.00	12.93	11.20	10.97	11.90	11.61	12.29	12.37
SUMMER '87	9.06	9.58	9.48	9.03	9.56	9.26	7.92	9.82	9.23	8.33

Table 9. Alkalinity (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	34.3	20.25	41.33	27.42	30.50	28.17	34.00	29.58	33.25	33.25
FALL	37.3	24.50	46.00	29.33	31.17	29.67	33.00	28.67	46.67	49.83
WINTER	-	-	29.67	20.50	21.33	21.00	24.50	17.67	32.50	32.17
SPRING	21.6	11.33	19.50	24.00	24.33	23.67	22.17	17.67	30.00	32.00
SUMMER '87	33.6	21.00	38.50	27.00	26.00	25.00	37.17	29.67	33.33	34.83

Table 10. pH.

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	7.79	7.88	7.79	7.25	7.74	7.50	7.38	7.49	7.57	7.48
FALL	7.37	7.31	7.57	7.06	7.38	7.37	7.19	7.19	7.73	7.57
WINTER	-	-	7.52	7.27	6.69	7.41	7.12	7.68	7.53	8.14
SPRING	7.03	7.09	6.82	6.83	7.50	8.00	7.10	7.20	7.22	7.30
SUMMER '87	7.61	7.43	7.65	7.23	7.57	7.52	7.50	7.53	7.56	7.44

With the exception of springtime values, the alkalinity at W1 was significantly greater than that found at W2, the upstream station. Increases in alkalinities from J2 to J1 were also observed, but these increases may have been caused by the small impoundment which was located between J2 and J1 (Table 9).

pH. All of the pH readings were circumneutral (Table 10). Only the spring time values for West Primrose and the winter time reading for Station 1 on Indian Grave were less than pH 7.0. These lower values were in fact greater than pH 6.6. Maximum pH value was pH 8.14. It was generally found, therefore, that pH ranged between 6 and 8. This is a suitable range for maintaining the integrity of the stream biota.

Chlorides. Concentrations of chlorides were lowest in the Primrose Brook system and significantly higher for the other three streams. All values, however, were low and indicative of a relatively undisturbed freshwater stream (Table 11 and 12).

Relatively high concentrations were found in the winter and spring samples from Indian Grave, Jersey Brook and Passaic River. Highest values were from Jersey Brook.

Either analytical technique satisfactorially measured the chloride concentrations (Galloway 1989) and gave comparable results (Table 11 and 12). A more complete data set, however, was obtained using the mercuric nitrate titration and any future discussion of chlorides will be based on the concentrations obtained using the mercuric nitrate technique.

Table 11. Chloride: Mercuric nitrate method (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	4.96	3.54	3.05	2.87	11.76	12.14	16.53	17.92	9.42	10.29
FALL	4.16	3.21	3.43	2.72	13.61	14.16	14.57	13.81	14.74	15.73
WINTER	-	-	3.13	3.10	15.65	16.05	24.85	26.18	22.70	23.85
SPRING	4.04	2.46	3.14	3.47	13.01	13.41	22.99	26.76	14.64	15.34
SUMMER '87	4.14	3.05	3.42	3.15	10.30	10.68	16.59	22.41	10.67	11.11

Table 12. Chloride: Mercuric thiocyanate method (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	-	-	-	-	-	-	-	-	-	-
FALL	4.14	3.25	3.06	2.35	12.57	13.07	13.16	12.84	13.53	14.33
WINTER	-	-	4.30	3.97	20.00	20.72	29.07	30.17	27.17	28.50
SPRING	7.47	3.97	4.57	4.73	17.20	17.93	26.30	28.60	19.70	20.23
SUMMER '87	2.12	1.83	3.52	2.02	10.93	10.79	16.38	20.17	10.93	11.33

Table 13. Ammonia-N (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	0.02	0.019	0.026	0.018	0.024	0.022	0.034	0.028	*	*
FALL	0.05	0.023	0.014	0.010	0.015	0.010	0.025	0.015	*	*
WINTER	-	-	0.018	0.010	*	*	0.011	*	*	*
SPRING	0.01	0.011	0.027	0.013	0.012	0.011	0.012	*	*	0.010
SUMMER '87	*	*	0.546	0.856	0.010	0.013	*	*	0.012	0.014

* = value less than 0.01 mg/l

Ammonia-Nitrogen. Concentrations of nitrogen in the form of ammonia were generally found to be extremely low and often below the 0.01 mg N/l detection limit (Table 13). Surprisingly, the lowest values were found in the Passaic River and highest concentrations were associated with West Primrose (all summer '87).

Nitrate-Nitrogen. The Cd-Reduction and the Brucine methods gave comparable estimates of nitrate-nitrogen concentrations (Table 14 and 15). The approximately 1:1 relationship (Galloway 1989) between these analytical estimates implied that the $\text{NO}_2\text{-N}$ concentrations were, as expected, very low. The Cd-Reduction method actually measured $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ combined, whereas the Brucine method estimates only nitrogen in the form of the NO_3 ion.

Nitrogen values ranged from a maximum of about 1.0 mg N/l in Indian Grave during the winter to a minimum of 0.005 to 0.013 mg N/l in East Primrose during the fall (Table 14 and 15). Highest concentrations appeared to be associated with Indian Grave and Passaic River waters. Only the Passaic River data unambiguously showed the expected seasonal pattern. Generally, temperate streams display a winter maximum of available inorganic nitrogen and a summer/fall minimum (Reid and Wood 1976). Nitrate-nitrogen concentrations for the other streams varied but a seasonal pattern was not obvious with the possible exception of Indian Grave (Table 14 and 15). Lowest concentrations were found at Station 2 on the East and West Branch of Primrose Brook.

Phosphorus. Total phosphorus (TP) concentrations were low to moderate with the exception of Indian Grave and Station 1 on Jersey Brook in the summer of 1987 (Table 16). The highest value of 87 ug P/l for Station 1 on Jersey Brook in the

Table 14. Nitrate plus nitrite-N: Cd reduction method (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	0.42	0.325	0.491	0.231	0.621	0.626	0.389	0.266	0.221	0.109
FALL	0.01	0.011	0.199	0.082	0.615	0.640	0.160	0.154	0.162	0.164
WINTER	-	-	0.524	0.198	0.904	0.998	0.397	0.266	0.793	0.811
SPRING	0.41	0.136	0.483	0.276	1.048	1.074	0.339	0.181	0.735	0.720
SUMMER '87	0.41	0.309	0.505	0.277	0.767	0.720	0.214	0.463	0.291	0.189

Table 15. Nitrate-N: Brucine method (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	0.41	0.308	0.550	0.298	0.608	0.251	0.400	0.329	0.260	0.168
FALL	0.00	0.012	0.237	0.113	0.633	0.679	0.188	0.174	0.178	0.194
WINTER	-	-	0.479	0.122	0.920	1.002	0.389	0.277	0.839	0.807
SPRING	0.40	0.112	0.458	0.274	0.777	0.776	0.353	0.243	0.717	0.692
SUMMER '87	0.39	0.299	0.472	0.241	0.669	0.706	0.210	0.423	0.232	0.199

Table 16. Total phosphorus (ug/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	27.1	9.00	25.17	20.17	21.17	19.17	21.83	16.83	16.17	17.17
FALL	7.50	8.83	5.50	6.00	7.67	6.00	7.33	6.50	8.50	10.50
WINTER	-	-	13.80	12.20	16.50	17.20	16.20	16.30	24.00	25.70
SPRING	15.8	10.20	18.00	16.70	25.80	24.30	21.20	19.70	21.30	22.70
SUMMER '87	24.1	20.67	21.83	23.60	60.00	61.17	87.00	31.33	35.50	44.00

Table 17. Soluble reactive phosphorus (ug/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	10.6	2.33	9.67	6.33	8.00	6.50	5.00	9.50	5.00	3.83
FALL	0.50	0.00	0.33	1.00	2.33	2.00	0.67	2.17	0.00	0.17
WINTER	-	-	4.80	3.70	5.00	5.00	5.20	5.30	2.80	3.00
SPRING	4.80	2.20	4.30	4.00	5.80	4.50	5.30	5.70	2.20	2.30
SUMMER '87	10.3	4.50	9.33	11.70	16.50	16.00	14.17	16.70	6.00	5.33

summer of 1987 was slightly less than the 100 $\mu\text{g P/l}$ upper limit recommended for control of algal growth in impounded stream water. In general, most TP concentrations were well below the 100 $\mu\text{g P/l}$ limit. Minimum concentrations were found in the fall samples. Station 2 on East Primrose had very low concentrations of TP (Table 16).

The readily available form of phosphorus for uptake by aquatic plant is the dissolved inorganic phosphate. Soluble reactive phosphorus (SRP) is essentially equivalent to the orthophosphate form which is the inorganic form of phosphorus that is generally reported. All SRP concentrations in these streams were relatively low (Table 17). Highest values were found in the Indian Grave and Jersey Brook systems. A maximum of 16.70 $\mu\text{g P/l}$ was found in Jersey Brook at Station 2 in the summer of 1987 (Table 17). Minimum values were associated with Station 2 on East Primrose, and all streams displayed a seasonal low concentration in the fall (Table 17). According to Goldman and Horne (1983) soluble phosphate concentrations in unpolluted rivers are usually less than 10 $\mu\text{g P/l}$ and commonly only 1 $\mu\text{g P/l}$. With the exception of the summer 87, the SRP concentrations in these streams fall into that range.

II. Concentrations of Aluminum

Surface Water Samples.

Mean concentrations of total recoverable aluminum in surface water samples for the 10 sites are given in Table 18. Mean concentrations were based on duplicate determinations from duplicate grab samples. Values were generally low and ranged from 0.022 mg/l at J2 in the fall of 1986 to a high of 0.103 mg/l also at J2 in the spring and summer of 1987 (Table 8).

Except for the Passaic, all streams exhibited a seasonal pattern with minimum concentrations in the fall and/or winter and maximum values in the spring and/or summer (Fig. 2a,b). Concentrations in the Passaic range from 0.039 mg/l to 0.070 mg/l, which were similar to concentrations found in the other streams, but with little or no evidence for a seasonal trend (Table 18, Fig. 2a,b).

Concentrations did not differ significantly between the sites on the West Branch of Primrose, Indian Graves, or the Passaic (Fig. 2a,b). Aluminum concentrations at Station 2 (upstream) on the East Branch of Primrose and Jersey Brook appeared to be somewhat higher than concentrations at the downstream stations (Sta. 1). This difference was especially evident in the winter 1986 and the spring/summer 1987 samples (Fig. 2a,b).

Soil Samples

Soil pH values in water and in 0.01 M CaCl_2 were clearly acidic, and the pH in 0.01 M CaCl_2 was significantly lower than the pH in water. According to Dr.

Table 18. Total recoverable aluminum (mg/l).

TIME OF YEAR (1986-1987)	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
SUMMER '86	0.064	0.089	0.045	0.043	0.047	0.048	0.043	0.043	0.047	0.041
FALL	0.024	0.030	0.024	0.026	0.029	0.032	0.026	0.022	0.039	0.049
WINTER	*	*	0.030	0.025	0.026	0.027	0.056	0.078	0.053	0.070
SPRING '87	0.047	0.082	0.062	0.066	0.041	0.047	0.053	0.103	0.052	0.052
SUMMER	0.051	0.092	0.060	0.057	0.089	0.079	0.051	0.103	0.047	0.036

*No Sample Taken

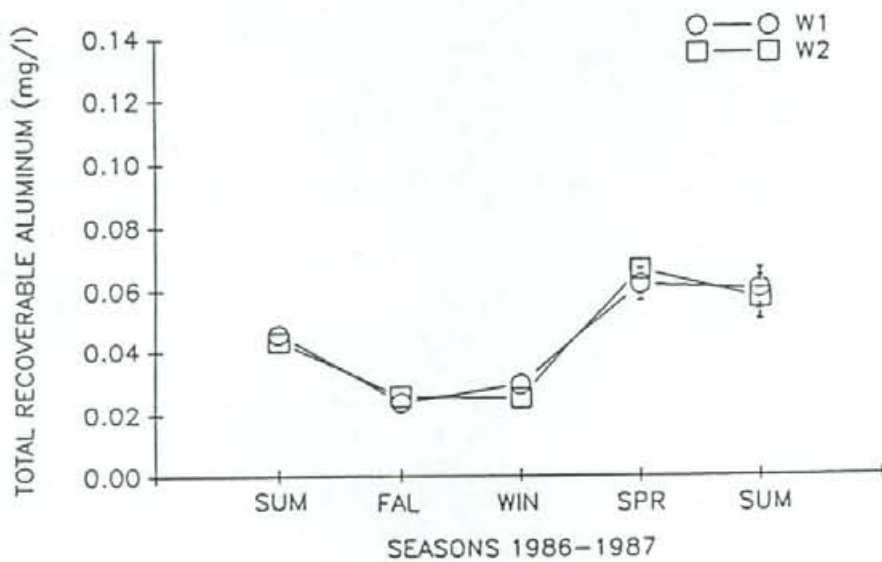
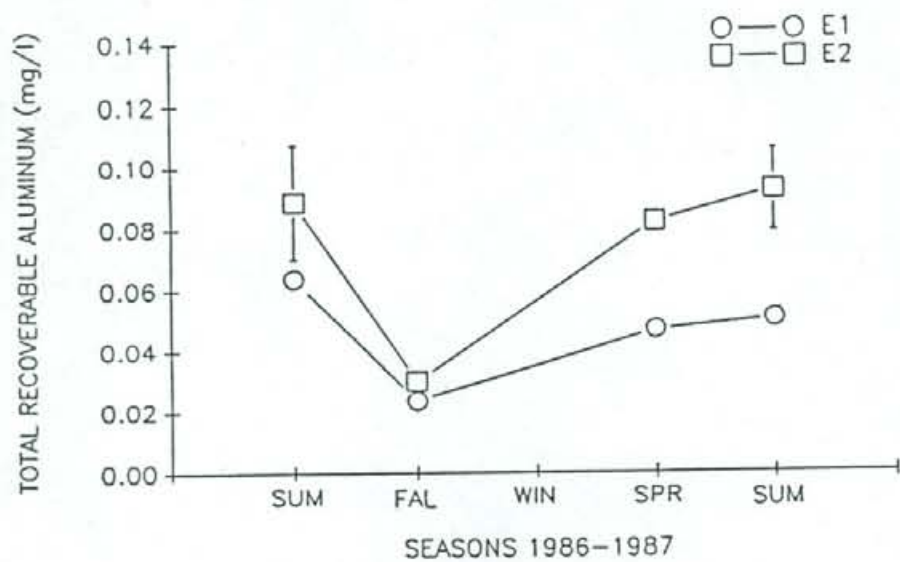


Fig. 2a. Seasonal concentrations $\pm$ S.E.M. ($n=2-3$) of total recoverable aluminum (mg/l) in East Branch and West Branch of Primrose Brook.

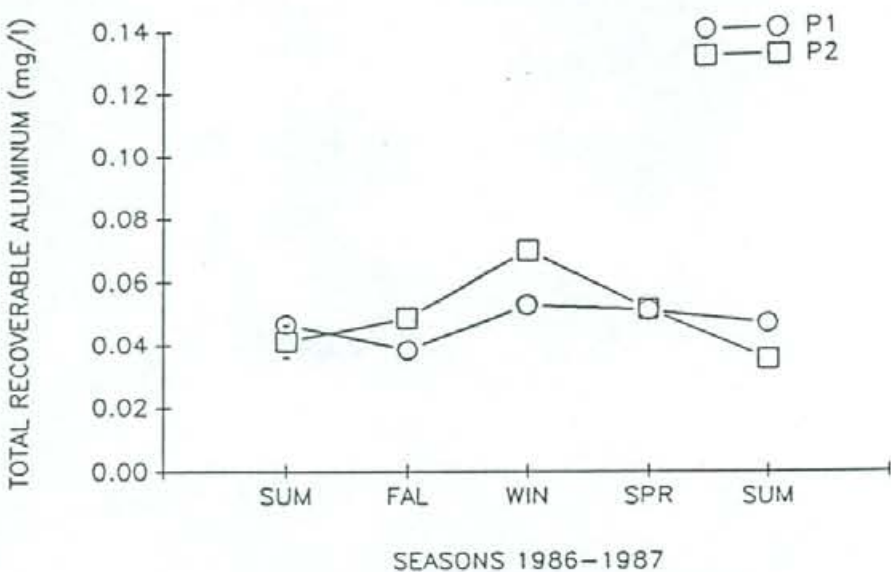
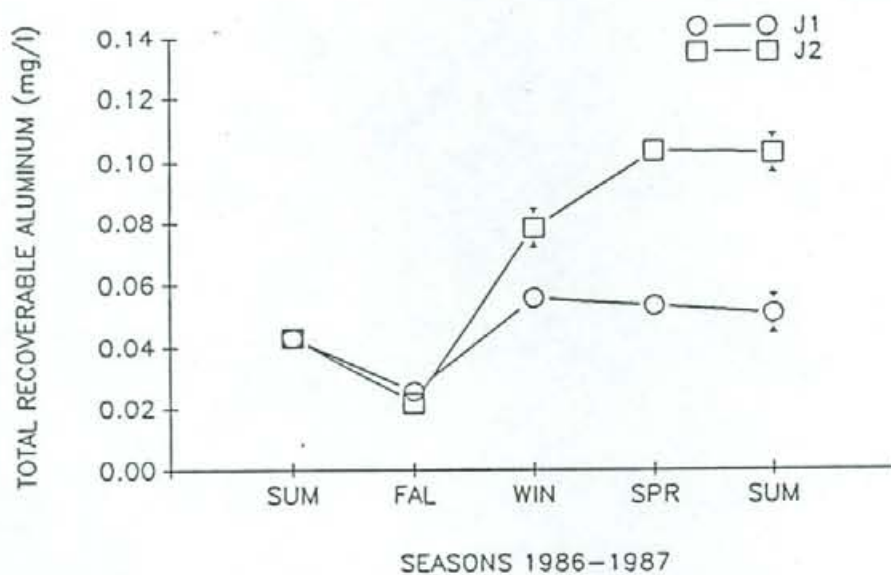
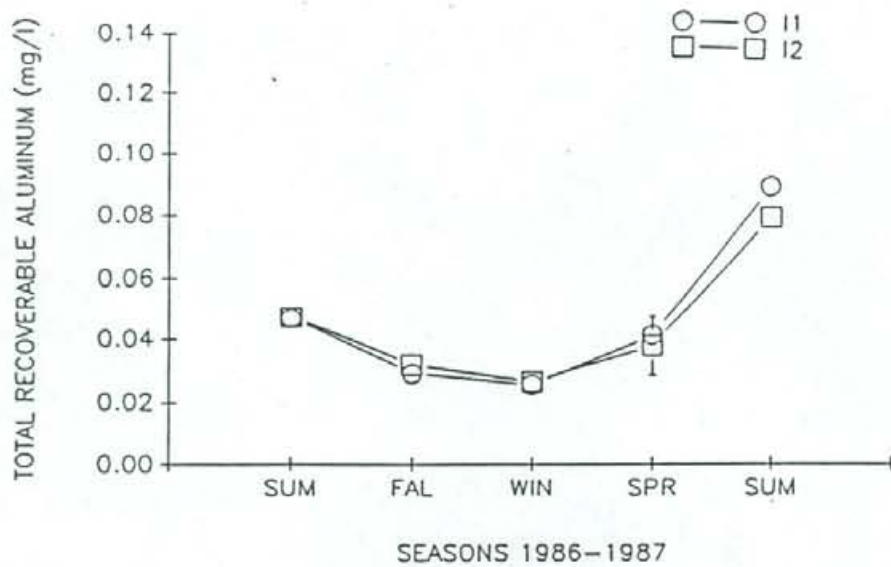


Fig. 2b. Seasonal concentrations $\pm$ S.E.M. ($n=2-3$) of total recoverable aluminum (mg/l) in Indian Grave Brook, Jersey Brook, and Passaic River.

Hsu (personal communication) that is an indication of the presence of exchangeable aluminum. The pH readings were as follows:

Sample	pH	
	in water	in 0.01 M CaCl_2
E1	4.716	4.068
E2	4.630	4.092
W1	5.723	5.172
W2	4.970	4.317

Exchangeable aluminum (1M KCl) concentrations ranged from a low of 0.4 mg/100 g soil at W1 to a high of 27.2 mg/100 g at E2 (Table 19). Extractible aluminum was, as expected, greater than exchangeable (Table 19). The low concentration found at W1 was not expected since there appeared to be little difference in soil or vegetation between the W1 and W2 areas. The low concentration of exchangeable aluminum of 0.4 mg/100 g soil at W1, however, was consistent with the higher pH observed for the soils of W1 (see above). Mobilization of soil aluminum becomes significant whenever the pH attains and passes 5. Above pH 5 the Al^{3+} ion is changed to hydroxyaluminum polymers (Bonneau and Souchier 1982). For the limited data in this study there was a negative relationship between soil pH (in water) and the exchangeable aluminum concentrations in the soil.

Table 19. Mean concentrations $\pm$ S.D. (n=5) of exchangeable and extractible aluminum in surface soils in the area of Stations 1 and 2 on the East and West Branches of Primrose Brook. Samples taken in July 1987.

Sample Location	Soil Concentrations (mg/100g)	
	Exchangeable Al	Extractible Al
East Branch Primrose		
Site 1	23.3 $\pm$ 0.2	35.2 $\pm$ 0.4
Site 2	27.2 $\pm$ 0.3	40.3 $\pm$ 0.4
West Branch Primrose		
Site 1	0.4 $\pm$ 0.1	3.7 $\pm$ 0.2
Site 2	18.9 $\pm$ 0.6	34.8 $\pm$ 0.2

Quality Assurance and Control

Two EPA QA/QC samples (Trace Metals 1 and 2) were used to check reliability of the analyses. Trace Metals 1 had a true value of 106 $\mu\text{g}/\text{l}$ with a reported mean recovery of 134 ± 23.2 $\mu\text{g}/\text{l}$ using the flameless AA. Our mean determination ($n=17$) was 139 ± 20.6 $\mu\text{g}/\text{l}$. Analyses of water samples spiked to give concentrations of 44 $\mu\text{g}/\text{l}$ and 155 $\mu\text{g}/\text{l}$ yielded 43 ± 7.1 and 145 ± 16 $\mu\text{g}/\text{l}$, respectively ($n=7$). This represented recoveries of 98 and 94%, respectively.

Trace Metal 2 had a true value of 730 $\mu\text{g}/\text{l}$ with a reported mean recovery of 746 ± 63.6 $\mu\text{g}/\text{l}$. Using the flame AA, the mean of 5 repetitive determinations was 0.7 ± 0.2 mg/l .

III. Fecal Coliforms and Fecal Streptococci

A 93% accuracy in differentiating between coliforms from warm blooded animals and coliforms from other sources was reported by Standard Methods (1985) for the technique used in this study. Concentrations of fecal coliform bacteria (FC) reported in this study are presumed, therefore, to be coliforms from warm blooded animals and not from other sources. Since the normal habitat for fecal streptococci (FS) is the intestinal tract of man and other animals, they too may be used as an indicator of fecal pollution. Data on fecal streptococci densities when used with fecal coliform counts may reveal more specific information about the source of fecal pollution since certain of the fecal streptococci bacteria are host specific (Standard Methods 1985). A FC/FS ratio greater than 4.1 is indicative of the presence of human waste and ratios less than 0.7 suggest contamination from non-human sources. Ratios between 0.7 and 4.4 usually indicate wastes of mixed human and animal sources (Standard Methods 1985). These ratios, however, must be cautiously applied. The FC/FS ratio should not be used, for example, when fecal streptococci counts are less than 100/100 ml.

The numbers of fecal coliform and fecal streptococci bacteria per 100 ml and the FC/FS ratios for all stations and seasons of the year are summarized in Table 20. Fecal coliform counts never exceeded 100/100 ml in East Primrose or the Passaic River. With the exception of the summer '87 sample, Indian Grave and Jersey Brook did not exceed 200/100 ml. The FC/FS ratios for the summer '87 samples from Indian Grave and Jersey Brook, however, ranged from 0.1 to 0.3, and did not, therefore, indicate human waste as the likely source for the fecal

Table 20. Seasonal counts of fecal coliform and fecal streptococci bacteria per 100 ml and their ratios for the streams of Morristown National Historical Park.

EAST PRIMROSE						
TIME OF YEAR (1986-87)	STATION 1			STATION 2		
	FECAL COLIFORM	FECAL STREPTOC	RATIO	FECAL COLIFORM	FECAL STREPTOC	RATIO
SUMMER '86	34	110	0.3	62	186	0.3
FALL	3	23	0.1	11	31	0.4
WINTER	-	-	-	-	-	-
SPRING '87	32	24	1.3	50	57	0.9
SUMMER	90	360	0.3	86	470	0.2

WEST PRIMROSE						
TIME OF YEAR (1986-87)	STATION 1			STATION 2		
	FECAL COLIFORM	FECAL STREPTOC	RATIO	FECAL COLIFORM	FECAL STREPTOC	RATIO
SUMMER '86	190	185	1.0	440	240	1.8
FALL	12	33	0.4	35	35	1.0
WINTER	20	10	2.0	10	4	2.5
SPRING '87	44	47	0.9	24	44	0.6
SUMMER	218	995	0.2	175	910	0.2

Table 20 (contd)

INDIAN GRAVE

TIME OF YEAR (1986-87)	STATION 1			STATION 2		
	FECAL COLIFORM	FECAL STREPTOC	RATIO	FECAL COLIFORM	FECAL STREPTOC	RATIO
SUMMER '86	49	413	0.1	63	915	0.1
FALL	32	198	0.1	1	385	0.0
WINTER	41	16	2.6	21	26	0.8
SPRING '87	20	49	0.4	25	72	0.4
SUMMER	283	2485	0.1	275	2360	0.1

JERSEY BROOK

TIME OF YEAR (1986-87)	STATION 1			STATION 2		
	FECAL COLIFORM	FECAL STREPTOC	RATIO	FECAL COLIFORM	FECAL STREPTOC	RATIO
SUMMER '86	74	1060	0.1	104	90	1.2
FALL	42	130	0.3	11	25	0.4
WINTER	60	22	2.7	184	22	8.4
SPRING '87	46	91	0.5	24	70	0.3
SUMMER	210	610	0.3	88	353	0.2

PASSAIC RIVER

TIME OF YEAR (1986-87)	STATION 1			STATION 2		
	FECAL COLIFORM	FECAL STREPTOC	RATIO	FECAL COLIFORM	FECAL STREPTOC	RATIO
SUMMER '86	59	2068	0.0	45	3283	0.0
FALL	88	100	0.9	45	55	0.8
WINTER	91	62	1.5	63	53	1.2
SPRING '87	9	8	1.1	12	10	1.2
SUMMER	45	963	0.0	50	1318	0.0

coliform bacteria found. Data for West Primrose were difficult to interpret in that the results for the two summers were contradictory. The fecal coliform counts were close to or exceeded the 200/100 ml limit.

The FC/FS ratios for most of the fall, winter and spring samples were based on fecal streptococci counts that were fewer than 100/100 ml and were, therefore, unreliable (Table 20). The low bacteria counts associated with samples other than those obtained in the summer months (hence, warmer water temperatures) preclude any blanket application of the FC/FS ratios. Based on the summer samples and with the exception of West Primrose in summer of '86, there was no indication that these streams were being polluted by domestic wastes containing human excrement.

IV. Benthic Algae and Macrophytes

No rooted aquatic macrophytes were observed at any of the sampling areas at any time. The absence of these plants may have been due to the rapid water currents, rocky substrates, changing water levels, low nutrient availability and/or limiting amounts of solar radiation in the growing season. The aquatic moss, Fontinalis was commonly observed growing on the rocks in these swiftly flowing streams. Occasionally, liverworts were also found on exposed rocks in the stream channel and along the wet banks.

Benthic algae were rarely abundant, and maximum growth was observed in the spring time when rocks became quite slippery because of the diatom populations. A composite listing of the algae observed in this study is given in Table 21. The seasonal distribution of benthic algae for each stream system is presented in Table 22, and the distribution by locality for the summer, fall and spring samples is found in Table 23.

Diatoms were the predominant algae found in these streams. The genera of diatoms observed on the rocks were characteristic of shallow rocky streams with high water quality. These diatoms also formed an excellent food base for the herbivorous aquatic macroinvertebrates inhabiting these biotic systems.

Table 21. Composite list of the genera of benthic algae found in the streams of Morristown National Historical Park, Morris County, New Jersey, from July 1986 to April 1987.

BLUEGREEN

Oscillatoria

GREEN

Ankistrodesmus

Cladophora

Closterium

Draparnaldia

Gleocystis

Oedogonium

Scenedesmus

Ulothrix

DESMID

Closterium

EUGLENOPHYTE

Euglena

Trachelomonas

DIATOM

Amphora

Bacillaria (paradoxa)

Cocconeis

Cymbella

Diatoma

Diploneis

Fragilaria

Gomphonema

Melosira

Meridion

Navicula

Pinnularia

Rhoicosphenia

Stauroneis

Surirella

Synedra

RED

Batrachospermum

Table 22. Seasonal occurrence of benthic algae.

EAST PRIMROSE						
GENERA	SUMMER 1986		FALL 1986		SPRING 1987	
	1	2	1	2	1	2

BLUEGREEN						
Oscillatoria		+		+		+
	N					
DESMID	O					
Closterium		+				
	S					
DIATOMS	A					
Cocconeis	M		+	+		
Cymbella	P			+		
Diatoma	L			+		
Melosira	E				+	
Meridion					+	+
Navicula	T	+	+	+	+	+
Pinnularia	A	+		+	+	
Rhoicosphenia	K			+		
Surirella	E	+				
Synedra	N	+	+			
EUGLENOPHYTE						
Trachelomonas		+				

Table 22 (contd)

WEST PRIMROSE

GENERA	SUMMER 1986		FALL 1986		SPRING 1987	
	1	2	1	2	1	2
BLUEGREEN				N		
Oscillatoria				O		+
GREEN				A		
Oedogonium	+		+	L		
				G		
DIATOM				A		
Amphora				E		+
Cocconeis	+		+			
Cymbella			+	F		
Diatoma			+	O		
Melosira	+		+	U		
Meridion				N	+	+
Navicula	+	+	+	D	+	+
Pinnularia	+	+			+	+
Rhoicosphenia			+	I		
Stauroneis	+	+	+	N		
Synedra	+	+				
EUGLENOPHYTE				S		
Trachelomonas			+	A		
				M		
				P		
				L		
				E		

Table 22 (contd)

INDIAN GRAVE

GENERA	SUMMER 1986		FALL 1986		SPRING 1987	
	1	2	1	2	1	2
BLUEGREEN						
Oscillatoria						+
GREEN						
Cladophora			+			
Oedogonium			+			
DIATOMS						
Cocconeis	+	+	+	+		
Cymbella			+	+		+
Diatoma		+	+	+		+
Diploneis						+
Melosira	+	+	+	+		+
Navicula	+	+	+	+	+	+
Rhoicosphenia			+	+		
Surirella				+		
Synedra	+	+	+	+	+	

Table 22 (contd)

JERSEY BROOK						
GENERA	SUMMER 1986		FALL 1986		SPRING 1987	
	1	2	1	2	1	2

BLUEGREEN						
Oscillatoria					+	
GREEN						
Cladophora		N			+	
Closterium		O			+	
Draparnaldia					+	
Oedogonium		S			+	
		A	+			
DIATOMS		M				
Cocconeis	+	P		+		
Cymbella		L	+			+
Diatoma	+	E		+		
Melosira	+			+	+	
Meridion		T			+	+
Navicula	+	A	+	+	+	+
Pinnularia		K	+		+	
Rhoicosphenia		E	+	+		
Synedra		N	+		+	+
EUGLENOPHYTE						
Euglena					+	
Trachelomonas	+					

Table 22 (contd)

PASSAIC RIVER						
GENERA	SUMMER 1986		FALL 1986		SPRING 1987	
	1	2	1	2	1	2

BLUEGREEN						
Oscillatoria				+		+
GREEN						
Ankistrodesmus			+		+	
Cladophora					+	
Closterium					+	+
Gleocystis	+					
Oedogonium	+	N				
Scenedesmus		O				+
Ulothrix					+	
		S				
DIATOMA		A				
Bacillaria (paradoxa)		M		+		
Cocconeis	+	P	+	+		+
Cymbella		L	+	+	+	+
Diatoma		E	+		+	+
Fragilaria				+	+	
Gomphonema		T			+	+
Melosira	+	A	+	+	+	+
Meridion		K			+	+
Navicula	+	E	+	+	+	+
Pinnularia		N	+	+		
Rhoicosphenia			+		+	+
Stauroneis					+	+
Synedra	+			+	+	+
EUGLENOPHYTE						
Trachelomonas	+					
RED						
Batrachospermum				+	+	

Table 23. Benthic algae found in the summer, fall and spring at each stream site.

GENERA	SAMPLE LOCATIONS						SUMMER 1986			
	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
BLUEGREEN										
Oscillatoria		+								
GREEN										
Gleocystis	N						N		+	N
Oedogonium	O						O		+	O
Ulothrix			+							
DESMID	S						S			S
Closterium	A						A			A
	M	+					M			M
	P						P			P
DIATOM	L						L			L
Cocconeis	E		+		+	+	+	E	+	E
Diatoma						+	+			
Melosira	T		+		+	+	+	T	+	T
Navicula	A	+	+	+	+	+	+	A	+	A
Pinnularia	K	+	+	+			K			K
Stauroneis	E		+	+			E			E
Surirella	N	+					N			N
Synedra		+	+	+	+	+			+	
EUGLENOPHYTE										
Trachelomonas		+					+		+	

Table 23 (contd)

GENERA	SAMPLE LOCATIONS						FALL 1986			
	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
BLUEGREEN										
Oscillatoria		+		N						+
				O						
GREEN										
Ankistrodesmus				A					+	
Cladophora				L	+					
Oedogonium			+	G	+		+			
				A						
DIATOM				E						
Bacillaria (paradoxa)										+
Cocconeis	+	+	+	F	+	+	+	+	+	+
Cymbella		+	+	O	+	+	+		+	+
Diatoma		+	+	U	+	+		+	+	
Fragilaria				N						+
Melosira			+	D	+	+		+	+	+
Navicula	+	+	+		+	+	+	+	+	+
Pinnularia		+		I			+		+	+
Rhoicosphenia		+	+	N	+	+	+	+	+	
Stauroneis			+							
Surirella				S		+				
Synedra	+			A	+	+	+			+
				M						
EUGLENOPHYTE				P						
Trachelomonas			+	L						
				E						
RED										
Batrachospermum										+

Table 23 (contd)

GENERA	SAMPLE LOCATIONS				SPRING 1987					
	EAST PRIMROSE		WEST PRIMROSE		INDIAN GRAVE		JERSEY BROOK		PASSAIC RIVER	
	1	2	1	2	1	2	1	2	1	2
BLUEGREEN										
Oscillatoria		+		+		+	+			+
GREEN										
Ankistrodesmus									+	
Cladophora							+		+	
Closterium							+		+	+
Draparnaldia							+			
Scenedesmus										+
Ulothrix									+	
DIATOM										
Amphora				+						
Cocconeis										+
Cymbella						+		+	+	+
Diatoma						+			+	+
Diploneis						+				
Fragilaria									+	
Gomphonema									+	+
Melosira	+					+	+		+	+
Meridion	+	+	+	+			+	+	+	+
Navicula	+	+	+	+	+	+	+	+	+	+
Pinnularia	+		+	+			+			
Rhoicosphenia									+	+
Stauroneis									+	+
Synedra					+		+	+	+	+
EUGLENOPHYTE										
Euglena							+			
RED										
Batrachospermum									+	

V. Benthic Macroinvertebrates

Survey Results.

The results of the benthic macroinvertebrate survey are summarized in Tables 24-33 which summarize by site and collection period the number of individuals collected from each taxon from approximately 0.5 m² of substrate. The total number of taxa and individuals collected each period appears at the end of each table. Specimens from four phyla, Platyhelminthes, Annelida, Arthropoda, and Mollusca, were found over the course of the survey. Arthropods were ubiquitous, especially the class Insecta. Nine order of insects were represented. Plecoptera (stoneflies), Ephemeroptera (mayflies), Odonata (dragonflies), Trichoptera (caddisflies), Coleoptera (beetles), and Diptera (true flies) were ubiquitous among the sites over the collection period.

Community Structure.

Community structure was examined in terms of species diversity and evenness. Shannon diversity and evenness index values for the sites during each collection period can be found in Tables 34 and 35. Diversity index values for individual samples ranged from 0.819 to 2.887, and evenness index values ranged from 0.310 to 0.974 (Galloway 1988).

There were no significant differences among the streams or among the collection periods with respect to species diversity. Analyses were performed on a square transformation of diversity index values to maintain a normal distribution.

There were no significant differences in evenness among the streams. Evenness, however, did differ significantly between collection periods ($p < 0.035$). Duncan's multiple range test ($p < 0.05$) revealed that in terms of evenness the fall was significantly different from the spring. The interaction of collection period x stream was significant ($p < 0.001$) for diversity and evenness. This significant interaction was the failure of the differences in diversity and evenness of the streams to be the same for each collection period.

Reference Collection.

A reference collection of the macroinvertebrates found in the park streams during the course of this study was assembled (Galloway 1989). Specimens were classified and cataloged according to the Natural History Hierarchial Classification Outline provided by the National Park Service. A catalog of the specimens in this collection appears in Appendix B.

The collection, at the present time, is held by the Department of Entomology and Economic Zoology, Rutgers University, New Brunswick, New Jersey.

Table 24. Species list and number of individuals collected from 0.46 m² at site E1: East Branch Primrose Brook, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Haplotaxida			
Naididae	1		
Plecoptera			
<u>Acroneuria</u> sp.	3	4	1
<u>Acroneuria</u> <u>abnormis</u>	3	3	2
<u>Allonarcys</u> sp.	26	11	3
<u>Isoperla</u> sp.			3
<u>Leuctra</u> <u>truncata</u>	82		
<u>Remenus</u> sp.			1
<u>Tallaperla</u> sp.	43	11	6
<u>Utaperla</u> <u>gaspesiana</u>	1	7	3
Ephemeroptera			
<u>Baetis</u> sp.	2	3	70
<u>Cinygmula</u> <u>subaequalis</u>			57
<u>Epeorus</u> <u>pleuralis</u>			22
<u>Ephemerella</u> sp.			164
<u>Isonychia</u> sp.		2	
<u>Paraleptophlebia</u> sp.	3	36	5
<u>Stenonema</u> sp.		2	
Odonata			
<u>Lanthus</u> <u>vernalis</u>	5	1	
Hemiptera			
<u>Gerris</u> <u>marginatus</u>	1		1
<u>Microvelia</u> <u>fontinalis</u>	3		
<u>Rhagovelia</u> <u>obesa</u>		1	
Trichoptera			
<u>Cheumatopsyche</u> sp.	4	20	2
<u>Diplectrona</u> <u>modesta</u>	5	7	2
<u>Dolophilodes</u> sp.	15	28	1
<u>Glossosoma</u> sp.	8	1	2
<u>Hydropsyche</u> sp.	14	11	1
<u>Lepidostoma</u> sp.			3
<u>Neophylax</u> sp.			37
<u>Neophylax</u> <u>mittchelli</u>	1		1
<u>Neophylax</u> <u>oligius</u>	4		11
<u>Polycentropus</u> sp.	2	2	1
<u>Rhyacophila</u> <u>fuscula</u>	5	3	15
<u>Rhyacophila</u> <u>vibox</u>	8	3	11
Coleoptera			
<u>Ectopria</u> <u>nervosa/thoracica</u>		2	3
<u>Hydrobius</u> <u>tumidus</u>	1		

Table 24 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Optioservus</u> sp.	1	1	1
<u>Optioservus ovalis</u>	101	40	1
Diptera			
<u>Antocha</u> sp.			1
<u>Diamesinae</u>	11	25	
<u>Dicranota</u> sp.	1	1	6
<u>Eriocera spinosa</u>	9	4	3
<u>Orthocladiinae</u>		28	7
<u>Palpomyia</u> sp.		3	
<u>Prosimulium mixtum</u>			97
<u>Simulium jenningsi</u>	18	6	25
<u>Simulium venustum</u>			2
<u>Tanypodinae</u>	6		2
<u>Tipula</u> sp.		7	
<u>Tipula abdominalis</u>			4
no. taxa	30	29	37
no. individuals	387	273	577

Table 25. Species list and number of individuals collected from 0.46 m² at site E2: East Branch Primrose Brook, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Haplotaxida			
<u>Naididae</u>		2	
Decapoda			
<u>Cambarus bartoni</u>	3		3
Collembola			
<u>Isotoma</u> sp.	1		
Plecoptera			
<u>Acroneuria</u> sp.	4	4	1
<u>Acroneuria abnormis</u>		2	
<u>Eccopectura</u> sp.		1	
<u>Isoperla</u> sp.		1	4
<u>Leuctra truncata</u>	285		1
<u>Tallaperla</u> sp.	138	30	5
<u>Utaperla gaspesiana</u>	4	6	13
Ephemeroptera			
<u>Baetis</u> sp.	23	5	9
<u>Cinygmula subaequalis</u>			50
<u>Epeorus pleuralis</u>			20
<u>Ephemerella</u> sp.			263
<u>Eurylophella</u> sp.			1
<u>Habrophlebiodes</u> sp.	5		
<u>Paraleptophlebia</u> sp.	43	163	265
<u>Stenonema</u> sp.	1	24	7
Odonata			
<u>Cordulegaster erronea</u>	1		
<u>Lanthus vernalis</u>	16	14	22
Hemiptera			
<u>Hebrus</u> sp.	1		
<u>Microvelia fontinalis</u>	11	1	
<u>Rhagovalia obesa</u>		3	
Megaloptera			
<u>Nigronia fasciatus</u>	2	4	1
<u>Sialis</u> sp.		1	
Trichoptera			
<u>Diplectrona modesta</u>	15	36	35
<u>Dolophilodes</u> sp.	22	4	
<u>Glossosoma</u> sp.	1		9
<u>Goera fuscata</u>	1		
<u>Hydropsyche</u> sp.		3	6

Table 25 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Lepidostoma</u> sp.	4		22
<u>Molannodes</u> sp.			1
<u>Neophylax</u> sp.			3
<u>Neophylax mitchelli</u>	5		2
<u>Neophylax oligius</u>	19		28
<u>Polycentropus</u> sp.	3		
<u>Psilotreta</u> sp.	9	4	16
<u>Rhyacophila vibox</u>	2	2	19
<u>Wormaldia</u> sp.		3	
Coleoptera			
<u>Cymbiodyta chamberlaini/blanchardi</u>			1
<u>Ectopria nervosa/thoracica</u>	2	5	
<u>Hydrobius</u> sp.	4		
<u>Optioservus</u> sp.	11	2	4
<u>Optioservus ovalis</u>	55	18	16
Diptera			
Chironominae			7
<u>Dicranota</u> sp.	15	1	4
<u>Dixa</u> sp.	6	2	
<u>Eriocera spinosa</u>	12	2	7
<u>Limnophila</u> sp.		2	
Orthocladiinae		1	13
<u>Palpomyia</u> sp.	1	2	
<u>Prosimulium mixtum</u>			237
<u>Psuedolimnophila</u> sp.		2	
<u>Simulium jenningsi</u>	10	1	9
<u>Simulium vittatum</u>			1
<u>Tabanus</u> sp.		1	1
Tanypodinae	5		
<u>Tipula</u> sp.	2	12	
<u>Tipula abdominalis</u>	2	1	
no. taxa	37	35	36
no. individuals	744	365	1106

Table 26. Species list and number of individuals collected from 0.46 m² at site W1: West Branch Primrose Brook, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Haplotaxidae			
Naididae	3		
Decapoda			
<u>Cambarus bartoni</u>	1		
Plecoptera			
<u>Acroneuria</u> sp.	1	1	
<u>Acroneuria</u> <u>abnormis</u>		1	
<u>Allonarcys</u> sp.		2	1
<u>Amphinemura</u> <u>delosa</u>			5
<u>Isoperla</u> sp.	3		5
<u>Leuctra</u> <u>truncata</u>	65		5
<u>Phasganophora</u> sp.	6		
<u>Remus</u> sp.	1		3
<u>Tallaperla</u> sp.	60	9	1
<u>Utaperla</u> <u>gaspesiana</u>		6	6
Ephemeroptera			
<u>Baetis</u> sp.	3	17	50
<u>Cinygmula</u> <u>subaequalis</u>			97
<u>Epeorus</u> <u>pleuralis</u>			31
<u>Ephemerella</u> sp.			264
<u>Isonychia</u> sp.	1	1	
<u>Paraleptophlebia</u> sp.	7	25	
<u>Pseudocloeon</u> sp.		4	
<u>Serratella</u> sp.		3	
<u>Stenonema</u> sp.	1	5	2
Odonata			
<u>Cordulegaster</u> <u>erronea</u>		1	
<u>Lanthus</u> <u>vernalis</u>	12	3	2
Hemiptera			
<u>Rhagovelia</u> <u>obesa</u>		6	
Megaloptera			
<u>Nigronia</u> <u>faciatus</u>		1	
<u>Sialis</u> sp.	1		
Trichoptera			
<u>Cheumatopsyche</u> sp.		19	
<u>Diplectrona</u> <u>modesta</u>	8	5	11
<u>Dolophilodes</u> sp.	21	7	
<u>Glossosoma</u> sp.	13	2	1
<u>Goera</u> <u>fuscula</u>		2	
<u>Hydropsyche</u> sp.	12	12	2

Table 26 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Neophylax</u> sp.			46
<u>Neophylax mitchelli</u>	20		7
<u>Neophylax oligius</u>	13		5
<u>Polycentropus</u> sp.	3		1
<u>Psilotreta</u> sp.			1
<u>Pycnopsyche luculenta</u>	6		
<u>Rhyacophila fuscula</u>	3	4	11
<u>Rhyacophila vibox</u>	1		12
<u>Wormaldia</u> sp.		4	
<u>Coleoptera</u>			
<u>Ectopria nervosa/thoracica</u>	1	6	
<u>Optiosevus</u> sp.	3	5	4
<u>Optioservus ovalis</u>	53	49	14
<u>Diptera</u>			
<u>Antocha</u> sp.	1		1
<u>Culcidae</u>	1		
<u>Diamesinae</u>	13	12	6
<u>Dixa</u> sp.		1	
<u>Ephydridae</u>		1	
<u>Eriocera spinosa</u>	12	10	9
<u>Orthocladiinae</u>		15	8
<u>Palpomyia</u> sp.	1	2	2
<u>Prosimulium mixtum</u>			61
<u>Pseudolimnophila</u> sp.		1	
<u>Simulium jenningsi</u>	3	4	8
<u>Simulium venustum</u>			2
<u>Tabanus</u> sp.	1		
<u>Tanypodinae</u>	5	1	
<u>Tipula</u> sp.		3	
<u>Tipula abdominalis</u>	3		
no. taxa	36	36	32
no. individuals	362	250	682

Table 27: Species list and number of individuals collected from 0.46 m² at site W2: West Branch Primrose Brook, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Turbellaria			1
Decapoda			
<u>Cambarus bartoni</u>	3		1
Plecoptera			
<u>Amphinemura delosa</u>			71
<u>Isoperla</u> sp.		10	
<u>Leuctra truncata</u>	72		16
<u>Perlesta</u> sp.		1	
<u>Tallaperla</u> sp.	92	67	12
<u>Utaperla gaspesiana</u>		19	17
Ephemeroptera			
<u>Baetis</u> sp.	17	4	3
<u>Cinygmula subaequalis</u>			9
<u>Epeorus pleuralis</u>			1
<u>Ephemerella</u> sp.			150
<u>Eurylophella</u> sp.	1	1	
<u>Habrophlebiodes</u> sp.	1		
<u>Paraleptophlebiodes</u> sp.	10	10	16
<u>Stenonema</u> sp.		19	2
<u>Stenonema carolina</u>		6	
Odonata			
<u>Lanthus vernalis</u>	7	9	1
Megaloptera			
<u>Nigronia fasciatus</u>	1	1	
Trichoptera			
<u>Cheumatopsyche</u> sp.		14	1
<u>Diplectrona modesta</u>	2	12	1
<u>Dolophilodes</u> sp.	10	3	
<u>Glossosoma</u> sp.	3		4
<u>Hydropsyche</u> sp.	1	19	
<u>Lepidostoma</u> sp.	4		
<u>Neophylax</u> sp.			15
<u>Neophylax mitchelli</u>	80		6
<u>Neophylax oligius</u>	81		21
<u>Polycentropus</u> sp.	1		1
<u>Psilotreta</u> sp.	1	1	2
<u>Pycnopsyche luculenta</u>	1		
<u>Rhyacophila fuscula</u>		2	3
<u>Rhyacophila vibox</u>			7
<u>Wormaldia</u> sp.		7	3

Table 27 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Coleoptera</u>			
<u>Ectopria nervosa/thoracica</u>		1	1
<u>Hydrobius</u> sp.	3		
<u>Hydrobius tumidus</u>	1		
<u>Optioservus</u> sp.	4		5
<u>Optioservus ovalis</u>	11	15	2
<u>Diptera</u>			
<u>Antocha</u> sp.		1	
<u>Diamesinae</u>	7	10	
<u>Dicranota</u> sp.	14		
<u>Eriocera spinosa</u>	11	11	16
<u>Limnophila</u> sp.	4	1	1
<u>Orthocladiinae</u>		15	35
<u>Palpomyia</u>			1
<u>Prosimulium mixtum</u>			232
<u>Pseudolimnophila</u> sp.	2		
<u>Simulium jenningsi</u>	28	5	201
<u>Simulium vittatum</u>			2
<u>Tanypodinae</u>	9		3
<u>Tipula</u> sp.	1	16	
<u>Tipula ignobilis</u>		1	
no. taxa	31	28	35
no. individuals	483	281	863

Table 28. Species list and number of individuals collected from 0.46 m² at site 11: Indian Grave Brook, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Turbellaria			1
Haplotaxida			
Naididae	5	4	5
Decapoda			
<u>Cambarus bartoni</u>	4	1	1
Collembola			
<u>Isotoma</u> sp.	1	1	
Plecoptera			
<u>Acroneuria</u> sp.	46	17	6
<u>Acroneuria abnormis</u>	9	10	7
<u>Allonarcys</u> sp.	1	1	1
<u>Amphinemura delosa</u>			5
<u>Isoperla</u> sp.			1
<u>Leuctra truncata</u>	168		2
<u>Phasganophora</u> sp.	5		
<u>Paragnetina</u> sp.		1	1
<u>Tallaperla</u> sp.	1	7	
Ephemeroptera			
<u>Baetis</u> sp.	26	12	62
<u>Caenis</u> sp.	3		
<u>Centroptilium</u> sp.	4		
<u>Epeorus pleuralis</u>	9		61
<u>Ephemerella</u> sp.			229
<u>Ephemerella cornuta</u>			15
<u>Isonychia</u> sp.	19	19	
<u>Paraleptophlebia</u> sp.	20	18	1
<u>Stenonema</u> sp.	4	17	7
Odonata			
<u>Lanthus vernalis</u>	3		
Hemiptera			
<u>Microvelia fontinalis</u>		1	
Megaloptera			
<u>Nigronia serricornis</u>	6	1	
Trichoptera			
<u>Apatania</u> sp.		3	
<u>Cheumatopsyche</u> sp.	23	14	2
<u>Chimarra obscura</u>		1	1
<u>Diplectrona modesta</u>		2	3

Table 28 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Dolophilodes</u> sp.	33	61	4
<u>Glossosoma</u> sp.	21	9	6
<u>Hydropsyche</u> sp.	56	42	16
<u>Neophylax</u> sp.			4
<u>Neophylax oligius</u>	2		3
<u>Polycentropus</u> sp.	2		1
<u>Rhyacophila fuscula</u>	2	6	6
<u>Rhyacophila vibox</u>		1	2
<u>Wormaldia</u> sp.			1
<u>Coleoptera</u>			
<u>Ectopria nervosa/thoracica</u>	2		
<u>Optioservus</u> sp.	6	2	
<u>Optioservus ovalis</u>	22		
<u>Psephenus herricki</u>	14		4
<u>Diptera</u>			
<u>Antocha</u> sp.			10
<u>Blepharicera</u> sp.			2
<u>Diamesinae</u>	2	1	
<u>Dicranota</u> sp.	13	5	
<u>Dixa</u> sp.		1	
<u>Empididae</u>			7
<u>Eriocera spinosa</u>	9	1	5
<u>Orthocladiinae</u>	1	8	23
<u>Prosimulium mixtum</u>			268
<u>Psychoda</u> sp.	1		
<u>Simulium jenningsi</u>	1	2	2
<u>Simulium vittatum</u>			146
<u>Tanypodinae</u>	7	1	2
<u>Tipula</u> sp.		10	
no. taxa	36	32	38
no. individuals	551	280	923

Table 29. Species list and number of individuals collected from 0.46 m² at site I2: Indian Grave Brook, for each collection period.

Taxa	Seasons 1986-1987		
	Summer	Fall	Spring
Haplotaaxida			
Naididae	15	5	10
Decapoda			
<u>Cambarus bartoni</u>	4		
Plecoptera			
<u>Acroneuria</u> sp.	27	20	11
<u>Acroneuria abnormis</u>	11	13	10
<u>Allonarcys</u> sp.	1	1	1
<u>Leuctra truncata</u>	101		
<u>Tallaperla</u> sp.	1	2	1
Ephemeroptera			
<u>Baetis</u> sp.	24	11	15
<u>Epeorus pleuralis</u>	4		59
<u>Ephemerella</u> sp.			206
<u>Ephemerella cornuta</u>			2
<u>Eurylophella</u> sp.			2
<u>Isonychia</u> sp.		2	
<u>Paraleptophlebia</u> sp.	30	64	6
<u>Serratella</u> sp.	1	15	
<u>Stenonema</u> sp.	2	13	5
Odonata			
<u>Lanthus vernalis</u>	7	3	4
Megaloptera			
<u>Nigronia serricornis</u>	9	3	4
Trichoptera			
<u>Cheumatopsyche</u> sp.	30	23	5
<u>Chimarra obscura</u>	5	4	3
<u>Diplectrona modesta</u>	3	10	15
<u>Dolophilodes</u> sp.	39	12	2
<u>Glossosoma</u> sp.	38	6	6
<u>Hydropsyche</u> sp.	94	37	16
<u>Micrasema</u> sp.		1	
<u>Neophylax</u> sp.			1
<u>Neophylax mitchelli</u>	1		2
<u>Neophylax oligius</u>	2		3
<u>Polycentropus</u> sp.		1	3
<u>Pycnopsyche</u> sp.			1
<u>Rhyacophila fuscula</u>	6		7
<u>Rhyacophila vibox</u>	2	10	2
Coleoptera			

Table 29 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Anacaena</u> sp.	1		
<u>Anchytarsus</u> <u>bicolor</u>	1		
<u>Ectopria</u> <u>nervosa/thoracica</u>	4	2	1
<u>Optioservus</u> sp.	3	3	
<u>Optioservus</u> <u>ovalis</u>	17	4	3
<u>Promoresia</u> sp.	3		
<u>Psephenus</u> <u>herricki</u>	17	11	6
<u>Stenelmis</u> <u>markeli</u>	1	1	
<u>Stenelmis</u> <u>sandersoni</u>	1		
Diptera			
<u>Antocha</u> sp.	2		3
Chironomidae	8		
Diamesinae	12	1	1
<u>Dicranota</u> sp.	8	6	
Empididae			7
<u>Eriocera</u> <u>spinosa</u>	4	5	3
Orthocladiinae	1	3	9
<u>Palpomyia</u> sp.		2	1
<u>Prosimulium</u> <u>mixtum</u>			74
<u>Simulium</u> <u>jenningsi</u>	4		1
Tanypodinae	6		3
<u>Tipula</u> sp.		6	1
no. taxa	41	32	40
no. individuals	550	300	515

Table 30. Species list and number of individuals collected from 0.46 m² at site J1: Jersey Brook, for each collection period.

Taxa	Seasons 1986-1987		
	Summer	Fall	Spring
Turbellaria			1
Haplotaxida			
Naididae		5	
Decapoda			
<u>Cambarus bartoni</u>	2	3	3
Collembola			
<u>Isotoma</u> sp.			1
Plecoptera			
<u>Acroneuria</u> sp.		2	
<u>Acroneuris abnormis</u>	8	8	2
<u>Allonarcys</u> sp.		1	
<u>Amphinemura delosa</u>			5
<u>Cultus</u> sp.			1
<u>Leuctra truncata</u>	88		26
<u>Phasganophora</u> sp.	13		
<u>Tallaperla</u> sp.	4	5	
Ephemeroptera			
<u>Baetis</u> sp.	30	29	39
<u>Epeorus pleuralis</u>	2		24
<u>Ephemerella</u> sp.			101
<u>Ephemerella cornuta</u>			2
<u>Ephemerella walkeri</u>			4
<u>Eurylophella</u> sp.			1
<u>Habrophlebiodes</u> sp.	4		113
<u>Isonychia</u> sp.	41	72	2
<u>Paraleptophlebia</u> sp.	18	17	
<u>Psuedocloeon</u> sp.			2
<u>Serratella</u> sp.	27	1	
<u>Stenonema</u> sp.	5	90	30
Odonata			
<u>Lanthus vernalis</u>	1	4	2
Hemiptera			
<u>Microvelia fontinalis</u>	1	1	
<u>Rhagovelis obesa</u>		1	
Megaloptera			
<u>Nigronia serricornis</u>	10	9	1
Trichoptera			
<u>Cheumatopsyche</u> sp.	21	42	2

Table 30 (contd)

Taxa	Seasons 1986-1987		
	Summer	Fall	Spring
<u>Chimarra obscura</u>	18	141	1
<u>Cyrnellus</u> sp.			1
<u>Diplectrona modesta</u>		4	1
<u>Dolophilodes</u> sp.	113	49	1
<u>Glossosoma</u> sp.	28	9	
<u>Goera fuscula</u>		1	
<u>Hydropsyche</u> sp.	37	73	8
<u>Neophylax</u> sp.			1
<u>Neophylax mitchelli</u>			2
<u>Neophylax oligius</u>	10		9
<u>Polycentropus</u> sp.	10	6	3
<u>Rhyacophila fuscula</u>	1	2	2
<u>Rhyacophila vibox</u>	11	12	
Coleoptera			
<u>Anchytarsus bicolor</u>	3	8	5
<u>Ectopria nervosa/thoracica</u>	4	13	1
<u>Optioservus</u> sp.	3	6	
<u>Optioservus ovalis</u>	26	3	4
<u>Promoresia</u> sp.		1	
<u>Psephenus herricki</u>	10	3	1
<u>Stenelmis markeli</u>		1	
<u>Stenelmis sandersoni</u>	1		
Diptera			
<u>Antocha</u> sp.			2
<u>Diamesinae</u>	1		
<u>Dicranota</u> sp.	7		1
<u>Dixa</u> sp.		1	
<u>Eriocera spinosa</u>	6	2	5
<u>Orthocladiinae</u>	2	5	83
<u>Palpomyia</u> sp.		3	
<u>Prosimulium mixtum</u>			2
<u>Pseudolimnophila</u> sp.			10
<u>Simulium jenningsi</u>	1	9	112
<u>Tabanus</u> sp.			1
<u>Tanypodinae</u>	8	3	2
<u>Tipula</u> sp.		2	
<u>Tipula abdominalis</u>	1		
no. taxa	37	39	43
no. individuals	576	647	620

Table 31. Species list and number of individuals collected from 0.46 m² at site J2: Jersey Brook, for each collection period.

Taxa	Seasons 1986-1987		
	Summer	Fall	Spring
Decapoda			
<u>Cambarus bartoni</u>	8	3	3
Plecoptera			
<u>Allonarcys</u> sp.	3	2	3
<u>Amphinemura delosa</u>			282
<u>Isoperla</u>			1
<u>Leuctra truncata</u>	9		2
<u>Tallaperla</u> sp.	96	39	3
Ephemeroptera			
<u>Baetis</u> sp.	7		29
<u>Cinygmula subaequalis</u>			1
<u>Epeorus pleuralis</u>			3
<u>Ephemerella</u> sp.			148
<u>Eurylophella</u>		1	
<u>Stenonema</u> sp.	6		
Odonata			
<u>Lanthus vernalis</u>	10	10	
Hemiptera			
<u>Microvelia fontinalis</u>		1	
<u>Trepobates</u> sp.	1		
Trichoptera			
<u>Apatania</u> sp.		1	
<u>Brachycentrus</u> sp.	1		
<u>Chimarra obscura</u>	1		
<u>Diplectrona modesta</u>	1		2
<u>Dolophilodes</u> sp.	1	1	
<u>Glossosoma</u> sp.	6	1	
<u>Goera fuscula</u>		2	
<u>Hydropsyche</u> sp.		1	
<u>Neophylax</u> sp.			8
<u>Neophylax mitchelli</u>	5		8
<u>Neophylax oligius</u>	18		7
<u>Pycnopsyche</u> sp.	4		
<u>Rhyacophila fuscula</u>			5
<u>Rhyacophila vibox</u>	2	2	5
<u>Wormaldia</u> sp.			2
Coleoptera			
<u>Anchytarsus bicolor</u>	1		
<u>Ectopria nervosa/thoracica</u>	10	14	3
<u>Optioservus</u> sp.	1	1	1
<u>Optioservus ovalis</u>	42	6	4

Table 31 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Diptera			
<u>Antocha</u> sp.	2		1
<u>Diamesinae</u>	5	1	
<u>Dicranota</u> sp.		3	1
<u>Dixa</u> sp.	3	1	
<u>Orthoclaadiinae</u>		9	132
<u>Oxycera</u> sp	2		
<u>Prosimulium mixtum</u>			546
<u>Simulium jenningsi</u>	27	1	83
<u>Tanypodinae</u>		1	2
<u>Tipula</u> sp.	8	18	
<u>Tipula abdominalis</u>	3	3	1
no. taxa	28	23	27
no. individuals	283	122	1286

Table 32. Species list and number of individuals collected from 0.46 m² at site P1: Passaic River, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Turbellaria		4	
Haplotaxida			
Naididae	24	56	38
Decapoda			
<u>Cambarus bartoni</u>			1
Plecoptera			
<u>Acroneuria</u> sp.	4		
<u>Allonarcys</u> sp.			1
<u>Amphinemura delosa</u>			19
<u>Leuctra truncata</u>			2
<u>Paragnetina</u> sp.		1	3
<u>Tallaperla</u> sp.	2		1
<u>Utaperla gaspesiana</u>			4
Ephemeroptera			
<u>Baetis</u> sp.	8	6	23
<u>Centroptilium</u> sp.	1		
<u>Epeorus pleuralis</u>			1
<u>Ephemerella</u> sp.			41
<u>Ephemerella cornuta</u>			19
<u>Ephemerella walkeri</u>			6
<u>Isonychia</u> sp.		45	15
<u>Pseudocloeon</u> sp.		1	18
<u>Stenonema</u> sp.		1	
Odonata			
<u>Boyeria vinosa</u>	1	1	
<u>Calopteryx maculata</u>		1	
<u>Lanthus vernalis</u>	3		3
Hemiptera			
<u>Gerris marginatus</u>	1		
<u>Microvelia fontinalis</u>	4		
Megaloptera			
<u>Corydalus cornutus</u>		11	4
<u>Nigronia serricornis</u>	10	8	1
Trichoptera			
<u>Agapetus</u> sp.			36
<u>Cheumatopsyche</u> sp.	68	55	
<u>Chimarra obscura</u>	65	141	11
<u>Cyrnellus</u> sp.			6
<u>Diplectrona modesta</u>			3

Table 32 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Dolophilodes</u> sp.		15	
<u>Glossosoma</u> sp.	2	2	6
<u>Hydropsyche</u> sp.	26	60	16
<u>Neophylax oligius</u>	1		9
<u>Rhyacophila fuscula</u>			7
<u>Rhyacophila vibox</u>	1	1	3
<u>Wormaldia</u> sp.			14
Coleoptera			
<u>Optioservus</u> sp.	4	6	1
<u>Optioservus ovalis</u>	3	1	2
<u>Psephenus herricki</u>	4	1	2
<u>Stenelmis</u> sp.		2	3
<u>Stenelmis markeli</u>		5	
<u>Stenelmis sandersoni</u>	3	3	
Diptera			
<u>Antocha</u> sp.		1	4
Diamesinae	10		
Empididae	1		2
Orthocladiinae		7	28
<u>Psychoda</u> sp.	1		
<u>Prosimulium mixtum</u>			1
<u>Simulium jenningsi</u>	10	15	89
<u>Simulium venustum</u>		2	
Tanypodinae			5
<u>Tipula</u> sp.		1	
no. taxa	24	28	38
no. individual	257	453	448

Table 33. Species list and number of individuals collected from 0.46 m² at site P2: Passaic River, for each collection period.

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
Turbellaria		5	2
Haplotaxida			
<u>Naididae</u>	7	49	26
Decapoda			
<u>Cambarus bartoni</u>			2
Plecoptera			
<u>Amphinemura delosa</u>			125
<u>Leuctra truncata</u>			3
<u>Paragnetina</u> sp.		1	
<u>Remenus</u> sp.			1
<u>Utaperla gaspesiana</u>			1
Ephemeroptera			
<u>Baetis</u> sp.	2	10	10
<u>Ephemerella</u> sp.			82
<u>Ephemerella cornuta</u>			28
<u>Ephemerella septentrionalis</u>			3
<u>Ephemerella walkeri</u>			28
<u>Habrophlebiodes</u> sp.			1
<u>Isonychia</u> sp.	9	113	26
<u>Paraleptophlebia</u>			2
<u>Pseudocloeon</u> sp.			2
<u>Stenonema</u> sp.			1
Odonata			
<u>Boyeria vinosa</u>	3	1	
<u>Lanthus vernalis</u>	2	1	1
Hemiptera			
<u>Microvelia fontinalis</u>	2		
Megaloptera			
<u>Corydalus cornutus</u>		6	2
<u>Nigronia serricornis</u>	18	12	1
<u>Sialis</u> sp.	1		1
Trichoptera			
<u>Agapetus</u> sp.			113
<u>Cheumatopsyche</u> sp.	147	199	110
<u>Chimarra obscura</u>	14	20	30
<u>Diplectrona modesta</u>			6
<u>Glossosoma</u> sp.	1	1	3
<u>Hydropsyche</u> sp.	30	96	40

Table 33 (contd)

<u>Taxa</u>	<u>Seasons 1986-1987</u>		
	<u>Summer</u>	<u>Fall</u>	<u>Spring</u>
<u>Neophylax mitchelli</u>			1
<u>Neophylax oligius</u>	1		6
<u>Polycentropus</u> sp.			1
<u>Rhyacophila vibox</u>			4
Coleoptera			
<u>Dineutus</u> sp.	3		
<u>Ectopria nervosa/thoracica</u>	1		
<u>Optioservus</u> sp.	6	2	
<u>Optioservus ovalis</u>		1	
<u>Stenelmis</u> sp.		4	9
<u>Stenelmis sandersoni</u>	10	16	14
Diptera			
<u>Antocha</u> sp.		1	
Diamesinae	2		
<u>Dicranota</u> sp.	5		
Empididae	2		1
Orthoclaadiinae	2		35
<u>Prosimulium mixtum</u>		1	
<u>Simulium jenningsi</u>	2	1	441
<u>Simulium piscicidium</u>			1
<u>Simulium venustum</u>			94
<u>Tabanus</u> sp.			1
Tanypodinae	1		2
Gastropoda			
<u>Physa</u> sp.		1	
Pelecypoda			
<u>Elliptio</u> sp.		2	
no. taxa	23	22	40
no. individuals	271	543	1260

Table 34. Shannon diversity index values for sampling sites during each collection period. Values are mean $\pm$ S.E.M. (n=5).

<u>SITE</u>	<u>SEASONS 1986-1987</u>		
	<u>SUMMER</u>	<u>FALL</u>	<u>SPRING</u>
E1	2.168 $\pm$ 0.179	2.303 $\pm$ 0.142	2.254 $\pm$ 0.153
E2	2.137 $\pm$ 0.137	1.973 $\pm$ 0.075	2.145 $\pm$ 0.082
I1	2.373 $\pm$ 0.085	2.230 $\pm$ 0.216	1.815 $\pm$ 0.073
I2	2.601 $\pm$ 0.058	2.390 $\pm$ 0.125	2.037 $\pm$ 0.110
J1	2.464 $\pm$ 0.177	2.210 $\pm$ 0.219	2.238 $\pm$ 0.102
J2	2.091 $\pm$ 0.097	1.904 $\pm$ 0.160	1.612 $\pm$ 0.200
P1	1.640 $\pm$ 0.170	2.039 $\pm$ 0.105	2.596 $\pm$ 0.057
P2	1.495 $\pm$ 0.119	1.522 $\pm$ 0.160	2.058 $\pm$ 0.216
W1	2.320 $\pm$ 0.096	2.501 $\pm$ 0.066	2.081 $\pm$ 0.086
W2	2.170 $\pm$ 0.082	2.265 $\pm$ 0.117	2.085 $\pm$ 0.123

Table 35. Shannon evenness index values for sampling sites during each collection period. Values are mean $\pm$ S.E.M. (n=5).

<u>SITE</u>	<u>SEASONS 1986-1987</u>		
	<u>SUMMER</u>	<u>FALL</u>	<u>SPRING</u>
E1	0.804 $\pm$ 0.054	0.837 $\pm$ 0.024	0.791 $\pm$ 0.025
E2	0.713 $\pm$ 0.035	0.716 $\pm$ 0.022	0.714 $\pm$ 0.035
I1	0.789 $\pm$ 0.025	0.863 $\pm$ 0.023	0.609 $\pm$ 0.031
I2	0.842 $\pm$ 0.028	0.859 $\pm$ 0.032	0.680 $\pm$ 0.041
J1	0.821 $\pm$ 0.041	0.791 $\pm$ 0.035	0.762 $\pm$ 0.020
J2	0.794 $\pm$ 0.050	0.872 $\pm$ 0.037	0.605 $\pm$ 0.076
P1	0.807 $\pm$ 0.048	0.780 $\pm$ 0.039	0.850 $\pm$ 0.029
P2	0.671 $\pm$ 0.054	0.731 $\pm$ 0.028	0.687 $\pm$ 0.058
W1	0.812 $\pm$ 0.028	0.873 $\pm$ 0.026	0.715 $\pm$ 0.024
W2	0.779 $\pm$ 0.032	0.838 $\pm$ 0.039	0.706 $\pm$ 0.040

DISCUSSION

Stream Flow and Discharge

With the exception of the Passaic River, which flows through a relatively small area of the park (Fig. 1), the streams are narrow and shallow; they range in width from only about 1m at E2, 2m in Jersey Brook and West Branch of Primrose Brook, to 3 or 4 m at E1 and Indian Grave Brook. Average depths do not exceed 0.16m even for spring time flows. It is highly unlikely, nevertheless, that these swiftly flowing small streams would dry up completely except during a rare prolonged drought.

Primrose Brook, with the exception of a small region at the headwaters of the East Branch, arises wholly within the park's boundary (Fig. 1). The East and West Branches of Primrose, therefore, represent a major and critical aquatic resource for the park. Both branches are permanent streams and depend upon the groundwater for their flow between periods of surface runoff resulting from rainfall or melting snow and ice. Their small but significant discharge varies seasonally but is ever present. Assuming that W1 discharge (Table 3) represents the total contribution of the West Branch to the flow of Primrose Brook (E1) below the confluence of the two branches (Fig. 1), the West Branch contributes approximately between 25 and 50% of the flow in Primrose Brook at E1 during the summer and fall and about 65% of the flow in the spring. In general, each branch contributes roughly equal discharge to the confluent Primrose Brook, which traverses additional parkland (Fig. 1).

The flow at the Passaic sites is apparently strongly influenced by an upstream impoundment, Leddell Pond (Fig. 1). There is ample flow at all times and the high spring time flows are not as excursive as in the smaller streams (Table 3). Although no data were taken, the flow in the Passaic under all circumstances is probably subject to less extreme discharges than the other streams because of a moderating influence from the upstream impoundment.

Surface Water Quality

Abiotic and biotic components and the processes that contribute to water quality are integrated within the confines of a specific catchment ecosystem (Gower 1980). The park's catchment system includes the streams, their drainage areas, and the airshed or atmospheric influences. As Gower points out, the quality, or characteristics, acquired by water is the result of a series of physical, chemical, and biological processes outside of and within a stream or body of water.

Physico-Chemical

Prevailing moderate to low water temperatures and essentially 100% oxygen saturation for all of the park's streams signal a potentially highly suited habitat for aquatic organisms. The circumneutral pH and low alkalinity of these biotic waters reflect a low calcium/magnesium source in this drainage basin or watershed, and this produces an aquatic medium with a low to modest buffering capacity. In short, the pH of these waters is currently highly suitable for all purposes but is subject to a significant change if there were certain perturbations in the watershed or airshed.

Atmospheric deposition of acid-forming anions (SO_x , NO_x) can and are being neutralized by the soils in the drainage basin of these streams. Acidic precipitation and dry fallout should not seriously effect the water chemistry of these streams as long as the soil can, in a sense, absorb these pollutants. Although the extent of this soil's capacity to netralize acid anions is not known, it is probably not very extensive. Similarly, a large influx of alkali, which is unlikely in the absence of intensive agricultural activity or an accidental spill, would overwhelm the buffering capacity of these surface waters and would lead to a significant rise in the pH, alteration of the water chemistry, and a change in flora and fauna of these streams.

None of the environmental variables measured (eg. $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, TP, Cl, etc.) were found in concentrations considered as excessive or detrimental to aquatic organisms. Total dissolved solids and specific conductance were significantly lower in samples from Site 2 on the East Branch of Primrose than in samples from any other location (Table 5 and 6). Site 2 of East Branch of Primrose also consistently had a lower alkalinity value than the other sites (Table 9). Primrose Brook, in general, contained less chloride ion than any of the other streams (Table 11). Since Primrose arises essentially within the park's boundary, it is not subjected to pollutants associated with deicing salts on roadways, septic tank drainage, and fertilization of landscapes.

Water Quality Indices

Attempts to use numerical water quality indices (WQI) to rank various levels of water quality date back a little more than two decades. With the exception of fecal coliform counts, these indices have been for the most part

based on the physical and chemical data available from a broad range of monitoring activity. In spite of their obvious interrelatedness, biological and physico-chemical indices of water quality are usually evaluated separately. Integration of the two generally massive data sets has proven to be a most formidable task.

Of the several physico-chemical indices found in the literature, those pertaining to a general water quality or those developed for specific uses of the water (eg. public water supply, fishing, etc.) are most relevant to the park's needs. In addition, specific-use WQI's seem to be subsets of information contained within a general WQI. Ott (1978) points out that the FAWL and PWS specific-use indices of O'Connor (1972) appear to be subsets of information contained in the NSF WQI, a general water quality index. He further states that the NSF WQI may actually be a "weighted average" of all possible specific-use indices.

In any event, any agency can establish its own list of environmental variables, assign a relative weighting to those variables, and develop its own WQI. That WQI, if consistently derived, can serve as a benchmark for the purpose of longterm monitoring and management. Of course, the WQI thusly derived cannot be compared directly to other indices which may be based upon different variables and weightings.

Many general WQI's have been introduced in the literature, and most have fallen into disuse. A frequently used index is the National Sanitation Foundation water quality index (NSF WQI). According to Canter (1985) 10 of the 51 state agencies use an index; 17 states and 1 interstate commission are

considering the use of an index, and, of these, 14 are giving consideration to the NSF WQI. Most frequently cited reasons for using a WQI are: 1) annual reports, 2) public information and presentations, and 3) assessment of trends in water quality (Canter 1985).

House and Ellis (1980) evaluated existing practices for water quality classification in the United Kingdom and assessed the use of the WQI as a monitoring device. They found good agreement between the geometric weighted WQI (Brown et al. 1970; McClelland 1974) and the index/classification systems in use in the UK. They concluded that a general WQI was as efficient as any of the many use-related indices used to monitor water quality.

The NSF WQI consists of a set of 9 parameter-quality curves and an assignment of a relative weight to each of the 9 environmental parameters (Canter 1985). The curves are used to derive subindex values from the measured values of each of the 9 parameters or variables. Each subindex value is either multiplied by its weighting factor (summation of these products is the arithmetic weighted index or WQI_a) or raised to the power of its weighting factor (the factorial product of these is the geometric weighted index or WQI_g). The 9 environmental parameters or variables are: dissolved oxygen, fecal coliforms, pH, BOD₅, NO₃, PO₄, temperature deviation from equilibrium, turbidity, and total solids.

A "Modified" NSF WQI Index

Instead of computing a WQI for each seasonal sample, a composite WQI was derived for each of the 10 sites by selecting the "worst case" measurement obtained over the year's sampling period. In other words, this index represents

a hypothetical water sample showing the poorest quality for the parameters or variables measured. In addition, because the BOD_5 and turbidity were not measured, it was necessary to make certain assumptions. The BOD_5 value for each stream was obtained from data given by Mele and Mele (1983); the highest reported BOD_5 was used for both sites on a single stream. Turbidity measurements in Jackson Turbidity Units (JTU) were not available, and the instrumentation is reportedly unreliable below readings of 25 JTU; JTU's are not readily converted into other standard units of turbidity (Standard Methods 1985). All stream water samples collected in the 1986-87 surveys would have been less than 25 JTU, and a constant 5 JTU was more or less arbitrarily used as the "measured" turbidity. Temperature deviation (the deviation from an equilibrium temperature) was taken to be zero for all cases. Total solids was computed as the sum of total dissolved and total suspended solids as measured in the 1986-87 surveys. Nitrate (NO_3) was computed as $(NO_3-N) \times 4.43$ and phosphate (PO_4) as $SRP \times 3.06$. Table 36 is an example of the calculations used to compute this "modified" NSF WQI. Table 37 provides the "modified" WQIg for both sites on all streams sampled. The WQIg is used since it is less sensitive to change if any one of the variables shows as extremely poor quality (Canter 1985).

Ott (1978) presented a stream water quality classification based on five ranges of the geometric weighted NSF WQIg:

<u>WQIg Range</u>	<u>Classification</u>
0 - 25	very bad
26 - 50	bad
51 - 70	medium
71 - 90	good
91 - 100	excellent

Table 36. Calculation of Water Quality Index of hypothetical water sample from Primrose Brook (E2). WQIa=arithmetic-weighted index and WQIg=geometric weighted index. Modified from Canter (1985).

Variable	"Worst case" measurement	*Ii	**Wi	IiWi	Ii expWi
DO (%)	139	76	0.17	12.9	2.09
Fecal Coliforms(#/100ml)	86	40	0.15	6.0	1.74
pH	7.88	89	0.12	10.7	1.71
BOD5 (mg/l)	1.3	90	0.10	9.0	1.57
NO3 (mg/l)	1.36	90	0.10	9.0	1.57
PO4 (mg/l)	0.014	95	0.10	9.5	1.58
Temperature Deviation (C)	0	93	0.10	9.3	1.57
Turbidity (JTU)	5	90	0.08	7.2	1.43
Total Solids	52	86	0.08	6.9	1.43
				-----	-----
				WQIa=80.5	WQIg=77.8

*Ii - Subindex values derived from pollutant variable curves given by Canter (1985) and Ott (1978)

**Wi - Subindex weighting factors from Cantor (1985) and Ott (1978)

Table 37. "Modified" Water Quality Index for both sites of each stream in Morristown National Historical Park.

Site	Primrose Brook		Indian Grave	Jersey Brook	Passaic River
	East	West			
1	77	74	80	84	86
2	78	74	80	85	86

* This geometric weighted WQI is a modification of the NSF WQI that is computed from methods given by Brown et al (1970), McClelland (1974), Ott (1978), and Canter (1985). See text for details of computation.

The "modified" WQI_g values obtained for a worst case analysis range from 77 to 86 (Table 37). All stream waters, under the poorest of circumstances, would be classified as "good" and approach an "excellent" status assuming that these WQI's are comparable with the NSF WQI.

The "modified" WQI values in Table 37 unexpectedly imply the following order for increasing water quality: West Branch < East Branch < Indian Grave < Jersey Brook < Passaic River. Intuitively, the highest water quality should have been associated with the Primrose Brook system. The unusually high percentage saturation of dissolved oxygen reported for East and West Primrose and Indian Grave samples in the summer of 1986 (Table 7) significantly reduces the dissolved oxygen subindex value. Percentage saturation in all these streams most likely remains approximately 100% at all times. Adjusting the saturation measurement to 100% (subindex = 100) raises the WQI_g in Table 37 from 78 to 82. If all DO saturation values were 100%, a comparable increase in WQI_g would be found for other sites.

Prati's Classification System

Prati et al. (1971) developed a single surface water quality index (Implicit Index of Pollution) from a set of subindices based on 13 pollutant variables. Prati also recommended a classification system based on the indices derived. The index ranges from 0 to 14 and above, and a water quality index of 0-1 is considered as excellent. Only 7 of 13 pollutant variables used by Prati can be estimated from data in the current study and a Prati index, as such, cannot be actually computed.

It is instructive, however, to compare the measured variables available for the park streams with the values regarded as indicative of the highest water quality by Prati et al. (1971). Data in Table 38 compare the measured ranges of pH, dissolved oxygen, total suspended solids, ammonia, nitrate, chloride, and the BOD₅ (from Mele and Mele 1983) with Prati's ranges for the "excellent" status. Of the seven variables in Table 38, four are within the excellence range. The measured range of dissolved oxygen exceeds the 112% excellent range of Prati for all streams except Jersey Brook (Table 38), but, as was pointed out above, these supersaturated values may be either incorrect or exceptional. Only one ammonia value (West Branch) in Table 38 exceeds the 0-0.1 mg/l excellent rating, and this value of 1.04 mg/l is most likely an outlier (Table 38). Similarly, only one NO₃ concentration (Indian Grave) exceeds the 0-4 mg/l excellent rating. The NO₃ concentration of 4.44 mg/l for Indian Grave is probably a valid measure, but it is representative of winter conditions at which time unpolluted temperate streams normally have maximal nitrate concentrations.

This limited comparison of the pollutant variables in the park streams to Prati's classification indicates that these stream waters are of excellent or near excellent quality.

Fecal Bacteria

Enteric bacteria such as fecal coliforms and fecal streptococci are normally found in the intestinal tracts of man and other warm blooded animals. The presence of indicator organisms, such as these, has been traditionally considered as evidence of fecal contamination. The occurrence and density of

Table 38. Comparison of park streams to Prati's classification system. Only 7 of the 13 Prati variables are utilized due to limited data collection.

Variable	Range of Variables					
	*Excellent Classification	Primrose Brook		Indian Grave	Jersey Brook	Passaic River
		East	West			
pH	6.5-8.0	7.0-7.9	6.8-7.8	6.7-8.0	7.1-7.7	7.2-8.1
DO (%)	88-112	92-142	90-139	100-138	87-112	91-120
TSS(mg/l)	0-20	5.4	6.5	7.2	9.5	4.4
NH3(mg/l)	0-0.1	0.07	**1.04	0.03	0.04	0.02
NO3(mg/l)	0-4	1.83	2.43	4.44	1.87	3.72
CL(mg/l)	0-50	4.96	3.47	16.05	26.76	23.85
*** BOD5(mg/l)	0-1.5	1.3	1.4	1.1	1.4	0.9

* Prati, L. et al (1971)

** Probably an outlier. Most likely value is 0.03 mg/l.

*** Data taken from Mele and Mele (1983)

these indicator organisms are widely accepted as a measure of water quality. Drinking water standards (USEPA 1975) establish the number of samples to be taken and permit a maximum number of less than 1 coliform per 100 ml of finished water. Fecal coliform counts should not exceed 200 per 100 ml (based on 5 samples over 30 days) for bathing waters (recreational) and 14 per 100 ml in shellfish harvesting waters (USEPA 1976). More recent Quality Criteria for Water (USEPA 1986) stipulates that based on the same sampling frequency, the E. coli counts (not fecal coliform) should not exceed 126 per 100 ml for freshwater bathing.

The determinations of fecal coliforms and fecal streptococci in the streams of the park were neither performed by a certified laboratory nor were they identified to species. These results, therefore, must be regarded as advisory and indicative of the fecal contamination and not as truly descriptive.

Rarely did fecal coliform counts exceed 200/100 ml except for a few summer samples from West Brook, Indian Grave, and Jersey Brook. The Passaic and East Branch samples never show more than 100 fecal coliforms per 100 ml. Unexpectedly, the highest coliform counts are in the West Branch of Primrose Brook (Table 20). Further investigation of these summer-time maxima may be warranted. Fecal coliform counts reported by Mele and Mele (1983) for these same streams are generally lower than those in the 1986-87 surveys. They report that only Jersey Brook and East Branch of Primrose have more than 100 coliforms per 100 ml, and this is only for the August 15, 1983 sample.

Fecal streptococci counts are also maximal in summer months and generally are fewer than 100 per 100 ml in the fall, winter, and spring samples. The ratios of fecal coliform to fecal streptococci counts (FC/FS), whenever applicable, are extremely low and indicate a fecal contamination from warm blooded animals other than man. In cases where fecal streptococci counts are fewer than 100 per 100 ml, the FC/FS ratio may not be a valid indicator of the source of fecal contamination (Standard Methods 1985).

Community Structure of Benthic Macroinvertebrates.

Although the physico-chemical parameters measured indicate waters of high quality, a complete evaluation of water quality at Morristown National Historical Park necessitates an examination of benthic macroinvertebrate community structure. When the value of water includes aesthetic, recreational and ecological uses, the measurement of physical, chemical, and bacteriological parameters alone will not suffice to evaluate water quality (Pratt and Coler 1976). To evaluate community structure, the data were examined in terms of species composition and the indices of Shannon diversity and evenness.

Species Composition

Insects are probably one of the most successful groups in the animal kingdom. They are very abundant and highly diverse. Although most insects occur in the terrestrial environment, many inhabit aquatic environments. Of those that are aquatic, most are freshwater. Of the 30 to 35 Orders of insects, 11 are known to contain species that are aquatic or semiaquatic (Pennak 1978). Nine of the 11 aquatic Orders of insects are represented at Morristown National Historical Park.

No specimens of Lepidoptera or Neuroptera were collected. Hynes (1970) provides a generalized list of families of invertebrates (including insects) commonly found in hard substrate streams similar to those found in the park. Approximately 50% of the families listed by Hynes were collected from the park and include:

Oligochaeta:	Nauididae
Pelecypoda:	Unionidae
Eucarida:	Astacidae
Plecoptera:	All families
Odonata:	Gomphidae, Cordulegastridae
Ephemeroptera:	Baetidae, Leptophlebiidae, Oligoneuriidae, Ephemerellidae, Caenidae
Hemiptera:	Veliidae, Gerridae
Megaloptera:	Corydalidae
Trichoptera:	Rhyacophilidae, Philopotamidae, Polycentropodidae, Hydropsychidae
Coleoptera:	Elmidae, Psephenidae, Gyrinidae
Diptera:	Chironomidae, Simuliidae, Blepharoceridae, Tipulidae

The benthic fauna collected from the park are characteristic of a typical stony or hard substrate temperate stream. Furthermore, the strong presence of ephemeropterans (mayflies), plecopterans (stoneflies), and trichopterans (caddisflies) implies a healthy system (NCDNR, 1986). These three groups were well represented in each of the park's streams, indicating a relatively healthy community within each stream system.

Shannon Diversity and Evenness

Species diversity is an expression of community structure. Two factors are involved in the expression of diversity: the number of species and the number of individuals per species within a community and the evenness of the distribution of individuals among these species. Disturbances to a system may bring about detectable changes in community structure which should be apparent in diversity index values. Diversity indices are desirable because they provide a simple account of complex systems and are applicable in any geographic location. Diversity indices provide a means of noting similarities among the structures of communities regardless of their species occurrences. Diversity indices have been criticized; some of the basic problems include a dependence on sample size and a failure to take into account various qualitative aspects of the organisms involved (Washington 1984).

From the plethora of diversity indices the Shannon diversity index (H'):

$$H' = - \sum_{i=1}^s (n_i/n) \ln (n_i/n)$$

where s = the number of species

n_i = the number of individuals in a species i of a sample from a community

n = the number of individuals in a sample from a community

and the Shannon evenness index (J'):

$$J' = H' / \log s$$

were selected to examine the community structure of the benthic macroinvertebrates at Morristown National Historical Park (Shannon and Weaver 1949). H' , which is based on information theory, is probably the best known and the most commonly used diversity index. According to information theory diversity is related to the degree of uncertainty associated with predicting the identity of an individual selected at random from a population. The more species present and the more equal their distribution, the greater the uncertainty and thus the greater the diversity. This index is desirable because it takes into account the number of species as well as their relative abundances. H' is also relatively independent of sample size (Washington 1984). Furthermore, according to Pielou (1966, 1975) H' is appropriate when a random sample of individuals has been taken from a larger group. Essentially, the benthic macroinvertebrate survey taken at the park is a sample of the community. Such a random sample of an entire community will not contain all species, therefore, H' acts as an estimate of community structure.

Wilhm and Dorris (1968) suggested the following relationship between index values and the relative condition of the system: >3 - clean water, $1-3$ - moderately polluted, and <1 - heavily polluted. These values were calculated using a logarithm of base two. Converted to the natural logarithm the relationships are as follows: >2.08 - clean water, $0.69-2.08$ - moderately polluted, and <0.69 - heavily polluted. Many researchers have reported values falling under the moderately polluted category for relatively undisturbed streams (Mathis 1968; Wilhm 1970; Heister 1971; Wynes and Wissing 1981). Pratt and Coler (1976) and Hughes (1978) suggested that several factors could influence the outcome of index values in addition to water quality. Some of

these influences include sampling method, level of taxonomic identification, location and nature of the system, and the actual equation used. They suggest that a scale like Wilhm and Dorris' may not be universally applicable, and that these influences should be taken into consideration when making comparisons.

If considered over the course of the survey, the mean J' value for each stream ranged from 0.754 to 0.787. This indicates that individuals are evenly distributed among the taxa. Significant differences did occur with respect to collection period, but this may be due to temporal fluctuations in the life history stages of the insects collected. Pielou (1975) noted that diversity is high when individuals are evenly distributed among the species. If an uneven distribution occurs, diversity is expected to be low. If considered over the course of the survey, the mean H' value for each stream ranged from 1.892 to 2.241. There were no significant differences among the streams with respect to H' or J' . However, the Passaic River came under the category of moderately polluted according to the categorization of H' given by Wilhm and Dorris (1968), if considered over the course of the entire survey. The other streams came under the category of clean water. Lenat et al. (1981) suggested that land-disturbing activities may result in large amounts of sediment being introduced into nearby aquatic systems. During the course of the survey, a considerable amount of land clearing occurred within the drainage area of the Passaic River. Lenat et al. (1981) noted that as sediments are added to a stream, habitat decreases. They also noted that there may be no change in community structure, but that there is a drop in benthic macroinvertebrate density associated with increased sediment loading. Densities of benthic macroinvertebrates did not appear to be lower than those reported for the other four streams. In fact the West Branch of Primrose had the lowest number of individuals collected over the survey.

The lower value of H' at the Passaic River may not necessarily reflect a drop in environmental quality. Olive and Dambach (1973) note low index values may be related to minimal habitat diversity and temporal effects, rather than diminishing water quality. The Passaic may be different simply because of its proximity to Leddell Pond, which provides a physically and chemically different environment from that of the other streams. Based on the overall outcome of the index values, diverse benthic macroinvertebrate communities are present at Morristown National Historical Park.

Aluminum

Aluminum is one of the most abundant elements in surface rock and soil but is not found in a pure state. Many of the salts of aluminum are soluble in water but others are not. Chemical form and solubility are dependent upon pH, and aluminum is not likely to be found in high concentrations in natural stream waters because it precipitates and settles out or is adsorbed as the hydroxide or carbonate salt. Even in acid streams and in the presence of organics most of the dissolved aluminum will be sequestered and biologically unavailable.

The concentrations of total recoverable aluminum in the surface waters of Morristown Natural Historical Park were considerably lower than those reported by Mele and Mele (1983). Concentrations reported by them were almost an order of magnitude greater. No other data on aluminum concentrations in these streams were available, but 0.01 mg/l of dissolved aluminum was reported for the Passaic River near Millington (October 11, 1984) and 0.03 mg/l for the Whippany River at Morristown (June 5, 1985) by the U.S. Geological Survey (1985). The seasonal pattern of a maximum concentration in the spring and a minimum concentration in the fall was also observed by Mele and Mele (1983) for these streams including the Passaic River.

Likens et al. (1977) reported a weighted annual (1964-70) mean concentration of aluminum of 0.24 mg/l in a low-order stream in an undisturbed watershed of Hubbard Brook Experimental Forest, New Hampshire. Aluminum concentrations for several streams in Great Smoky Mountain National Park, North Carolina, ranged from 0.04 to 1.77 mg/l (Herrmann and Baron 1980). The unusually high value of 1.77 mg/l was associated with sulphide bearing rock.

Muniz and Leivestad (1980) reported that 0.19 mg/l of inorganic aluminum at pH 5 was toxic to brown trout in mountain stream water, but no toxic effects were found at pH 6 for concentrations of 0.90 mg/l. They concluded that speciation of inorganic aluminum varied with the pH and so did toxicity. Furthermore, since natural waters contain a series of possible complexing agents, they suggested that no clear cut relationship would be found between total aluminum concentrations in surface waters and disappearance of fish. The concentrations of aluminum found in the streams of Morristown National Historical Park at the reported pH values pose no threat to the wildlife in the area nor to the human visitor.

Soils of Jockey Hollow are derived from acid rock formations of granitic gneiss (Mele and Mele 1983) which is reported to contain from 7.2 to 8.2% aluminum (Kahata-Pendies and Pendies 1984). The soils of the park, therefore, are acidic, of low to negligible buffering capacity and regarded as Type-1 by Hendry et al. (1980). Hendry et al. demonstrated that total alkalinities (= buffering capacity) of surface waters in Type-1 and Type-2 sensitive areas were $\leq 200 \mu\text{eq/l}$ ($\leq 10 \text{ mg/l}$ as CaCO_3). Total alkalinities for the park's streams ranged from about 400 to 920 $\mu\text{eq/l}$ (20 to 46 mg/l) which, although regarded as low, were significantly higher than the 200 $\mu\text{eq/l}$ characteristic of areas thought to be sensitive to acid precipitation.

The concentrations of exchangeable aluminum in the acid soils associated with Primrose Brook contained from 0.4 to 27.2 mg Al/100 g or 0.04 to 3.0 meq Al/100g (Table 19). Guillet and Souchier (1982) reported exchangeable

concentrations of Al^{3+} in the A1 horizons of an acid brown soil as 3.77 meq/100 g (33.9 mg/100g) and of an ochreous podzolic soil as 5.33 meq/100g (48.0 mg/100g). Coppenet and Juste (1982) stated that the pH (1N KCl) of a soil was a good indicator of potential Al^{3+} toxicity to rooted plants. Exchangeable aluminum can be extracted and detected by a 1N KCl solution if the pH is 4.8 or less. The toxicity threshold is about 50 mg exchangeable aluminum per kilogram of soil or 100 mg per kilogram if the soil is rich in organic matter (Coppenet and Juste 1982). Actually, the mobilization of soil aluminum is not only a function of the pH but also the cation exchange capacity (CEC) of the soil. Soils with high CEC values sequester the aluminum and render it unavailable. It is not possible at this time to estimate the potential mobilization of the soil aluminum under the influence of acid precipitation since the CEC of these soils was not measured. How serious the threat of aluminum toxicity to the rooted plant is at this time remains unknown but is likely to be low.

It is highly unlikely that a serious threat of aluminum toxicity to the aquatic organisms in these streams exists. Even in the acid soils of the drainage area, soil solutions will probably be dominated by HCO_3^- salts of base cations, and the pH will be controlled by the CO_2 partial pressure. Upon release from the soil to the surface waters, with a much lower CO_2 environment, the pH will rise with the net result of an acid soil releasing alkaline water to the stream (Reuss and Johnson 1986). This is probably what is occurring now in the acid soils of the park and explains why the pH values of these clear water streams (low in organic anions) are circumneutral and not acid (Reuss and Johnson 1986). Base cation depletion depends upon the reservoir of exchangeable bases in the soil (base saturation x CEC) and under acid loading the proportion of base cations could be decreased and the aluminum species increased. How resistant these soils are to acid loading will be a function of their CEC.

SUMMARY

The streams associated with Morristown National Historical Park provide an adequate and continuous supply of high quality water for the maintenance of a robust aquatic macroinvertebrate community and for the park's wildlife. The shallow, flowing streams are well oxygenated at all times, circumneutral in pH, and low to moderate in terms of nitrate and phosphate concentrations. Total suspended solids, total dissolved solids, and the specific conductivities were found to be low in all streams and were lowest in the Primrose Brook system. Concentrations of chlorides were lowest in the Primrose Brook system and somewhat higher in Indian Grave, Jersey Brook, and the Passaic River. Primrose Brook is subject to much less human influence than are the other streams.

Low to moderate total alkalinity values, which are characteristic for streams in this area, indicate a limited buffering capacity for these surface waters. The ability of these stream systems to maintain their present pH values is, therefore, limited, and the streams are somewhat sensitive to outside influences. At this time the water chemistry is stable, and there are no signs of serious perturbations from within or outside the park. The exchangeable and extractable aluminum concentrations in the acidic soils associated with Primrose Brook range from low to high, but the concentrations of aluminum in the stream waters are low. These low concentrations are probably due to the neutral to slightly alkaline pH and high concentration of dissolved oxygen characteristic for these stream waters. A high aluminum content of the surrounding soil, therefore, poses no immediate threat to the aquatic communities as long as the pH and dissolved oxygen values remain as they are at the present time. A drop in pH (<6.0) and/or in the dissolved oxygen concentration might result in a greater mobilization of dissolved aluminum in the stream water.

Summer-time fecal coliform and fecal streptococci counts indicated that with the exception of the West Branch of Primrose there was little likelihood that the park's streams were tainted by human excrement. It was not evident why in the summer of 1986 the FC/FS ratios for W1 and W2 were 1.0 and 1.8, respectively. A valid FC/FS ratio greater than 0.7 would imply the presence of human wastes. The summer-time fecal coliform counts were close to or exceeded 200 per 100 ml of stream water from both sites on the West Branch of Primrose Brook.

No rooted aquatic macrophytes were found at any of the sites studied. Benthic algae were generally sparse and dominated by diatoms which were most numerous on the rocks during the spring collection period. The diatom flora was diverse and indicative of high quality lotic waters.

Populations of benthic macroinvertebrates were well represented in all streams. Individuals from the orders Plecoptera (stoneflies), Ephemeroptera (mayflies), and Trichoptera (caddisflies) were the most numerous among the nine orders of aquatic insects found in these streams. The Shannon diversity index ranged from 1.892 to 2.241 and indicated that all of the streams (except possibly the Passaic) were "clean" water. The mean Shannon index for the Passaic fell within the "moderately polluted" category. The mean evenness index values of 0.754 to 0.787 showed that the individual benthic macroinvertebrates were evenly distributed among the taxa.

Water quality of these streams was judged to be excellent to very good based on the analyses of chemical constituents and the water quality index. Baseline data on selected physical and chemical parameters were established in this study and could serve as benchmarks for future investigations. Similarly, the faunistic survey produced a qualitative and quantitative measure of the benthic macroinvertebrate populations in these streams. In general, the stream biota confirmed the high water quality in these streams. The taxonomic list and individual abundances, together with the permanent "type" collection now available, provide the Park Service with not only an inventory of a specific natural resource but also a biological assessment of the quality of the surface water resources in Morristown National Historical Park.

RECOMMENDATIONS

There is no substitute for a longterm record of water quality measurements. It is virtually impossible to assess an altered status (whether improving, declining, or no change) without such a record. The successful implementation of a modifiable management plan is directly dependent upon a previous and concurrent monitoring program. Changes in a mangement plan would thus be a consequence of an on-going monitoring program that is linked to a historical record of water quality parameters.

We believe that the results of the current study, when coupled with the study by Mele and Mele (1983), give a satisfactory assessment of the quantity and quality of the surface waters and provide a valuable inventory of the aquatic biota. Our conclusions logically result in a set of recommendations.

1. As soon as practical, establish a systematic monitoring program. The extent of that program will be limited by the resources available to the park. A minimal monitoring program should include:

<u>Parameters:</u>	Dissolved Oxygen Concentration
	pH
	Specific Conductance (or Total Dissolved Solids)
	Temperature
<u>Locations:</u>	West Branch Primrose Brook, Site W1
	Primrose Brook, Site E1
	Indian Grave, Site I1
	Jersey Brook, Site J1
<u>Frequency:</u>	Once each month (preferably biweekly)

Inclusion of additional parameters (nutrients, etc.) and monitoring locations is highly desirable.

2. Institute a management plan. No remedial or active management strategy is recommended at this time. Constant vigilance and observation must be maintained for signs of gross pollution or impending threats to the park's resources.
3. Assistance from an outside agency should be sought if: (a) gross pollution has occurred or seems to be a threat and (b) a significant, deleterious, and persistent change is recorded for one or more of the monitored water quality parameters. An extensive chemical and biological survey is recommended.
4. A chemical and biological survey should be conducted regularly on a 10-year interval. These periodic and extensive surveys will serve to: (a) confirm the continuing high quality of the park's aquatic resources, (b) reconfirm the accuracy and reliability of the on-going monitoring program, (c) offer modification to the management plan, and (d) provide a legally-recognized expert evaluation, if needed.
5. Check on and provide remedial action for any in-house practices that might adversely affect water quality in the park's streams.
6. Further investigate the high fecal coliform counts recorded in the West Branch of Primrose. Use of the State of New Jersey or other certified laboratory is recommended.

7. A survey of aluminum concentrations and the cation exchange capacity (CEC) of the soils in the park is recommended. As long as the stream waters maintain a circumneutral pH value, there is little or no threat to the aquatic biota. The concern here is for the possible deleterious effect of soil aluminum on the viability of the forest trees.

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Appendix A. Location of sampling sites.

<u>Stream System</u>	<u>Code</u>	<u>Location</u>
Primrose Brook	E1	Below confluence of East and West Branch; about 100 ft (30m) south of bridge on fire trail and 15 ft (5m) downstream of narrow, wood footbridge.
	E2	Roughly 600 ft (180m) northeast of the "gold-fish" pond in vicinity of intersection of two fire trails; about 50 ft (15m) above confluence of the two tributaries on the southern fork, close to the fire trail.
	W1	South on gravel foot path leading from Jockey Hollow Road at a point about 200 ft (60m) southwest of the Aqueduct parking area; between two small wood bridges where path comes closest to the stream.
	W2	About 1100 ft (335m) northwest on fire trail at a point about 200 ft (60m) southwest of the Aqueduct parking area; directly below path marker #6 on fire trail.
Jersey Brook	J1	Approximately 15 to 20 ft (5-6m) upstream of second bridge crossing on Tempe Wick Road from U.S. 202; below a small drain pipe on left bank.
	J2	About 5 to 15 ft (2-5m) upstream of wood bridge on Patriot's Path off Tempe Wick Road; at location of Map 35.
Indian Grave	I1	Upstream of Hardscrabble Road; follow fire trail to Map F-3 and bear left; follow deer path to main channel.
	I2	Approximately 50 ft (15m) downstream from bridge at intersection of Hardscrabble and Leddell Pond Road; at location of Map E-1.
Passaic River	P1	About 75 to 100 ft (23-30m) downstream of small stone bridge on Leddell Pond Road; this is the second bridge crossing of the stream on Leddell Pond Road below the dam.
	P2	Approximately 200 ft (60m) upstream from first bridge (concrete) crossing on Leddell Pond Road below Leddell Pond dam.

Appendix B. Natural history classification of benthic macroinvertebrates collected from Morristown National Historic Park, Morris County, New Jersey.

- | | |
|--|--|
| 1 Platyhelminthes
Turbellaria | 10 Arthropoda
Plecoptera
Perlidae
<u>Acroneuria abnormis</u> |
| 2 Annelida
Haplotaxida
Naididae | 11 Arthropoda
Plecoptera
Perlidae
<u>Eccoptura</u> sp. |
| 3 Arthropoda
Decapoda
Cambaridae
<u>Cambarus bartoni</u> | 12 Arthropoda
Plecoptera
Perlidae
<u>Paragnetina</u> sp. |
| 4 Arthropoda
Collembola
Isotomidae
<u>Isotoma</u> sp. | 13 Arthropoda
Plecoptera
Perlidae
<u>Perlesta</u> sp. |
| 5 Arthropoda
Plecoptera
Chloroperlidae
<u>Utaperla gaspesiana</u> | 14 Arthropoda
Plecoptera
Perlidae
<u>Phasganophora</u> sp. |
| 6 Arthropoda
Plecoptera
Leuctridae
<u>Leuctra truncata</u> | 15 Arthropoda
Plecoptera
Perlodidae
<u>Cultus</u> sp. |
| 7 Arthropoda
Plecoptera
Nemouridae
<u>Amphinemura delosa</u> | 16 Arthropoda
Plecoptera
Perlodidae
<u>Isoperla</u> sp. |
| 8 Arthropoda
Plecoptera
Peltoperlidae
<u>Tallaperla</u> sp. | 17 Arthropoda
Plecoptera
Perlodidae
<u>Remenus</u> sp. |
| 9 Arthropoda
Plecoptera
Perlidae
<u>Acroneuria</u> sp. | 18 Arthropoda
Plecoptera
Pteronarcyidae
<u>Allonarcys</u> sp. |

- 19 Arthropoda
Ephemeroptera
Baetidae
Baetis sp.
- 20 Arthropoda
Ephemeroptera
Baetidae
Centroptilium sp.
- 21 Arthropoda
Ephemeroptera
Baetidae
Pseudocloeon sp.
- 22 Arthropoda
Ephemeroptera
Caenidae
Caenis sp.
- 23 Arthropoda
Ephemeroptera
Ephemerellidae
Ephemerella sp.
- 24 Arthropoda
Ephemeroptera
Ephemerellidae
Ephemerella cornuta
- 25 Arthropoda
Ephemeroptera
Ephemerellidae
Ephemerella septentrionalis
- 26 Arthropoda
Ephemeroptera
Ephemerellidae
Ephemerella walkeri
- 27 Arthropoda
Ephemeroptera
Ephemerellidae
Eurylophella sp.
- 28 Arthropoda
Ephemeroptera
Ephemerellidae
Serratella sp.
- 29 Arthropoda
Ephemeroptera
Heptageniidae
Cinygmula subaequalis
- 30 Arthropoda
Ephemeroptera
Heptageniidae
Epeorus pleuralis
- 31 Arthropoda
Ephemeroptera
Heptageniidae
Stenonema sp.
- 32 Arthropoda
Ephemeroptera
Heptageniidae
Stenonema carolina
- 33 Arthropoda
Ephemeroptera
Oligoneuriidae
Isonychia sp.
- 34 Arthropoda
Ephemeroptera
Leptophlebiidae
Habrophlebiodes sp.
- 35 Arthropoda
Ephemeroptera
Leptophlebiidae
Paraleptophlebia sp.
- 36 Arthropoda
Odonata
Aeshnidae
Boyeria vinosa
- 37 Arthropoda
Odonata
Calopterygidae
Calopteryx maculata
- 38 Arthropoda
Odonata
Cordulgastridae
Cordulegaster erronea

- 39 Arthropoda
Odonata
Gomphidae
Lanthus vernalis
- 40 Arthropoda
Hemiptera
Gerridae
Gerris marginatus
- 41 Arthropoda
Hemiptera
Gerridae
Trepobates sp.
- 42 Arthropoda
Hemiptera
Hebridae
Hebrus sp.
- 43 Arthropoda
Hemiptera
Veliidae
Microvelia fontinalis
- 44 Arthropoda
Hemiptera
Veliidae
Rhaqovelia obesa
- 45 Arthropoda
Megaloptera
Corydalidae
Corydalis cornutus
- 46 Arthropoda
Megaloptera
Corydalidae
Nigronia faciatus
- 47 Arthropoda
Megaloptera
Corydalidae
Nigronia serricornis
- 48 Arthropoda
Megaloptera
Sialidae
Sialis sp.
- 49 Arthropoda
Trichoptera
Brachycentridae
Brachycentrus sp.
- 50 Arthropoda
Trichoptera
Brachycentridae
Micrasema sp.
- 51 Arthropoda
Trichoptera
Glossosomatidae
Agapetus sp.
- 52 Arthropoda
Trichoptera
Glossosomatidae
Glossosoma sp.
- 53 Arthropoda
Trichoptera
Hydropsychidae
Cheumatopsyche sp.
- 54 Arthropoda
Trichoptera
Hydropsychidae
Diplectrona modesta
- 55 Arthropoda
Trichoptera
Hydropsychidae
Hydropsyche sp.
- 56 Arthropoda
Trichoptera
Lepidostomatidae
Lepidostoma sp.
- 57 Arthropoda
Trichoptera
Limnephilidae
Apatania sp.
- 58 Arthropoda
Trichoptera
Limnephilidae
Goera fuscula

- 59 Arthropoda
Trichoptera
Limnephilidae
Neophylax sp.
- 60 Arthropoda
Trichoptera
Limnephilidae
Neophylax mitchelli
- 61 Arthropoda
Trichoptera
Limnephilidae
Neophylax oligius
- 62 Arthropoda
Trichoptera
Limnephilidae
Pycnopsyche sp.
- 63 Arthropoda
Trichoptera
Limnephilidae
Pycnopsyche luculenta
- 64 Arthropoda
Trichoptera
Molannidae
Molannodes sp.
- 65 Arthropoda
Trichoptera
Odontoceridae
Psilotreta sp.
- 66 Arthropoda
Trichoptera
Philopotamidae
Chimarra obscura
- 67 Arthropoda
Trichoptera
Philopotamidae
Dolophilodes sp.
- 68 Arthropoda
Trichoptera
Philopotamidae
Wormaldia sp.
- 69 Arthropoda
Trichoptera
Polycentropodidae
Cyrnellus sp.
- 70 Arthropoda
Trichoptera
Polycentropodidae
Polycentropus sp.
- 71 Arthropoda
Trichoptera
Rhyacophilidae
Rhyacophila fuscula
- 72 Arthropoda
Trichoptera
Rhyacophilidae
Rhyacophila vibox
- 73 Arthropoda
Coleoptera
Elmidae
Optioservus sp.
- 74 Arthropoda
Coleoptera
Elmidae
Optioservus ovalis
- 75 Arthropoda
Coleoptera
Elmidae
Promoresia sp.
- 76 Arthropoda
Coleoptera
Elmidae
Stenelmis sp.
- 76a Arthropoda
Coleoptera
Elmidae
Stenelmis sp.
- 77 Arthropoda
Coleoptera
Elmidae
Stenelmis markeli

- 78 Arthropoda
Coleoptera
Elmidae
Stenelmis sandersoni
- 79 Arthropoda
Coleoptera
Gyrinidae
Dineutus sp.
- 80 Arthropoda
Coleoptera
Hydrophilidae
Anacaena sp.
- 81 Arthropoda
Coleoptera
Hydrophilidae
Cymbiodyta chamberlaini/blanchardi
- 82 Arthropoda
Coleoptera
Hydrophilidae
Hydrobius sp.
- 83 Arthropoda
Coleoptera
Hydrophilidae
Hydrobius tumidus
- 84 Arthropoda
Coleoptera
Psephenidae
Ectopria nervosa/thoracica
- 85 Arthropoda
Coleoptera
Psephenidae
Psephenus herricki
- 85a Arthropoda
Coleoptera
Psephenidae
Psephenus herricki (adult)
- 86 Arthropoda
Coleoptera
Ptilodactylidae
Anchytarsus bicolor
- 87 Arthropoda
Diptera
Blephariceridae
Blepharicera sp.
- 88 Arthropoda
Diptera
Ceratopogonidae
Palpomyia sp.
- 89 Arthropoda
Diptera
Chironomidae
Chironominae
- 90 Arthropoda
Diptera
Chironomidae
Diamesinae
- 91 Arthropoda
Diptera
Chironomidae
Orthocladiinae
- 92 Arthropoda
Diptera
Chironomidae
Tanypodinae
- 93 Arthropoda
Diptera
Culcidae
- 94 Arthropoda
Diptera
Dixidae
Dixa sp.
- 95 Arthropoda
Diptera
Empididae
- 96 Arthropoda
Diptera
Ephydriidae

- 97 Arthropoda
Diptera
Psychodidae
Pericoma sp.
- 99 Arthropoda
Diptera
Simuliidae
Prosimulium mixtum
- 100 Arthropoda
Diptera
Simuliidae
Simulium jenningsi
- 101 Arthropoda
Diptera
Simuliidae
Simulium piscicidium
- 102 Arthropoda
Diptera
Simuliidae
Simulium venustum
- 103 Arthropoda
Diptera
Simuliidae
Simulium vittatum
- 104 Arthropoda
Diptera
Stratiomyidae
Oxycera sp.
- 105 Arthropoda
Diptera
Tabanidae
Tabanus sp.
- 106 Arthropoda
Diptera
Tipulidae
Antocha sp.
- 107 Arthropoda
Diptera
Tipulidae
Dicranota sp.
- 108 Arthropoda
Diptera
Tipulidae
Eriocera spinosa
- 109 Arthropoda
Diptera
Tipulidae
Limnophilia sp.
- 110 Arthropoda
Diptera
Tipulidae
Pseudolimnophila sp.
- 111 Arthropoda
Diptera
Tipulidae
Tipula sp.
- 112 Arthropoda
Diptera
Tipulidae
Tipula abdominalis
- 113 Arthropoda
Diptera
Tipulidae
Tipula ignobilis
- 114 Mollusca
Gastropoda
Physidae
Physa sp.
- 115 Mollusca
Pelecypoda
Unionidae
Elliptio sp.