Bulletin 66

# Rehabilitation of Streams Receiving Acid Mine Drainage

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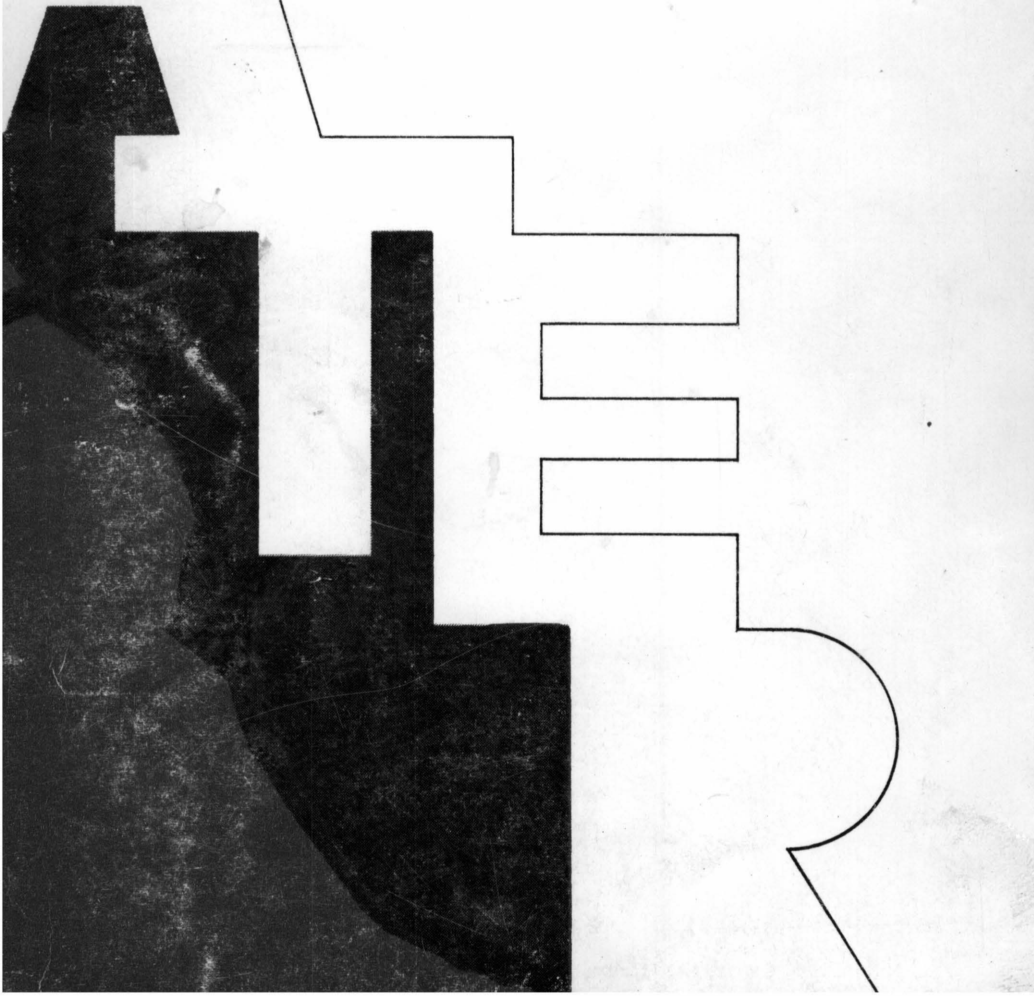

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# PREFACE

Thousands of miles of streams in the Appalachian area alone are affected by acid drainage from coal mines no longer in use. This study investigates the effect of such mine drainage on the numbers and varieties of organisms that live on the bottom of the streams.

Experiments for the study were carried out in Mill Creek, a tributary of the Roanoke River, and in two streams in Pennsylvania that receive acid mine drainage, Indian Creek and Little Scrubgrass Creek. Data collected determine the time and distance needed for artificial and natural recovery of the bottom-stream population. These data can be used to select proper rehabilitation procedures and to help locate mining sites that will least affect the watershed of the area around coal mines.

The authors extend thanks and acknowledgement to the following people who assisted in various phases of the project: Dr. George Grender, and Dr. James R. Craig, Department of Geology, Virginia Polytechnic Institute and State University (VPI&SU) who assisted in field geological interpretations; Dr. Vernon O. Shanholtz, Department of Agricultural Engineering, VPI&SU who assisted in the hydrological and water quality modeling phase of the study; Dr. Roger Kaesler, Department of Geology, University of Kansas who assisted in cluster analysis. Work of this type cannot be completed without competent field and laboratory assistance. Our special gratitude is extended to Mr. Garry Webb, Mr. Carl Grady, Ms. Joanne Johnson, Mr. Paul Singley and Mrs. Nancy Cromer.

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# ABSTRACT

The effects of short term low pH, and long term acid mine drainage (AMD) stress were studied in relation to recovery and restoration of aquatic macrobenthic communities. Experimental acid additions were made to a healthy productive stream, reducing pH from 8.0 to 4.0 for 15 minutes. Diversity and density were decreased (3.91 and 74 organisms/ft$^2$ before acid vs. 2.79 and 43 organisms/ft$^2$ after acid). Recovery was related to downstream drift of recolonizing organisms; full recovery occurred within 19 to 28 days with density and diversity equaling pre-stress values. A second study was made to observe drift-borne recolonizing organisms. *Baetis sp.* dominated drift collections, and was most abundant in bottom fauna collections indicating a relationship between drift and section recovery. Average drift intensity was 10 organisms or less during one 15-minute drift sample; drift rates were calculated to be in excess of 5000 organisms/day.

To assess the effects of AMD on a stream system, a two-year study was made of Indian Creek, Fayette Co., Pennsylvania. Indian Creek received one major and several minor AMD discharges in its upstream region. Recovery was shown by density and diversity values similar to upstream reference stations. Mechanisms of recovery were additions of unpolluted tributary waters which maintained good water quality through both chemical reaction and dilution thus providing suitable habitats for recolonizing organisms. The source areas of recolonizing organisms were the healthy tributaries, and recovery occurred within 10 miles of initial AMD discharges.

In addition to the biological studies, hydrologic and water quality models were applied and developed to better define the physical-chemical systems in the stream. Estimated periods of high stream discharge correlated well with periods of high density and diversity in the stream biota. Dilution of AMD was increased by high volume improving water quality and making some areas of the stream suitable for recolonization which were normally unsuitable. A second stream study was made on Little Scrubgrass Creek, Venango Co., Pennsylvania, to observe the effect of lime neutralization on the recovery processes. Water quality was restored immediately downstream from the neutralization plant, but recovery of bottom fauna communities did not occur until the confluence with healthy tributaries. Recovery occurred within 8 miles of the neutralization plant. The occurrence of hydroxide floc, a byproduct of AMD neutralization, created secondary stress at some times. Recovery was dependent on tributary sources of recolonizing organisms.

Detailed biological collection data have been deposited with Microfiche Publications. See NAPS document # 02256 for 224 pages of supplementary material. Order from ASIS/NAPS, c/o Microfiche Publications, 305 E. 46th Street, New York, New York 10017. Remit in advance for each NAPS accession number $1.50 for microfiche or $5.00 for photocopies up to 30 pages, $.15 for each additional page. Make checks payable to Microfiche Publications.

# INTRODUCTION

Acid mine drainage originates from the oxidation of sulfide minerals. By far the most common acid producing sulfide mineral is iron sulfide, but other sulfide minerals ($\mathrm{Cu_2S}$, ZnS, or PbS) may be found associated with coal deposits.

$$\mathrm{2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + H_2SO_4} \qquad [1]$$

$$\mathrm{4FeSO_4 + O_2 + H_2SO_4 \rightarrow 2Fe_2\,(SO_4)_3 + 2H_2O} \qquad [2]$$

$$\mathrm{Fe_2\,(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4} \qquad [3]$$

Upon exposure of iron sulfide to oxygen in a moist environment, ferrous sulfate and sulfuric acid are first produced (Equation 1). The ferrous sulfate is further oxidized (Equation 2) to produce ferric sulfate. This step is naturally catalyzed by the iron bacteria of the *Thiobacillus-Ferrobacillus* group providing both chemical and biochemical pathways of acid formation. The ferric sulfate is further oxidized (Equation 3) to produce ferric hydroxide (a precipitate) and more acid. The end product of these reactions can be described as a solution of mixed salts containing a variety of elements, and possibly charged with carbon dioxide, depending on the acid source.

The origin of the acid discharge, whether from underground or surface sources, and the mineralogy of the coal seam play an important role in the formation, intensity, and eventual impact of the mine drainage. While surface acid sources are well oxidized, acid drainage from subsurface sources is usually poorly oxidized, the major components being ferrous sulfate, hydrogen ion, and possibly carbon dioxide. If the alkalinity of the mine water is not sufficient to neutralize the ferrous sulfate, the resulting mine drainage will become strongly acidic upon aeration (Equation 4).

$$\mathrm{12FESO_4 + 30_2 + 6H_2O \quad 4FE_2\,(SO_4)_3 + 4FE(OH)_3} \qquad [4]$$

This reaction mechanism represents a highly buffered system (Bateman, 1950) whereas hydrogen ions are neutralized by basic minerals, other hydrogen ions are released, and the acidity of the mine water is maintained. Addition of dilution water without a high alkalinity promotes the hydrolysis of the ferrous sulfate, releasing more hydrogen ions and depressing the pH.

The quality of water affected by acid mine drainage is variable, but general criteria for the identification of streams with major mine drainage influence are given in Table 1. Due to the low pH, the dissolved solids loading may contain significant quantities of iron, aluminium, and other heavy metals, depending on mineralogical composition of the ore deposit and associated strata. The most useful indicator of acid mine drainage presence and concentration is sulfate. Calcium sulfate, the most common neutralization product, is soluble at concentrations usually encountered in receiving streams. The other materials in acid mine drainage tend to precipitate or plate out of solution and are difficult to analyze reliably as the pH and alkalinity of the receiving water change. Because sulfates are usually present in low concentrations in Appalachian waters (less than 20 ppm) and are found in high concentrations in acid mine drainage, the presence of sulfate gives an accurate indication of mine drainage presence. In addition, one molecular weight of sulfate is formed for each molecular weight of sulfuric acid allowing interpretation of total acid loading of streams from increased sulfate concentration over background levels.

Table 1

Criteria for Determining Acid Mine Drainage

| | |
|---|---|
| pH | less than 6.0 |
| Acidity | greater than 3mg/l |
| Alkalinity | normally 0 |
| Alkalinity/Acidity | less than 1.0 |
| Fe | greater than 0.5 mg/l |
| $SO_4$ | greater than 250 mg/l |
| Total Suspended Solids | greater than 250 mg/l |
| Total Dissolved Solids | greater than 500 mg/l |
| Total Hardness | greater than 250 mg/l |

## I. Literature Review

Two comprehensive reviews of the literature dealing in part with the effect of acid mine drainage on the biota have appeared, Parsons (1958) and Katz (1969). Roback and Richardson (1969) dealt specifically with the effect of acid mine drainage on aquatic insects. They found Odonata, Ephemeroptera, and Plecoptera are the most severely affected by acid drainage. Of the remaining orders of aquatic insects, some species proved tolerant including several Diptera, species of Chironomidae, and at least one Megaloptera, *Sialis sp.*

Parsons (1956) studied the effects of excessive flows from lakes in surface mined areas on the aquatic communities of Cedar Creek, Missouri. Rainfall produced overflows of these lakes, and acid drainage slugs occurred after heavy or extended rainfall. The severity of the stress and the rate of recovery of aquatic communities depended on the distribution, intensity, and time interval between rainfall. Parsons found downstream recovery occurred quickly, depending on the intensity and duration of the stress (e.g., low intensity, short duration stress events recovered rapidly). Parsons (1968) provided a more detailed description of the biota of Cedar Creek. He identified a region under almost constant acid mine drainage stress associated with a gradient of decreasing stress downstream. Related to these changes in physical conditions, he found a shift in benthic populations which could be related to changes in severity of the acid mine drainage. The benthic communities downstream under decreasing or variable stress showed distinct patterns of recovery. Under normal conditions, all communities had high diversity and species abundance. The species abundance was reduced by acid mine drainage, and the recovery stage included species other than those present in exposed areas. Those communities not adapted to a constant mine drainage showed the greatest damage.

Stehr and Branson (1938) discussed the repopulation of an intermittent stream by aquatic insects. They felt the major source of aquatic insects was oviposition by adults from nearby streams which resulted in larval development. In addition, recolonization could occur through upstream migration. Hoffman and Drooz (1953) studied the destruction and repopulation of streams subjected to DDT spraying. They found that repopulation of treated streams was dependent on seasonal conditions and flow volumes in the streams. In addition, they felt that repopulation was related to the diverse habitats and life cycles of aquatic organisms and variable susceptibility to stress thus the aquatic fauna was never completely eliminated. Repopulation was generally rapid, occurring for most species within two to three months, but some of the least tolerant species did not return for 12 to 15 months.

Kennedy (1955) discussed the colonization by trout and invertebrates of a flood bypass which had been dry for several years prior to the study. High streamflow maintained water in the channel for 87 days; sampling was carried out near the end of this period. Invertebrate communities in the experimental site along with normal channels above and below the bypass were quite similar. He speculates that most of the colonizing organisms were carried by the current into the experimental section.

A comprehensive study on the re-establishment of aquatic communities after a severe drought which virtually destroyed the aquatic populations in the stream was made by Larimore et al. (1959). Some fish and invertebrates were able to survive in two pools which persisted throughout the drought period. The authors related the rate of reinvasion of destroyed habitat to five factors: (1) extent of the damaged area, (2) source areas of recolonizing organisms, (3) degree of long term damage or residual toxicity, (4) water levels, and (5) season of the year. The major source of recolonizing organisms were ovipositing adults. Organisms in the residual pools did contribute to recolonization.

Possibly the most widely accepted model of stream recolonization is that proposed by Muller (1954). The model proposes that the general movement of larval forms of aquatic insects is downstream which implies headwater regions would become depleted of organisms after a time. Muller postulated that upstream flight results in oviposition, replenishing headwater portions of the stream, resulting in a continued supply of aquatic organisms.

## II. Recovery Models

The biological recovery and restoration of damaged streams is based on the type, intensity, and duration of the stress. Stress can usually be placed into three categories: (1) habitat destruction through alteration of the physical system (e.g., disruption of the stream bottom or heavy sediment deposition), (2) reduction or elimination of any element of the habitat which is essential for continued biotic function (e.g., removal of oxygen from the water due to biological or chemical processes), (3) destruction or injury of the biota by addition of toxic elements (e.g., all organic and inorganic discharges in water solution which act directly on the organism impairing or destroying normal function causing elimination from the food chain). Low stress intensity of short duration may result in little damage and rapid recovery. If either stress intensity or duration is increased, the probability of damage to the biota is increased and recovery may take longer. For example, acid mine drainage is typically a high intensity stress of long duration with elements of one or more categories. In addition, residual toxicity of some materials may make sections of receiving streams unsuitable for recolonization.

To account for variability in stress, two models of recovery have been developed. Recovery can occur as a function of time from the reduction or elimination of the stress, or as a function of distance from the point of stress introduction. Recovery through time is dependent on removal of all stress effects at their source. The model usually applies to acute stress loads; i.e., slug discharges, but may also apply to recovery after a chronic stress has been removed. In general, stress effects decrease as the discharge slug dissipates due to mixing characteristics of the stream. Exposure to peak concentration is usually short, but will vary due to stream velocity, channel morphology, the quality of receiving waters, and stress discharge characteristics. Restoration may begin as soon as the slug passes. Organisms which survived the stress, and recolonizing organisms from upstream unaffected regions, contribute to restoration. The stream may be considered recovered when post-stress indicators of the community health (such as diversity) are similar to pre-stress levels.

Recovery as a function of distance is usually applicable when the stress is not completely eliminated; i.e., residual toxicity or a high chronic stress exists. Reduction and elimination of stress occur as downstream tributaries contribute to the alteration or dilution of the deleterious conditions. The gradient of high to low stress is usually well defined; reduction of stress effects is controlled by watershed characteristics, such as tributary location and discharge. Recolonization is dependent on the restoration of suitable habitat through chemical, biological, or physical alteration of the stress conditions. Upstream sources of recolonizing organisms may at times be blocked by high stress conditions near the discharge source. The major sources of recolonizing organisms are ovipositing adults, and healthy tributaries which restore the damaged habitat; i.e., dilution or neutralization, and provide organisms for recolonization. Recovery occurs at the point from the discharge which maintains macrobenthic communities with high diversity, or indication of health, similar to upstream regions or similar habitats in other rivers.

## III. Selection of Organisms

The macrobenthos was selected in this study because it is an effective tool in the identification of stress effects on aquatic communities (Cairns *et al.*, 1969 and Goodnight, 1972). The macrobenthos includes seven orders of insects, and representatives from Decapoda and Mollusca. Macrobenthic organisms are accurate indicators of present and past stream conditions. Because most macrobenthic organisms have long life cycles, some measured in years, the presence or absence of certain species may indicate satisfactory conditions over a relatively long period of time. In addition, the sessile nature of most macrobenthic organisms enhances the probability that the effects measured are associated primarily with the area where collections were made.

# METHODS AND PROCEDURES

Methods of biological and chemical sampling and analysis were similar for all studies. Evaluation and analysis of physical parameters of the study areas were in part dependent on the availability of published data and thus varied with each study. The most extensive physical system evaluation was made for the Indian Creek watershed, the study area of major importance in this report. Because extensive use was made of computer simulation techniques to complement biological and chemical data for Indian Creek, English units were used to conform with input data requirements of the simulation models. Similarly, computer generated graphs and tables retain English units, thus for consistency, all graphs and tables were presented in English units. Conversion to metric equivalents has been made for all measurements noted in the text; metric equivalents follow each English unit in parentheses.

Water chemistry analyses were performed in the field whenever possible. Titrametric analysis for carbon dioxide, phenolphthalein alkalinity, methyl purple alkalinity, methyl orange acidity, phenolphthalein total acidity (hot and cold), and the versenate method for total hardness were regularly performed in the field. Water samples collected for sulfate analysis were preserved with 10% formalin and returned to the laboratory for analysis. The turbidimetric method was used for sulfate analysis. All analytical procedures followed APHA Standard Methods, 12th edition. Dissolved oxygen was determined by the Hach Chemical Company modification of the Winkler method (Because samples were not taken around-the-clock to measure natural variability, a more precise determination was not deemed necessary); iron was determined colormetrically with the Hach modification of the phenanthroline method. Field pH determinations were made colormetrically using Mallot Chemical Company pH test kits. Laboratory pH analyses were carried out with a Fisher Acumet pH meter. Some field water chemistry analyses were performed with a Hach Engineers' Water Quality Test Kit.

In addition to normal water chemistry analysis, a series of heavy metal analyses were made to supplement regular sampling efforts. These water samples were preserved with concentrated nitric acid. The samples were analyzed with a Perkin Elmer Model #6100 Atomic absorption spectrophotometer for zinc, copper, lead, calcium, magnesium, and mercury.

Physical data acquisition varied for each site; details of methods and procedures for each site will be discussed with appropriate site descriptions.

Although methods of biological sampling differed in each study, biological collection methods may be placed in three categories, qualitive, quantitative, and drift sampling. Qualitative sampling was carried out with a Turtox 8 x 10 x 18 in. (20 x 25.4 x 45.8 cm) bottom net. Sampling was systematized to assure that an equal sampling effort was made at each station. A section of the bottom was randomly selected, and five 1-minute kick samples were taken in an upstream direction. In addition, all habitats within a 50 yd (45 m) section of the stream were sampled. Normally one qualitative sample was collected at each station. When stream width was more than 100 ft (30 m), or a clearly defined difference between right bank and left bank was evident, two or more qualitative samples were collected. Quantitative sampling used the Surber 1 ft$^2$ (0.l m$^2$) bottom sampler. Five square feet of bottom to a depth of 1 to 3 in. (2.6 cm to 7.7 cm) were collected at each station. The usual procedure called for sampling in a transect across the stream from left bank to right bank (looking downstream). Each sample was placed in separate containers, identified by station number and sample location. This procedure gave an indication of non-uniform mixing of acid discharges, or the channeling of tributary water along one bank. When stream channel width or other physical conditions, such as deep channels, restricted transect sampling, samples were collected in an upstream direction.

Drift nets were constructed after Waters (1968) using Turtox #20, 0.05 in$^2$ (1.2 cm$^2$) netting. Nets were left in the streamflow for 15 minutes. The collection schedules varied depending on experimental design. All samples were preserved in either 70% alcohol or 10% formalin and returned to the laboratory for analysis.

After preserved samples were taken to the laboratory, the bottom fauna were separated from substrate materials with sugar flotation; a method modified from Anderson (1959). Each sample was drained of preserving solution and placed in tap water for 1 hour. The sample was then placed in a pan, and a 1.12 s.g. sugar solution was added. Most bottom organisms floated to the surface where they were removed with a fine scoop. The material was searched for a minimum of 15 minutes. If samples were large, each sample was picked until no more organisms floated to the surface. The sugar solution was poured off, and tap water was again placed in the container. The substrate material was searched for organisms too heavy to float, and the sample was left in tap water for a minimum of 30 minutes. The tap water was drained off, and the sample was again floated with sugar solution. After this float, the samples were usually well separated, and substrate materials were discarded. All organisms were stored in 70% alcohol. Drift samples were very difficult to separate by this flotation technique because nearly all the material retained by the net had the same specific gravity as animal tissue. Drift fauna were separated from this extraneous material by hand picking each sample under a magnifying lens. Each sample was picked twice, rinsed in fresh tap water, and picked again. Samples were then separated into taxonomically similar groups for further identification.

Identification was carried out to the species level whenever possible. Because of the time and distances involved in transporting live organisms, no rearing of larval forms to adults was attempted to verify species identification. Differentiation was attempted on the specific level using available keys, mainly for the Ephemeroptera and Plecoptera. In taxonomic lists those organisms which are differentiated on the species level are identified by a species number.

Analysis of biological data was made to assess community condition; i.e., healthy, unhealthy, or unstressed, stressed. Several methods have been proposed to aid in this analysis of community health. Forbes and Richardson in their work on the Illinois River, (Forbes and Richardson, 1913; Richard, 1928) based their analysis on the presence or absence of species with differing tolerance to stress. Several methods have been proposed to quantify biological collections. One of the earliest was the use of histograms (Patrick, 1949, 1950) to display community structure. It was possible using these techniques to define "healthy" and "unhealthy" communities based on community structure. Various methods of quantification have been developed to describe community relationships (Beck, 1955; Chutter, 1972; Erman and Helm, 1971). One of the most widely accepted quantification methods is calculation of the diversity index, $\bar{d}$., which describes the community diversity, (Wilhm and Dorris, 1968). A high $\bar{d}$., 3.0 or greater, normally indicates unpolluted or healthy conditions while a low $\bar{d}$ less than 2.0, usually indicates polluted or unhealthy conditions. Another technique which is partially quantitative and partially descriptive was used by Ulfstrand (1968). Taxonomic lists were used to develop rank-abundance data for various taxonomic levels; i.e., order or species. Mean ranks were then compared with total standing crop estimates, and a total score based on the combination of rank values of one order or species through all collections was determined. The lowest score identified the dominant members of the community.

Analysis of biological samples from the recovery studies involved a number of descriptive and numerical techniques. The diversity value was calculated for each sample using $\bar{d}$ as described by Wilhm and Dorris (1968). This analysis is based on information theory and takes into account not only the numbers of organisms and numbers of species present in a collection, but also the relative abundance of different species. The formula used by Wilhm and Dorris (1968) was:

$$\bar{d} = (n_i/n) \log_2(n_i/n)$$

where

$\bar{d}$ = diversity

$n_i$ = the number of individuals of each single species in the sample

n = total number of individuals of all species in the sample

which is quite similar to the formula proposed by Shannon (Shannon and Weaver, 1949). Pielou (1969) finds fault with this calculation as applied to diversity. She feels that calculation of diversity in this way assumes infinitely large population. In most cases only a sample of the population is measured; thus, the $\bar{d}$ value obtained is not a true population value, but a value for a random sample from the population. To overcome this difficulty, she suggested using a diversity measure which is appropriate to a finite population. The formula proposed by Brillouin (1962) defined the information content or the diversity for a finite population.

where $$H = \frac{1}{N} \log \frac{N!}{N_1!N_2!\ldots N_s!}$$

H = diversity index

N = number of organisms in the sample

$N_s$ = number of individuals of species s.

The use of the H-value as a measure of diversity for a collection which is treated as a population produces results which are free from sampling error. Because the $\bar{d}$ value is so widely used in the literature, and $\bar{d}$ values have been used to assess stream health, $\bar{d}$ diversity values are included in the tables of diversity values for a comparative purpose.

To further evaluate differences in community structure, relative abundance of tolerant, moderately tolerant, and non-tolerant organisms were determined for each sample. Initial selection of tolerant organisms was made by reference to available literature (Parsons, 1968; Roback and Richardson, 1969). Ulfstrand's technique of rank-abundance tabulation (Ulfstrand, 1968) was used as a basis for the tolerance determination of Indian Creek and Little

Scrubgrass Creek biota. At each station, and on each date, organisms collected were ranked according to their abundance in the collection. Those organisms which regularly appeared in high stress environments (e.g., low pH—high acidity) were considered tolerant. Those organisms which rarely or never appeared in high stress environments were considered non-tolerant. The remainder were roughly classed as moderately tolerant.

In general, diversity analysis and relative abundance data are reliable techniques for the assessment of community conditions. Greater accuracy in description and evaluation of communities can be attained if additional information is available. This is especially true of assessment of tolerance. Because tolerant organisms can usually function in a wide range of environmental conditions, they are often found in moderate to high numbers in non-stressed environments. Their presence alone does not determine the impact of environmental conditions. Similarly non-tolerant organisms may occur in high stress environments, but they will be present in low numbers. Their presence should not be overemphasized. A valid solution to this problem is to use a variety of assessment techniques which employ descriptive and mathematical methods of information analysis. It is for these reasons that diversity, rank-abundance, number of taxa, total number of organisms collected, density, and relationship of biota at one station with a reference station will be used in discussion of community health.

The application of these methods of community analysis and species tolerance determination aid in the definition of stress, or the end product of high or prolonged stress damage. Damage to aquatic systems must be defined in terms of stress effects at both specific and community levels of organization. On a specific level, if the tolerance limit of a particular species is exceeded, the ability of that group of organisms to function within the community will be impaired and possibly destroyed, but normal community function may be maintained. If the community is diverse, there will be a redundancy of function; i.e., one or more organisms are able to assume the functional niche of the damaged species. If damage occurs, large numbers of species are eliminated from the community and the functional ability of the community may be impaired or destroyed by this loss. As community diversity is decreased, redundancy of function is eliminated because no additional species are able to assume the functional niche of stress-eliminated species. Thus, on a community level, stress may be defined as a change in environmental conditions (physical, chemical, or biological) which impairs or destroys the functional ability of one or more species in the community. The result is a decrease in diversity, loss of functional redundancy, and possible complete loss of function.

The use of diversity analysis makes no distinction of taxonomic composition of the community, only the number of taxa and their relative abundances. Several techniques exist which relate detailed taxonomic descriptions; two of these were used for analysis of Indian Creek biological data. Cluster analysis grouped together stations which had similar biota. Stations are shown in dendrograms relating various clusters at some level of similarity (distance or Jaccard coefficient value). A second analytical tool was the calculation of correlation matrices which were based on the relationships between the biota of all stations collected during one sampling period.

Initial cluster analysis clustered all stations collected on one date. Each station was related by distance values, similar to the taxonomic distance described by Sokal and Sneath (1963). The general procedure for cluster analysis required preparation of a data matrix for each station. This matrix included the numbers of organisms present in each taxa at each station; zero values were included for all organisms recorded from the watershed but not present in the station collection. The basis of the cluster analysis was the development of distance coefficients which related one station to another. The distance values calculated described the position of each station in terms of a Euclidean distance which separated each station in an n-dimensional space. The stations which had the least distance separating them were the most similar and were first clustered together. Those stations with greater distance values were not clustered until late in the clustering procedure. There are several disadvantages to clustering data using the distance coefficient, the greatest being the effect of negative matches on the cluster results. If a station or a series of stations have the same taxa absent, they may show little distance separation and high similarity when there may be no similarity present.

To overcome the effect of negative matches, another technique of cluster analysis was used (Cairns and Kaesler, 1969). The data matrix prepared for previous analysis was transformed from a taxa-abundance matrix to a presence-absence matrix. The generation of coefficients of similarity was based on the formula proposed by Jaccard (1908) which omitted negative matches from consideration. In short, cluster analysis included computation of a matrix of coeffients of association. The clustering was then performed using the unweighted pair group method (Sokal and Sneath, 1963). The clusters were displayed in dendrograms and compared with the original matrix of coefficients of association.

Because two-dimensional displays in dendrograms may distort some relationships in the cluster, further analyses relating dendrogram display and matrix-values were made. The extent of this distortion is defined by the cophenetic correlation coefficient (Sokal and Rholf, 1962). The higher the value of this coefficient, the less distortion introduced in the display dendrograms.

The correlation matrix for each sampling period was calculated using taxa-abundance data. Each station collected was compared with all other stations collected during the sampling period. Although matrix values calculated in this manner are subject to the same inconsistencies of cluster analysis using taxa-abundance data, the correlation matrices confirm cluster relationships and indicate high similarity between stations collected on the same date.

# EXPERIMENTAL SITE

Recovery and restoration of bottom fauna communities from the effects of short term stress may be rapid or slow depending on several factors: (1) severity and duration of the stress, (2) recolonization of the damaged area by aquatic organisms, and (3) residual effect of the stress or associated materials. Typically, acid mine drainage is a high intensity stress of long duration. Where acid mine drainage is restricted by physical or climatic conditions, short term acid discharges may occur if conditions are suitable, for example, Parsons (1956). Usually mine drainage contains a variety of materials which may create residual stress effects. The area of intense residual toxicity is usually localized near the discharge source, while low pH stress may occur over a much larger distance. To simulate the release of a low pH acid mine drainage which leaves no residual toxicity, an acute acid stress was produced in a portion of a small mountain stream.

## I. Physiography and Description of Sampling Location

Mill Creek is a tributary to the North Fork of the Roanoke River, in Montgomery County, Virginia. The stream is located in the Valley and Ridge Province, with the major structural features trending northeast-southwest. The stream drains a small valley and flows southeast from Brush Mountain. The stream is intermittent for most of its 2.5 miles (5.6 km). Maximum total relief was 560 ft (171 m). As the stream reaches the approximate elevation of the North Fork valley floor, several springs feed the stream, and continuous flow is maintained for approximately 1 mile (1.6 km) to its confluence with the North Fork. Average width in the downstream region was 6 to 10 ft (1.8 to 3 m).

The geology of the Mill Creek—Mt. Tabor area was described by Hayman (1972). The bedrock of the area is composed primarily of Cambrian to Middle Ordovician carbonates. The structure of the area favors subsurface drainage. The strata dips southeast, and major joint sets are oriented northwest-southeast. There are several disappearing streams in the higher elevations along Brush Mountain. The substrate of Mill Creek is predominately limestone from the Liberty Hall Formation.

## II. Acute Acid Stress Study

The site selected for the experimental studies was a 100-ft (30-m) straight riffle section with an average width of 8 ft (2.4 m). This reach was divided along its length by a partition producing two stream sections approximately 4 ft (1.2 m) wide. Galvanized roofing material was used as the divider. A plastic skirt was attached to the lower portion of each sheet of roofing. The divider was anchored in the stream with metal stakes, and the plastic skirt was extended and covered with substrate materials. The divider created an experimental area with two comparable habitats side by side with similar fauna, and subject to similar natural environmental fluctuations. When stress was applied, the flow was alternately reduced on both sides of the divider for 15 minutes, increasing the flow on the opposite side. As the flow was reduced in the experimental side, concentrated technical grade sulfuric acid was poured along the length of the experimental area. The pH in the experimental area was reduced to well below 4.0 and maintained at that level for 15 minutes. As the water left the experimental section, it was neutralized to pH 7.0 with sodium hydroxide.

Macro-invertebrate bottom fauna samples were collected in both treated (experimental), and reference (control) sections four weeks before, as well as immediately before, acid addition. Samples were also collected immediately after acid addition (day 0), and on days 1, 6, 13, 19, 28, and 34, following with additional samples at 14 to 60-day intervals. Each sample represents a composite of five Surber square foot (.1 $m^2$) bottom samples from both treated and reference sections on each date. Diversity was calculated from the composite fauna of all five samples. Density was the average number of organisms in five square feet of bottom. Water quality analyses were performed with a Hach engineer's kit each time invertebrate collections were made.

## III. Chemical Results

Typical water quality analysis results are contained in Table 2. Temperature remained relatively constant throughout the late summer months varying between 15 and 20°C. During late fall and winter collections, water temperature dropped to 0 to 10°C. Because the first divider was constructed with galvanized roofing material, there was the possibility of heavy metal contamination. Several series of samples were collected upstream next to the divider (both reference and experimental sides) and downstream. Samples were analyzed by atomic absorption spectroscopy for zinc, none was detected.

## IV. Biological Results

Figures 1 and 2 show that both treated and reference sections were stressed as a result of the experimental procedure. Density declined over 30% in both

## Table 2

### Typical Water Quality Values For Mill Creek Acute Acid Stress Study

| | |
|---|---|
| pH | 8.0 to 8.5 |
| Total Alkalinity (ppm) | 260 to 280 |
| Free Acidity | 0 |
| Mineral Acidity | 0 |
| Total Hardness | 260 to 280 |
| Temperature °C | 0 to 20 |

$[H_2SO_4]$

$[O_4][OH]$

Figure 1

Density and Diversity Values for Experimental Section

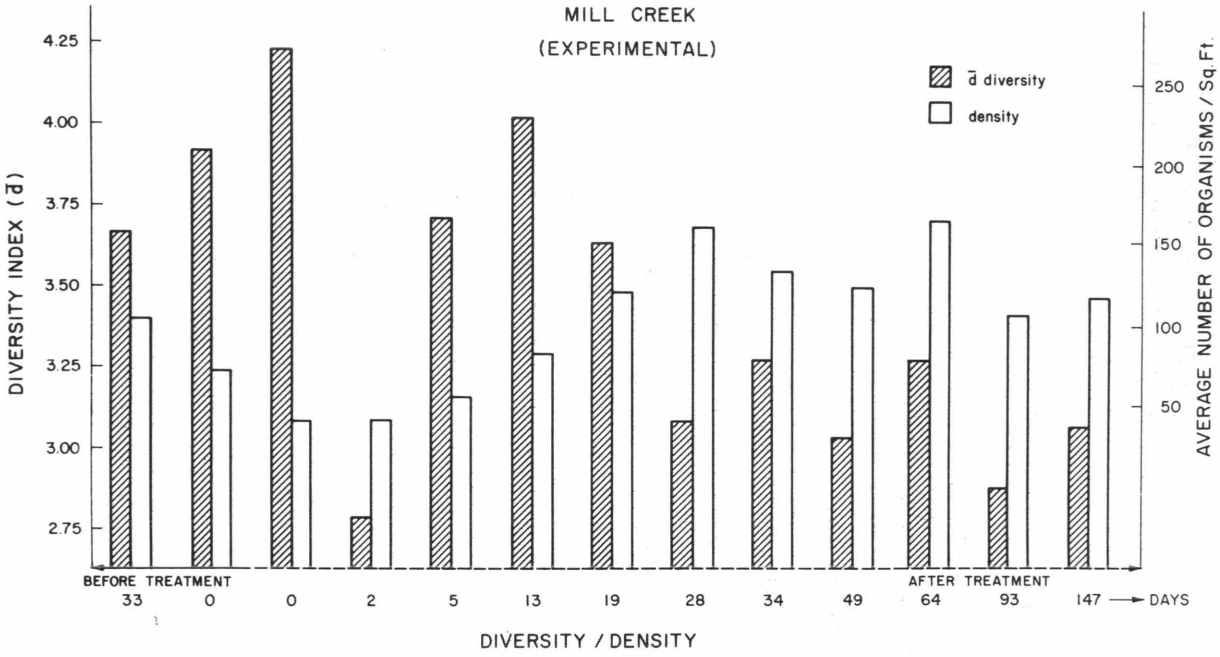
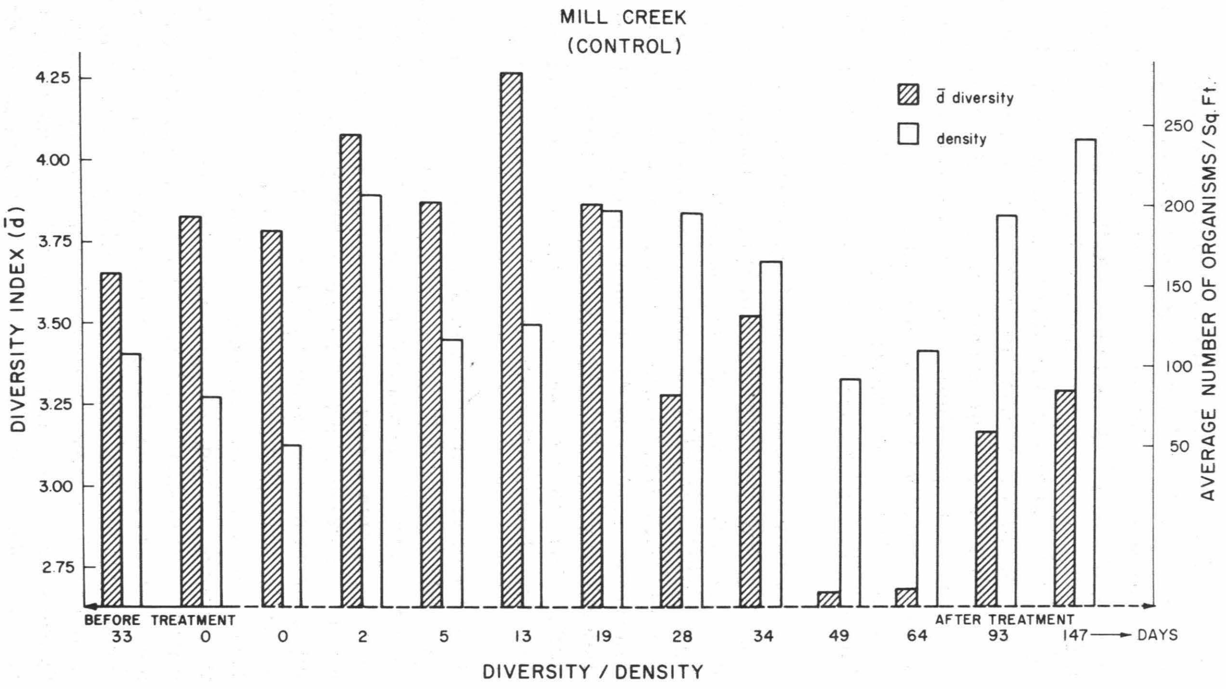


Figure 2

Density and Diversity Values for Reference (Control) Section



treated and reference sections after acid addition. Since flow was alternately reduced and increased in both sections, the decline in density in the reference section was due either to the detrimental effects of low flow, or to the increased flow when water was diverted from the other side. The acid treated area, however, showed a more dramatic alteration with marked changes in both diversity and density. Two days after treatment, the community structure diversity index ($\bar{d}$) in the treated section was below 3.0 (Appendix II-B, Table 1), indicating a stressed situation, while the $\bar{d}$ value for the reference section showed a healthy situation, above 4.0. Density at this time in the treated section remained near 40 organisms/ft$^2$ while the reference section showed a large increase to over 200 organisms/ft$^2$. Recovery continued in the experimental section through day 19 when $\bar{d}$ and density values reached or exceeded the values recorded 33 days before acid treatment. Restoration occurred after day 19, with an average $\bar{d}$ greater than 3.0 for days 28 to 147, and an average density of 130 organisms/ft$^2$.

Recovery in the reference section from the stress of low and high flow was very rapid. Two days after the experimental procedure was carried out the $\bar{d}$ value was greater than 4.0, and the density value was greater than 200 organisms/ft$^2$. The reference area was recolonized at a higher average density than the treated section, and diversity index values remained well above 3.0 through day 34. On day 49, the $\bar{d}$ value obtained 2.69, which indicated a stressed community. This decrease in $\bar{d}$ was accompanied by a decrease in density. The reference section showed a recovery pattern of increasing diversity and density through day 147 when the experiment was terminated.

Rank-abundance tabulation was also made on bottom fauna collections (Appendix II-B, Table 3). Before the acid stress, both reference and control section bottom fauna communities were dominated by Coleoptera, *Rhizelmis sp.* Ephemeroptera were present in slightly larger numbers in the control section. Immediately after the experimental procedure, both sections were still dominated by Coleoptera. Ephemeroptera abundance dropped in the reference section, but remained almost constant in the experimental section. Two days after acid addition, Coleoptera were the dominant in the experimental section, 42% of the total fauna, with Trichoptera and Plecoptera co-subdominant orders, 21 and 18%, respectively to total fauna. In the reference section, Ephemeroptera were clear dominants comprising almost 50% of the bottom fauna collected. Coleoptera, *Cleptelmis sp.* continued to dominate the experimental section through day 28, while Ephemeroptera dominated the bottom fauna community in the reference section. In the reference section no single species dominated the community on all successive dates, dominant taxa were *Baetis sp., Centroptilium sp.,* and

*Isonychia sp.* On day 34, Coleoptera, Trichoptera, and Ephemeroptera were co-dominant orders in the experimental section, *Cleptelmis sp.* and *Hydropsyche sp.* were the dominant taxa. Ephemeroptera were the dominant order (46% of the collection) in the reference section. On day 49, the community in the experimental section was dominated by Ephemeroptera, *Ephemerella sp.* the dominant taxon, while the bottom fauna in the reference section were dominated by Coleoptera, *Cleptelmis sp.* the dominant taxon. This same pattern was evident on day 64. By day 93, the pattern of Ephemeroptera dominance had returned to the reference section while Ephemeroptera and Coleoptera were co-dominant in the experimental section. Trichoptera were dominant in both sections on day 147.

## V. Discussion

Diversity and density analyses alone indicate trends in recovery. If rank-abundance data are included, these trends are shown to be shifts in dominant orders related to tolerance of one or more taxa to the low pH stress.

Immediately after treatment, the diversity index in the experimental section showed a temporary rise while density remained low (Figure 1). This was probably due in part to the immediacy of sampling after the stress (killed or injured organisms had not been removed by the current or had not decomposed) combined with an increase in downstream drift due to changes in flow (Minshall and Winger, 1968). Two days after treatment, the $\bar{d}$ value in the experimental section was very low (2.79) as was the density (43 organisms/ft$^2$). The reference collections showed little alteration in diversity, and had a very high density, 205 organisms/ft$^2$. This difference was probably due to the destruction of energy sources (i.e., algae and diatoms) which made immediate recolonization of the experimental section unsuitable. Some of the surviving species had striking increases in numbers of individuals on day 2, becoming dominant in the community. Dominance was probably a function of survival of acid stress, because the dominant taxon, *Cleptelmis sp.* was found in few drift samples. This dominance was reflected in the low diversity value obtained for this day. Five days after treatment, the community structure had regained some of its original complexity. The $\bar{d}$ value for day 5 was above 3.0, and density rose to 53 organisms/ft$^2$. During days 13 through 28, the community recovered from the low pH shock, re-establishing its former level of complexity, as evidenced by high diversity and density values. Decreases in $\bar{d}$ and density during the late stages of the experiment were undoubtedly due to a number of factors. The most important were fall emergence of adult insects, and a low grade stress produced by high suspended solids loading (Cairns, 1967).

The effect of higher than normal sediment loading was noted in the reference section. Rainfall shortly before sampling, on days 49 and 64, produced runoff with high suspended solids. Runoff from adjacent fields and a dirt road along the right bank was channeled along the reference section by the divider. This runoff added heavy suspended solids loading to the light sediment load carried by the stream during normal runoff situations. The two sides were otherwise similar. On day 49 the reference section had low values (Figure 2) for both $\bar{d}$ (2.69 reduced from 3.52) and density (95 organisms/ft$^2$ reduced from 166 organisms/ft$^2$) as compared with day 34.

The rank-abundance tabulation confirms the effect of the stress, and extends the recovery period beyond the diversity assessment to day 34 when the coleopteran, *Cleptelmis sp.* was no longer dominant. During the period of recovery the bottom fauna community in the reference section was dominated by Ephemeroptera. While the experimental section collections contained Ephemeroptera, the community was dominated by Coleoptera, *Cleptelmis sp.* This may be due to several factors, the most important of which are destruction of food resources for Ephemeroptera and destruction of egg and larval stages of Ephemeroptera by the low pH. Both of these factors could cause a selective reduction in numbers of Ephemeroptera. The coleopteran, *Cleptelmis sp.* dominated the bottom fauna community in the reference section on days 49 and 64 due to stress from high suspended solids loads, while the experimental section was dominated by Ephemeroptera.

The results of the experimental acidification of Mill Creek provide information on the response of a stream fauna to an acute stress, and the recovery which follows. Although there was no residual toxicity, the residual effects of the stress; i.e., damage of food resources and elimination of some organisms, have an extended effect on the bottom fauna community. During both periods of stress, the community was dominated by the coleopteran, *Cleptelmis sp.* and the recovered community was dominated by Ephemeroptera. Diversity and density analyses indicated recovery by day 28 while rank-abundance tabulations indicated recovery on day 34. The variability which may be encountered in a biological system is shown by the variable density and diversity values found for the reference section before suspended solids loading and in both sections after recovery.

## VI. Drift Study

A second experimental study was carried out on Mill Creek approximately 12 months after the acute stress study. Studies were made of macroinvertebrate drift and the relationship between drifting organisms, and recolonization and recovery of a damaged area. The literature dealing with drift of stream insects, the major group of macroinvertebrate bottom fauna, is extensive. Muller (1954) proposed the "recolonization cycle" where invertebrate bottom fauna are displaced downstream by drift, and upstream areas of the stream are replenished by adult flight in an upstream direction. Oviposition and development of larva in the upstream area renew the drift cycle. The environmental factors, both physical and biological, which control drift have been the subject of several investigations. Drift has been related to flow changes (Minshall and Winger, 1968), moonlight (Anderson, 1966), light intensity (Holt and Waters, 1967), density (Dimond, 1967), and general invertebrate activity (Devon, 1968). In general, drift in most streams fluctuates according to certain defined patterns. Elliot (1965) reported increased drift at night which was confirmed by several authors (Pearson and Franklin, 1968; Water, 1969; Reisen and Prins, 1972; and Klyuchereva, 1963). Monitoring drift has been proposed as a method to monitor the production rate of bottom fauna communities (Waters, 1962). In this regard, Waters (1964) studied the recolonization of an area of stream bottom which had been artificially denuded. He concluded that downstream drift of aquatic organisms is a suitable mechanism to restore a disrupted bottom fauna community to normal in a short time.

To test the effect of drifting organisms on the recovery of a damaged area, an experiment was designed similar to the acute acid stress study, but drift sampling was included. The experimental site was prepared in the same manner as the previous study. Streamflow was alternately reduced on both experimental and reference sides of the divider. As the flow was reduced on the experimental side, concentrated technical grade sulfuric acid was distributed as evenly as possible along the experimental acidification to assess normal drift activity in the stream. A drift sample was collected immediately after acid addition, and additional samples were collected at two-hour intervals for 66 hours. After this initial series of drift samples, additional samples were collected periodically at 6 to 12-hour intervals. In addition to drift sampling, five Surber samples were collected from both reference and experimental sections 4 days and 21 days following the acid addition. All sampling procedures were similar to previous studies as listed in methods and procedures.

## VII. Physical-Chemical Results

Water quality analysis was performed regularly. In addition to normal water quality analysis, stream temperature was recorded with each drift sample. An estimate of stream velocity was made with a Gurly pygmy flow meter, and water depth was measured in the stream.

Typical water chemistry results are shown in Table 3.

## VIII. Biological Results

Results of bottom fauna sampling are contained in Appendix II-B, Table 4. Results obtained for day 4, indicate a diversity index of 2.52 and a density of 110 organisms/ft$^2$ in the experimental section, while the diversity was 2.92 and the density was 159 organisms/ft$^2$ in the reference section. The bottom fauna community in the experimental section was dominated by Coleoptera, *Cleptelmis sp.* while the reference section was co-dominated by *Cleptelmis sp.* and the Ephemeroptera, *Baetis sp.* On day 21, diversity in the experimental section was 2.76 and the density was 262 organisms/ft$^2$, while the diversity was 3.18 and density was 210 organisms/ft$^2$ in the reference section. In both the reference and experimental sections on day 21, the bottom fauna community was dominated by Ephemeroptera, *Ephemerella sp.*

Drift samples collected before acid treatment indicated drift intensity was greatest at night, largest drift movement occurring between 0000 and 0600 hours (Figure 3). Ephemeroptera and Diptera were the orders which showed the greatest tendency to drift (Figure 3). Although total drift intensity was at times very high, the majority of those organisms drifting were adult forms, not recolonizing larval forms. During emergence, large numbers of adult Ephemeroptera and Diptera were often caught in the drift nets. The drift samples collected in conjunction with the experimental acid stress showed similar trends. Total number of recolonizing organisms collected in one 15-minute drift sample varied between 0 and 50, average numbers collected were well below 10 organisms/sample. Immediately after acid addition drift out of the experimental site was extremely high. Drift collections included several species of fish including sculpin, *Cottus sp.*, and large numbers of all orders of insect bottom fauna. Drift intensity was still high 2 hours after acid treatment, but the collections were dominated by Ephemeroptera, *Isonychia sp., Ephemerella sp.,* and *Baetis sp.* During the same period, drift intensity out of the reference section was low.

Drift into both experimental and reference sections following the acid stress was similar. Drift intensity was low between 0600 and 1800 hours, and high between 1800 and 0600 hours. The taxon which showed the highest drift intensity was *Baetis sp.* Several other Ephemeroptera, *Isonychia sp., Ephemerella sp.,* and *Stenonema sp.* were also recorded in samples. Three taxa of Diptera showed high drift rates, *Simulium sp.,* and *Antocha sp.* were recorded regularly, while Chironomidae were recorded irregularly. The trichopteran, *Hydropsyche sp.* was recorded infrequently in drift samples.

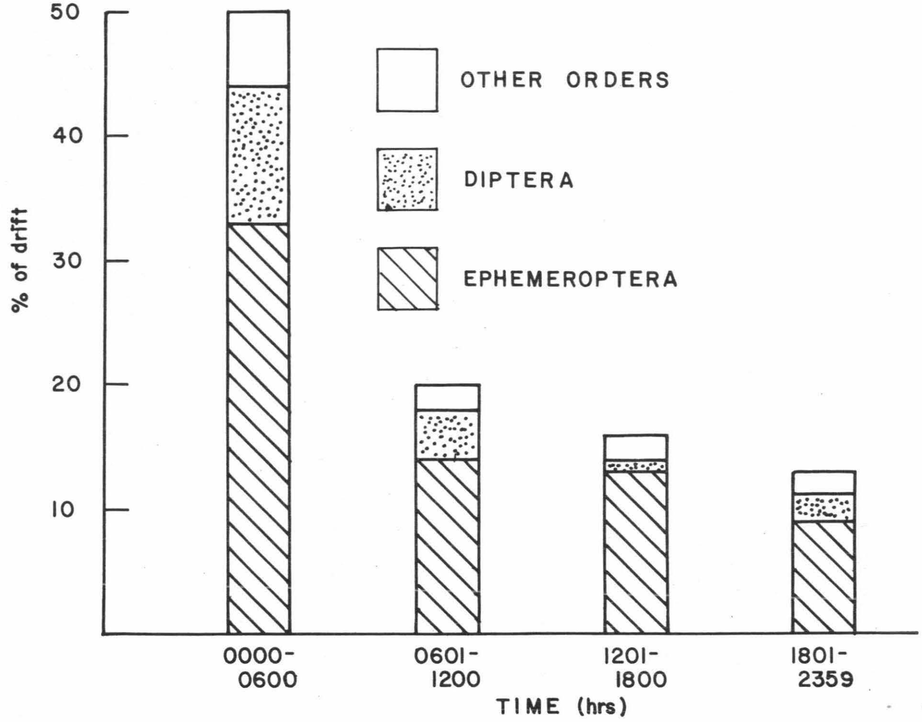
## Table 3

### Typical Water Chemistry Results
### For Drift Study

| | |
|---|---|
| pH | 8.0 to 8.5 |
| Total Alkalinity (ppm) | 185 to 210 |
| Free Acidity | 0 |
| Total Acidity | 0 |
| Total Hardness | 210 to 225 |
| Dissolved oxygen (ppm) | 6 to 8 |
| Temperature °C | 15 to 20 |

Figure 3

Number of Drifting Organisms Collected During Four 6-Hour Periods



Overall drift intensity was greatest immediately following the acid stress due mainly to drift out of the experimental section. As many as 50 recolonizing organisms were collected in one drift sample after acid stress. Drift intensity from the experimental section continued high for approximately 48 hours then numbers collected began to fall off. At the end of the 66-hour initial sampling period, drift intensity both into and out of the experimental and control sections was similar to pre-stress drift samples. The sampling which continued on an irregular basis revealed drift intensity similar to pre-stress levels, the drift fauna was dominated by the Ephemeroptera, *Baetis sp.*

## IX. Discussion

Physical conditions throughout the study were similar. Stream discharge remained relatively constant before and after addition of acid with the exception of flow alteration to allow addition of acid. The damage to the bottom fauna community was similar to previous acute stress experiment. Density and diversity were reduced in the experimental section, and the bottom fauna community after stress was dominated by the coleopteran, *Cleptelmis sp.* The recovery of the damaged section was evidenced by increased diversity and density, and the Ephemeroptera *Baetis sp.* dominated the bottom fauna community on day 21. This dominance of *Baetis sp.* appears to be directly related to drift-borne recolonizing organisms. In virtually all drift samples, *Baetis sp.* was present in greatest numbers. Other members of the drift community also appeared in bottom fauna collections although in reduced numbers. These included *Simulium sp., Antocha sp.,* and *Hydropsyche sp.*

There are a number of factors which may be related to drift initiation. From these studies, the dominant factor related to drift intensity throughout the stream appeared to be emergence activity. The density of recolonizing organisms in the total drift is small, but it may be a significant source of recolonizing organisms. During the periods of highest drift intensity, as many as 50 recolonizing organisms were collected from a 1-foot width of the stream. Average drift intensity was 10 organisms or less, but this number multiplied by stream width, and the number of 15-minute periods in a 24-hour period results in a total number of recolonizing organisms in excess of 5000/day. This number would be sufficient to bring about rapid recovery if these organisms found suitable habitat in the damaged area.

# OBSERVATION SITES

## I. Indian Creek

The recovery which occurs through distance is influenced by the interactions between various characteristics of the watershed and the biotic system. Indian Creek, Fayette County, Pennsylvania was selected to study the interactions between physical, chemical, and biological components of the watershed as they affect restoration and influence stream recovery from acid mine drainage.

### A. History

The Indian Creek watershed lies in the southwestern Pennsylvania coal fields. Mineral exploration reports were available dating back to 1858 (Rogers 1858). Coal mining in the Indian Creek valley began in the early 1900's near Indian Head and Melcroft (Figure 4). Production reached a peak of 34 million tons in 1916, (Anonymous, 1969), but steadily declined with decreasing demand; only 1.2 million tons were mined in 1967. Although the last active deep mine, Melcroft No. 1 on Champion Run, was shut down in 1966, several surface mining operations were active in the headwaters of both Champion Run and Poplar Run during this study.

Acid mine drainage has been a problem in the watershed since mining began. Mine drainage in Indian Creek was the subject of a ruling made by the Pennsylvania Supreme Court in 1924 (Anonymous, 1969). It was claimed that mine drainage polluted the reservoir at Normalville rendering the water unsuitable for use as boiler water for steam locomotives. As a result of this court action, a diversion system was constructed to carry mine drainage away from the upstream portion of Indian Creek and discharge the collected mine drainage below the reservoir. The diversion system was constructed in 1924, improvements had been made to several sections, and the diversion system was still in operation during this study. Portions of the diversion system used old mine works and depended on regular pumping of mine drainage from collecting basins near Champion Run. Several of these pumping stations were no longer maintained after the Melcroft No. 1 mine shut down and mine drainage was allowed to discharge into Champion Run, polluting Indian Creek. In addition to mine drainage from the abandoned underground works, a large quantity of acid drainage originated from gob piles of coal washing waste along the east bank of Champion Run. The combination of these two sources produced a severe acid mine drainage stress in Indian Creek.

## Figure 4a

Indian Creek Watershed Map
with Prominent Geology

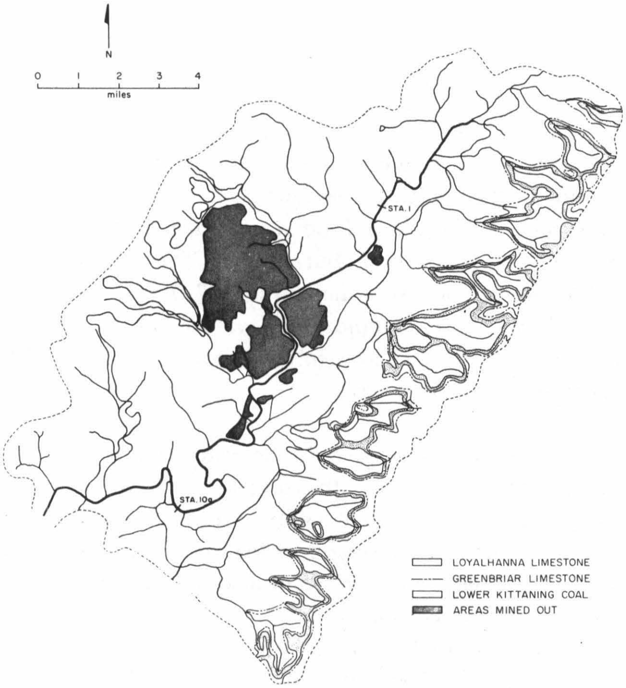
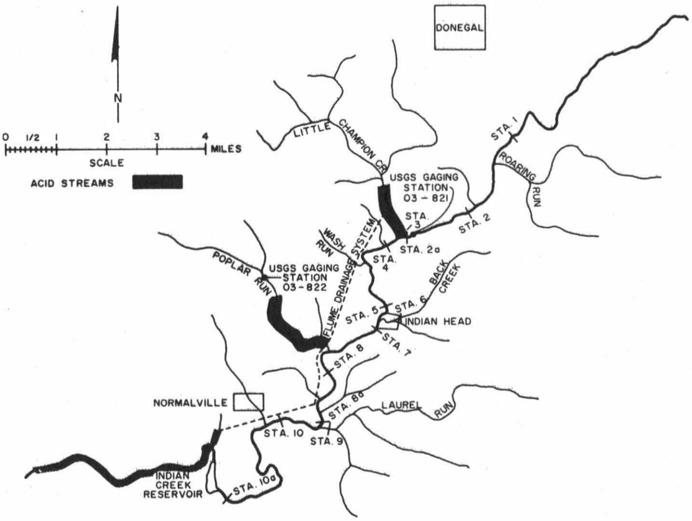


Figure 4b

Station Location Map
Indian Creek



In conjunction with the Youghiogheny River Basin Mine Drainage Pollution Abatement Project (Anonymous, 1969), a series of water quality studies were made in the Indian Creek watershed; all acid mine drainage sources were located and sampled for the Pennsylvania Department of Mines and Mineral Industries.

## B. Environmental Conditions

1. Physiography. The Indian Creek Valley is located in southwestern Pennsylvania in the Appalachian Plateau Province, Allegheny Mountain Section. The area is characterized by gently folded structures tending northeast-southwest. Indian Creek occupies a narrow valley between Laurel Hill and Chestnut Ridge which mark the main structural features (Laurel Hill Anticline and the Chestnut Ridge Anticline). Total relief is approximately 1750 ft (533 m); the main structural feature of the valley floor is the Ligonier Syncline. The rocks of the Indian Creek valley through which the main stem of Indian Creek flows are of Pennsylvanian age consisting of sandstones and shales interbedded with coal deposits. Laurel Hill and Chestnut Ridge are made up of Mississippian rocks which include the fossiliferous Greenbriar limestone and the siliceous Loyalhanna limestone (Figure 4). Coal deposits in the area include the Pittsburgh coal – Conemaugh Formation, the Upper Freeport, and Upper, Middle, and Lower Kittaning coals – Allegheny Group, and the Brookville, Mercer, Quakertown, and Sharon coals – Pottsville Group (Schaffner, 1963). The coal mined in the Indian Head and Melcroft areas was the Lower Kittaning coal. This coal was also mined in the surface operations on the headwaters of Poplar Run and Champion Run. Schaffner (1963) reported this coal contains between 0.8 and 3.8% sulfur.

The drainage area of Indian Creek is 124 mi$^2$ (200 km$^2$). Mainstem reach length is 32 mi (15 km). Only Indian Creek above the reservoir at Normalville was studied. Total reach length above the reservoir is 21.5 mi (34.6 km) and the average gradient is 39 ft/mi (7.5 m/km). Only a 13.5 mi (22 km) reach of the stream was sampled regularly, the gradient for this section is 16 ft/mi (3 m/km). Drainage direction is southwest. Indian Creek originates from sources flowing off Laurel Hill as do all eastern tributaries. Western tributaries flow generally southeast, originating along Chestnut Ridge.

2. Location and Description of Sampling Areas. Fifteen sampling stations were located on Indian Creek. Thirteen stations were sampled regularly for both physical-chemical and biological information. Initially, five stations were sampled, but increased interest and ongoing evaluation of samples required addition of mainstem and some tributary stations. Station locations and

## Table 4

Station Physical Characteristics — Indian Creek

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4 |
| Location (Stream miles) | 8.25 | 9.6 | 10.5 | 10.5 | — | 10.6 |
| (km) | 10.3 | 15.4 | 17 | 17 | — | 17.2 |
| Banks (max. height ft/m) | 2/.61 | 8/2.4 | 6/1.8 | 4/1.3 | 3/.9 | 10/.3 |
| Surroundings* | 2 + 5 | 2 + 3 + 5 | 3 + 5 | 3 + 4 | 2 + 4 | 2 + 4 |
| Average Width (ft) | 25-30 | 30 | 30 | 20-25 | 20-25 | 50-65 |
| Average Gradient (ft/100 ft) | 1 | 0.1 | 0.05 | NR | 1.1 | 0.3 |
| Substrate Size (in.) | | | | | | |
| Mean long dimension | 3.83 | 4.56 | — | — | 3.55 | 4.20 |
| Mean short dimension | 2.71 | 3.19 | — | — | 2.39 | 3.05 |

See footnotes on page 37.

## Table 4
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 8a | 9 | 10 |
| Location (Stream miles) | 12.75 | – | 13.1 | 15.8 | – | – | 18 |
| (km) | 20 | – | 21.1 | 25.4 | – | – | 29 |
| Banks (max. height ft/m) | 30/9 | 1/.3 | 10/3 | 3/.9 | 1/.3 | 2.5/7.5 | 2/.6 |
| Surroundings* | 2 + 3 | 1 + 5 | 3 + 5 | 2 + ,4 | 2 + 4 | 1 + 4 | 2 + 4 |
| Average Width (ft) | 60 | 20 | 60-65 | 80 | – | 10-15 | 100-125 |
| Average Gradient (ft/100 ft) | .1 | 1 | .3 | NR | 1 | .9 | .5 |
| Substrate Size (in.) | | | | | | | |
| Mean long dimension | 3.06 | 3.33 | 3.50 | – | – | 3.65 | 3.61 |
| Mean short dimension | 2.08 | 2.37 | 2.43 | – | – | 2.70 | 2.51 |

See footnotes on page 37.

## Table 4
(Continued)

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 8 | 8a | 9 | 10 |
| Estimated Mean Velocity (fps)** | .9 | 2.7 | – | 1.3 | – | – | 2.5 |
| For Depth (ft) | 3.9 | 2.3 | – | 3.2 | – | – | 2.5 |

*(1) forest, (2) light forest, (3) cleared land, (4) undeveloped area, (5) developed area
**Values derived from Water Surface Profile Program

physical parameters for all stations sampled are contained in Table 4. Notes of particular interest follow:

The original Station 2A was a short riffle section. After September 1971, the stream was channelized from 300 yds above Station 2a to below Station 4. This created an extensive riffle immediately upstream from the confluence of Champion Run with Indian Creek. Sampling after December 1971 used this riffle area.

Initially Champion Run at Station 3 was a rapid flowing stream with moderate gradient. The high flow and channelization which took place in September 1971 severely altered the station description. Large quantities of gravel were deposited at the mouth of Champion Run, a backwater area during the high flow. In addition, the stream channel was widened 40 to 50 ft (12 to 15 m) and steep, high banks, 3 to 6 ft (0.92 to 1.8 m) were cut. Normal streamflow was divided into two channels along each bank 2 to 4 ft (0.61 to 1.3 m) wide, streamflow was maintained year round in these channels.

Station 4 was also severely disturbed by channelization in September 1971. The left bank was left largely intact, but average stream width was increased from 50 to 65 ft (15 to 19.8 m). The right bank was built up as a levee 10 ft (3 m) high. Before September 1971, the stream channel was largely divided by flows from Champion Run, mixing was incomplete by this station. After channelization, the left channel was slightly higher than the right channel. Only at higher flows did streamflow along the left bank reach pre-channelization levels; the remainder of the time, the right channel was a shallow pool.

The stream valley began to narrow at Station 8, and high hills surrounded the station. This station was severely changed by the high flows which occurred in September 1971. Most fine materials were moved by the high flow, the stretch of stream which made up this station was severely scoured.

Station 10 had channels along the left and right banks. The center of the stream was a large bar which was covered by 0.5 to 0.75 ft (0.15 to 0.27 m) of water at normal flow. This bar area regularly dried out during summer low flow periods. Along the right bank was evidence of an abandoned coal washing operation, and USGS topographic maps show abandoned mines along this section of the stream.

Stations 8b and 10a were located on the mainstem of Indian Creek near stream miles 17.4 (28 km) and 21 (33.7 km). Station descriptions were similar to Stations 8 and 10.

## C. Results and Discussion

Results of chemical analyses and stream discharge values from hydrologic simulation are contained in Appendix II-A. For each sampling period, the tables list water analyses and estimated average daily discharge (EADD) for three weeks prior to, and including, the week of sampling. In addition, a supplemental table lists the high and low estimated daily discharge value for the same period with the date of occurrence. Discharge values were obtained from hydrologic modeling.

Results of biological sampling analysis are also contained in Appendix II-A. For each sampling period, data summaries include total number of organisms collected, total number of taxa collected, diversity and redundancy calculations (both $\bar{d}$ and H), and density. Additional biological data evaluation includes correlation matrices relating all stations collected during one sampling period. Dendrograms resulting from the cluster analysis of all stations collected during one sampling period are shown for all sampling periods with the exception of October 1971 and October 1972.

1. Water Quality. Water quality is poor in some areas of the watershed showing the impact of acid mine drainage on Indian Creek. The major source of mine drainage was the tributary Champion Run. The Pennsylvania Department of Mines and Mineral Industries (Anonymous, 1969) has identified 8 major sources of mine drainage in the Melcroft Mine area (Figure 5). These mine drainage sources severely polluted Champion Run approximately 1 mile (1.2 km) from its mouth. In addition to these major sources of acid mine drainage, additional sources of mine drainage were indicated upstream from Champion Run [acid bog, near Riffle's place (Station 2)], and Poplar Run (Station 8a), Table 5. Several gob piles, waste from coal washing operations, were observed along Indian Creek, specifically near Indian Head No. 1 (Station 5), Saltlick (Station 8), and the recovery station (Station 10). The gob pile near Indian Head No. 1 showed the potential of producing acid drainage by the increased iron concentrations found in the July 1971 sampling (Appendix II-A, Table 7). The pH was also decreased between Indian Head No. 1, and Indian Head No. 2 (Station 7) during this sampling period. The low EADD for this sampling period indicated that decreased dilution probably allowed a minor mine drainage source to have major effect on water quality.

## Table 5

### Supplementary Water Quality Analysis

| | pH | Conductivity µmohs | Total Hardness gpg | Ca ppm | $SO_4$ ppm | Zn ppm |
|---|---|---|---|---|---|---|
| Indian Creek Headwaters | | | | | | |
| Camp Run* | 6.5 | .35 | .18 | 1.0 | 10.8 | – |
| Upstream Indian Creek | 6.9 | 3.18 | 22.9 | 2.9 | 26.9 | – |
| Unident. Trib. | 7.1 | .97 | 12.2 | 1.3 | 12.5 | – |
| Reference Station | 6.9 | 2.54 | 19.6 | 8.2 | 21.4 | – |
| Roaring Run Watershed | | | | | | |
| Pike Run | 6.7 | 1.06 | 13.3 | 2.0 | 23.6 | – |
| Pike Run (us. conf. w/Roaring Run) | 7.05 | .95 | 9.5 | 1.3 | 10.9 | – |
| Roaring Run (us. conf. w/Pike Run) | 7.1 | .74 | 9.0 | 1.2 | 7.2 | – |
| Roaring Run | 6.9 | .87 | 21.6 | 1.3 | 8.5 | – |

*Names from U.S.G.S. 15-minute topographic map, Donegal, Pa. quad.

## Table 5
(Continued)

|  | pH | Conductivity µmohs | Total Hardness gpg | Ca ppm | SO$_4$ ppm | Zn ppm |
|---|---|---|---|---|---|---|
| Western Tributaries |  |  |  |  |  |  |
| Champion Run Watershed |  |  |  |  |  |  |
| Champion Run (us. conf.) w/Minnow Run) | 7.1 | 1.67 | 12.8 | 3.6 | 28.7 | – |
| Minnow Run | 7.0 | 4.75 | 26.6 | 5.8 | 46.1 | – |
| Unident. Trib. Champion Run | 7.1 | 1.86 | 18.3 | 3.8 | 30.7 | – |
| Champion Run (us. conf. w/Little Champion Run) | 7.1 | 3.29 | 20.6 | 4.7 | 36.7 | – |
| Unident. Trib. hdwr. Little Champion Run | 7.1 | 1.63 | 16.4 | 3.5 | 34.6 | – |
| Unident. Trib. hdwr. Little Champion Run | 6.9 | 1.86 | 15.6 | 2.6 | 30.6 | – |
| Hdwr. Little Champion Run | 6.6 | 3.97 | 34.7 | 13.6 | 35.2 | .39 |
| Little Champion Run (us. confl. w/Champion Run) | 6.7 | 13.0 | 29.2 | 10.6 | 26.4 | .37 |
| mouth Champion Run | 4.4 | 5.0 | 28.4 | 10.9 | 181.3 | .18 |

Table 5
(Continued)

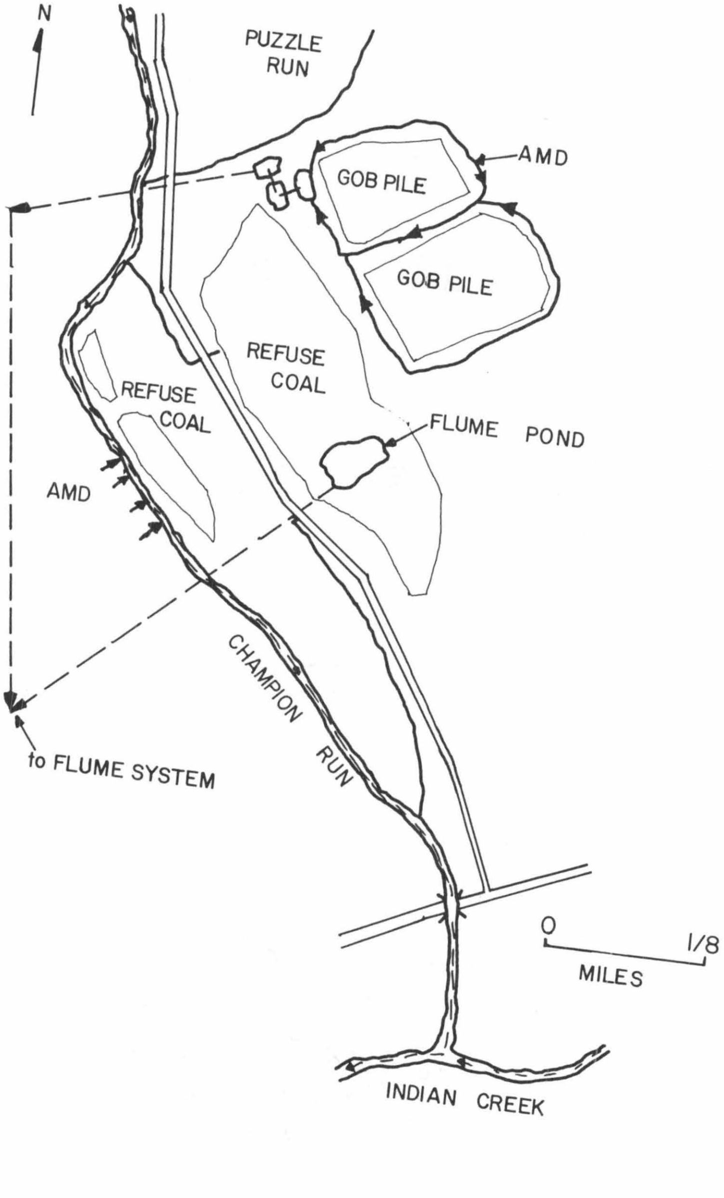
| | pH | Conductivity µmohs | Total Hardness gpg | Ca ppm | $SO_4$ ppm | Zn ppm |
|---|---|---|---|---|---|---|
| Poplar Run Watershed | | | | | | |
| hdwr. Poplar Run | 6.5 | 1.33 | 10.5 | 4.5 | 41.2 | .37 |
| hdwr. Newmeyer Run | 6.5 | .94 | 5.7 | 1.8 | 26.4 | .39 |
| Poplar Run | 5.1 | 2.38 | 19.9 | 6.2 | 42.2 | .27 |
| Eastern Tributaries | | | | | | |
| Back Creek Watershed | | | | | | |
| Trout Run | 7.2 | 1.09 | 13.7 | 1.5 | 8.4 | — |
| Neals Run | 7.3 | .85 | 10.5 | 1.3 | 10.5 | — |
| Back Creek (ds. confl. | | | | | | |
| w/Trout and Neals) | 7.2 | 1.01 | 13.9 | 1.4 | 8.6 | — |
| w/Back Creek us) | 7.1 | .99 | 12.8 | 1.4 | 8.5 | — |
| w/Back Creek Mouth) | 6.6 | 1.04 | 12.8 | 1.7 | 12.5 | — |

Table 5
(Continued)

| | pH | Conductivity µmohs | Total Hardness gpg | Ca ppm | $SO_4$ ppm | Zn ppm |
|---|---|---|---|---|---|---|
| Laurel Run Watershed | | | | | | |
| Laurel Run hdwr. | 7.0 | .59 | 5.2 | 1.1 | 8.0 | — |
| Middle Fork | 7.1 | .70 | 8.6 | 1.2 | 10.8 | — |
| Buck Run | 7.3 | .77 | 8.8 | 1.4 | 9.0 | — |
| Laurel Run Mouth | 6.9 | .73 | 7.7 | 1.2 | 9.9 | — |
| Mainstem Indian Creek | | | | | | |
| Indian Head No. 1 | 6.15 | 2.54 | 23.4 | 8.4 | 67.5 | .05 |
| Recovery Station | 6.8 | 2.04 | 19.1 | 5.6 | 49.1 | — |

Figure 5

Map of Melcroft Mine Area with Acid Mine Drainage Discharges Indicated



The results of water quality analyses performed for acidity, alkalinity, and sulfate during the two-year sampling effort have been summarized in Figures 6 through 8. The Figures show the mean and range of all recorded values at each station for acidity, alkalinity, and sulfate. The upstream reference (Station 1) had good water quality; alkalinity values were consistently high while acidity values were consistently low. Sulfate values had a small range, the average value being below 15 ppm. Riffle's place showed similar results, but Melcroft (Station 2a) had higher mean values for acidity and sulfate, and greater range for all three parameters. Champion Run had consistently high acidity and sulfate, and no alkalinity. Ranges for all parameters illustrated were large, indicating a variable but poor water quality, which may be attributed to variable discharge/AMD volume relationships in Champion Run. Station 4 was considered the "unmixed station." Figures 6 through 8 illustrate this characteristic. The right bank collections showed lower mean acidity and sulfate values, and a higher mean alkalinity when compared with the left bank. The range of values recorded for both right and left bank are large, indicating a variable water quality. Variability may be attributed to changes in discharge relationships between the upstream portion of Indian Creek and Champion Run. Indian Head No. 1 had higher mean acidity and sulfate values, and lower mean alkalinity values when compared with the upstream reference stations. The pH of Indian Head No. 1 was consistently higher than Champion Run, but lower than upstream reference stations (Appendix II-A, Tables 1-21). Iron concentration had decreased by Indian Head No. 1 probably due to precipitation of iron as the pH was raised. The water quality of the mainstem of Indian Creek improved considerably after the confluence with unpolluted tributaries, Back Creek (Station 6) and Laurel Run (Station 9). Figures 6 through 8 illustrate that all three parameters were similar to the mean and range indicated for upstream reference stations at Back Creek and Laurel Run. The addition of these unpolluted tributary waters improved the mainstem water quality not only by dilution, but also by chemical reaction.

At Indian Head No. 2 (Station 7) mean alkalinity values increased while mean acidity values remained similar when compared to Indian Head No. 1. Water quality at Saltlick showed further improvement. A curtailment of sampling at this station due to poor access reduced the number of samples, and may have biased the mean and range values shown. Poplar Run was another acid tributary. Sulfate values were consistently high as was acidity, while the mean alkalinity value was low. By the recovery station, mean sulfate values were lower. The range of acidity values for the recovery station was less than for Indian Head No. 2, and the mean alkalinity value, although lower than Saltlick, had little variability.

Figure 6

Mean and Range of Alkalinity Values Recorded During the Indian Creek Study

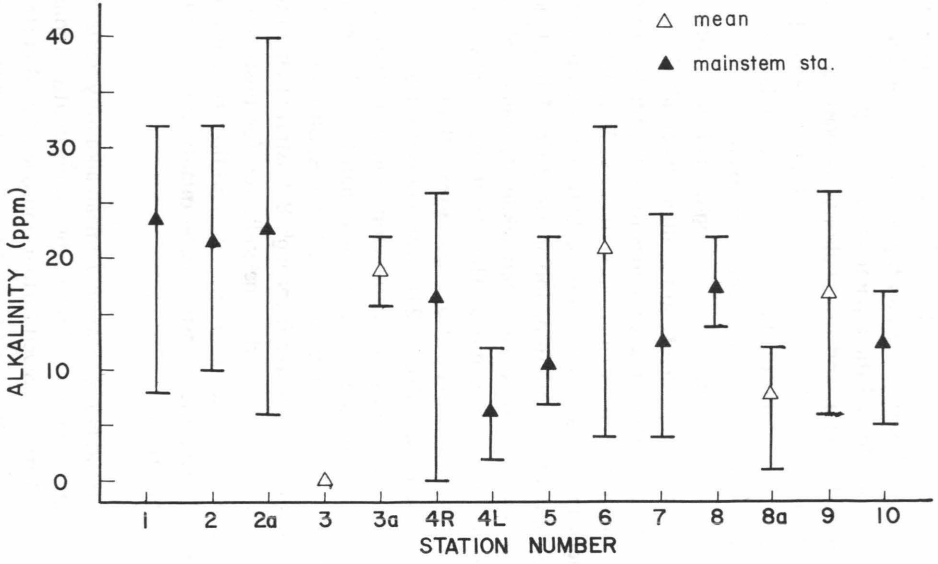
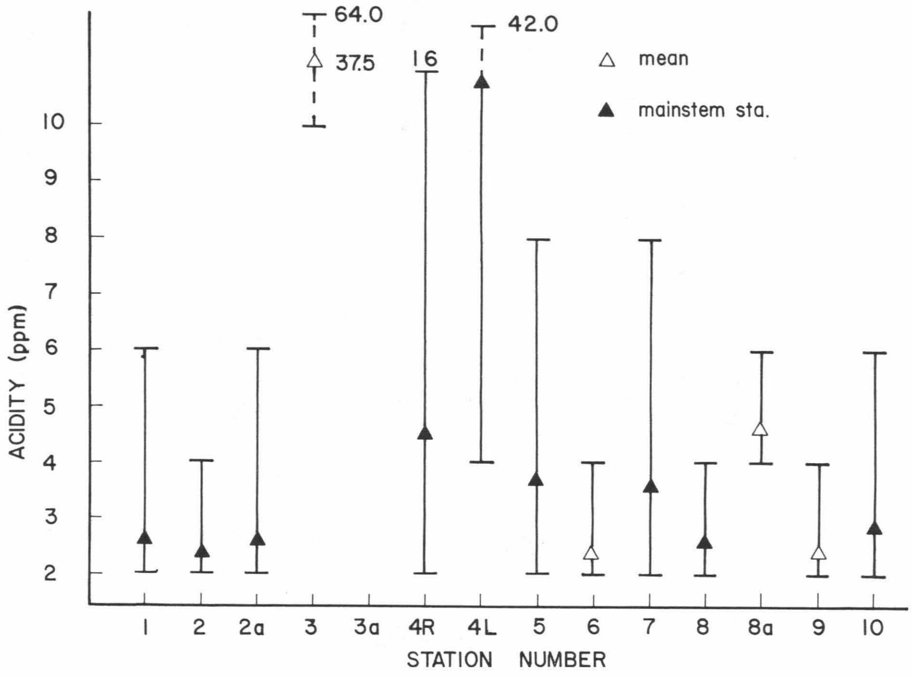


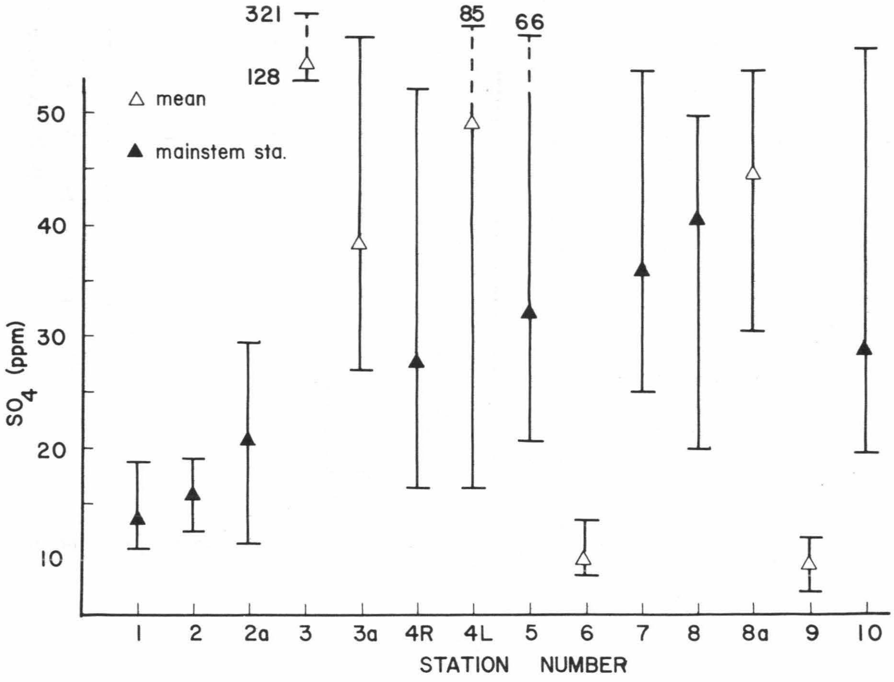
Figure 7

Mean and Range of Acidity Values Recorded During the Indian Creek Study



## Figure 8

Mean and Range of Sulfate Values Recorded During the Indian Creek Study



In summary, the water quality in the mainstem of Indian Creek illustrated the overall effect of a severe mine drainage influence. The upstream reference stations maintained good water quality throughout the study period. Although the mine drainage from Champion Run was poorly mixed at Station 4, water quality was reduced at this station. With complete mixing of the acid mine drainage and no tributary influence, Indian Head No. 1 had the poorest water quality when all three parameters were considered. Although sulfate concentrations did increase throughout the stream, the addition of unpolluted tributary water improved overall water quality. The water quality at Indian Head No. 2 was variable; this variability decreased at the recovery station indicating overall improvement in water quality.

The effect of mine drainage from Champion Run on Indian Creek varied throughout the study period due to seasonal and other influences. During high discharge periods the effect of the acid drainage was decreased. This decrease can be explained by the following: (1) flow volume from the upstream portion of Indian Creek was at times large enough so that the acid drainage in Champion Run was diluted; (2) higher flow volumes from mine drainage sources reduced the concentration of the mine drainage entering Indian Creek; and (3) higher discharges from tributaries including the upstream portion of Champion Run further diluted the acid drainage reducing its influence on the downstream portions of Indian Creek. Extremely high flows such as those in March 1972 (Appendix II-A, Table 15) diluted the acid mine drainage, but had little capacity for neutralization. Thus, during extended rainfall periods (e.g., the weeks preceding the March 1972 sampling) streamflow was predominantly direct runoff, and the alkalinity and pH of the water samples were very low.

During the low discharge periods, the effect of mine drainage from Champion Run was intensified. The acid drainage from the Melcroft mines was only partially diluted by discharge volumes from the upstream portions of Champion Run and Indian Creek. The pH of Champion Run was generally lower, and sulfate concentrations, when compared with mean values, were higher. During these periods both right and left bank sulfate concentrations at the unmixed station were high, and there was little change in sulfate concentrations by Indian Head No. 1. Mine drainage volumes at this time were sufficient to affect the total streambed across the full width at the unmixed station, and the acid drainage was only partially diluted by upstream flow. During these low discharge periods the effect of mine drainage extended further downstream, affecting Indian Head No. 2. Improvement of water quality occurred below each confluence with an unpolluted tributary. Even though the dilution ability based on streamflow was reduced, the neutralization capacity of the eastern tributaries was improved. Streamflow during low discharge periods is predominantly from groundwater. Because the groundwater in the headwaters of the eastern tributaries flows through calcareous rocks, alkalinity of the tributary waters in June 1971 and 1972 (Appendix II-A, Tables 6 and 19), was increased. Thus, the ability to neutralize the acid drainage was also increased.

The relationship between acid mine drainage intensity and streamflow deserves some discussion. Because most mine drainage in Champion Run was from underground sources, these discharges maintained a relatively constant AMD volume. Mine drainage volume and discharge intensity have been shown to be seasonally related (Appalachian Regional Comm., 1969, pp. C32-C33). The mine drainage volume is dependent on rainfall infiltration to underground areas. Although pyrite oxidation is not appreciably changed by the amount of water present, the concentration of pyritic oxidation end products will vary with volume. Because the infiltration rate is greater during the winter, the volume of mine discharges is increased from December through April. Infiltration decreases during the summer months thus mine discharge volumes also decrease.

The major source of acid in an underground mine is pyritic materials located above normal water levels. When the mine is flooded by high base flow (i.e., high infiltration rate) the pyritic oxidation is limited by oxygen transport relationships in the water reducing overall AMD concentration. If flow through the mine has been low for some time, the oxygen-rich atmosphere of the mine allows rapid oxidation of pyrite, and large quantities of oxidation products may be present on unflooded surfaces. As flow through the mine increases, these oxidation products are put into solution. The first flush discharges, caused by high flow through the mine, may be highly concentrated.

Superimposed on this pattern of seasonal changes in base flow and AMD concentration are several concentration and stream impact relationships. First, because the first flush discharges may be more concentrated, the assimilative capacity of the stream may be overloaded from slug loads. Second, the capacity of the receiving stream to assimilate a given acid mine drainage volume and concentration varies with stream discharge and is particularly related to the percentage of base flow represented in the receiving stream, presence of calcareous rocks, and several physical factors, such as temperature.

The stream assimilative capacity is based on both alkalinity (i.e., neutralization) and stream discharge volume (i.e., dilution). During the spring, mine drainage is usually high but dilution is increased by higher stream discharge (improving assimilative capacity). This is shown by May 1971 and March 1972 water quality analyses. As spring high flows recede, mine drainage volumes may remain high thus increasing the impact of the discharge. June 1971 and June 1972 water quality analyses indicate this; even though moderate to high discharge volumes during the week of sampling resulted in high sulfate concentrations in Champion Run (Appendix II-A, Tables 5 and 19). During the late spring and summer months when mine drainage is low, normal stream discharge is also low, resulting in extended periods of low water quality as indicated by high sulfate concentrations (Appendix II-A, Tables 7, 9, and 21). The assimilative capacity of the stream may be quite variable during these periods. The base flow of the stream during these periods is dominated by groundwater input.

In areas where groundwater moves through limestone formations, alkalinity is increased thus improving assimilative capacity. Increased alkalinity due to groundwater input is shown for July 1971 (Appendix II-A, Table 7). Although conditions may improve downstream due to tributary influence, the mid portion of Indian Creek, the unmixed station, and Indian Head No. 1 were under more severe stress, while Indian Head No. 2 showed decreased water quality probably due to poor mixing. In late summer, mine drainage volumes remain low because heavy vegetative cover maintains high transpiration rates, further reducing infiltration. As stream discharge increases in late summer and early fall due to greater rainfall, stream conditions improve because the dilution capacity of the receiving stream is increased. This trend is demonstrated by samples from October 1970 and October 1972 (Appendix II-A, Tables 1 and 23). During the winter the cycle begins again. High infiltration rates increase mine drainage volumes, but stream discharge volumes during this period are generally high, and the assimilative capacity is correspondingly good.

Temperature and seasonal climatic conditions affect mine drainage in other ways. The mine drainage from underground sources during the summer months is usually poorly oxidized because oxygen is limited in the mine drainage (Schumate, Smith, and Morth, 1972). The oxidation of this mine drainage in the receiving stream places a severe oxygen stress on the receiving stream. Thus a secondary stress occurs due to the high oxygen demand of the mine drainage which occurs when water temperatures are generally high, and dissolved oxygen is low.

A second seasonally related mine drainage discharge problem occurs from surface sources. Pyritic materials on gob piles are well oxidized. During the winter months the reduced surface temperature reduces oxidation rates, and temperatures below freezing prevent runoff from gob piles. Initial melt carries the oxidation products into the receiving stream, but high assimilative capacity due to high stream discharge reduces its effect. Chemical reactions on the gob piles are increased during the warm summer months. Rainfall during this period usually occurs as high intensity storms which flush unvegetated areas rapidly. The accumulation of pyritic oxidation end products makes initial runoff highly concentrated, and acid mine drainage slugs precede increased streamflow while assimilative capacity is low; major damage may occur. Although this surface runoff may occur most often during the summer months, water chemistry analyses from October 1972 demonstrate this effect. Initial sulfate levels in Champion Run were 180 ppm. Shortly after rainfall began, sulfate levels were 321 ppm indicating slug loading. Twenty-four hours later, sulfate concentration was 90 ppm due to increased dilution by high streamflow.

2. The Chemical-Physical System. A series of supplemental chemical analyses were made to characterize water quality throughout the watershed, and possibly illuminate relationships between the geology, water quality, and eventual stream recovery. Table 5 lists the results of chemical analyses performed on the sub-basins of the Indian Creek watershed. All water samples were collected in September after an extended dry period. Water chemistry analyses should indicate the influence of groundwater flow on total stream water quality. Water quality in the headwaters of Indian Creek and the eastern tributaries was generally good. The pH values ranged from 6.5 to 7.3; conductivity (i.e., dissolved solids) was low, 0.35 to 3.18 μmohs, and sulfate was less than 20 ppm. The low pH (6.5) and high conductivity (3.18 μmohs) combined with sulfate (26 ppm concentration) indicate the possibility of AMD influence in a portion of upstream Indian Creek. The headwaters regions of the western tributaries also had high pH (6.6 to 7.1) but conductivity was high (1.67 to 4.75 μ̂mohs) as was sulfate (above 20 ppm). AMD influence probably contributed to both increased sulfate and conductivity in these areas. Downstream from AMD sources the pH was 4.4 to 5.1, conductivity was as high as 5.0 μmohs, and sulfate concentrations were in the range of 42 to 181 ppm. The headwaters of Indian Creek and the eastern tributaries lie in formations of the Loyolhanna, and Greenbriar limestones. Although the same limestone formations occur on Laurel Ridge (eastern valley summit), no limestone formations are reported in the headwaters of the western tributaries. High sulfate and conductivity values, indicating significant AMD sources, were recorded throughout the western tributaries. The end result is the inability of the western tributaries to assimilate large quantities of AMD, thus the tributary waters entering Indian

Creek from both Champion Run and Poplar Run are highly acidic and significantly degrade the water quality of Indian Creek. Unlike the western tributaries, the eastern tributaries are relatively unaffected by AMD. By and large, the eastern tributaries have high pH and high alkalinity due to the limestone influence. This alkalinity from both the upstream region of Indian Creek and the eastern tributaries contributes to the neutralization of AMD from Champion Run and Poplar Run, restoring water quality and providing suitable habitats for biological recovery.

Tables 5 and 6 list the results of heavy metal analysis by atomic absorption spectroscopy. As much as 0.37 ppm zinc was found in samples from Champion Run, Indian Creek, and Poplar Run. The source of this zinc, and other heavy metals is evidently the coal deposit and related strata, specifically the pyritic material in the coal. Qualitative analysis of pyritic nodules found in Lower Kittaning coal samples (coal mined from Melcroft mines) by x-ray fluorescence indicated a wide variety of elements, including copper, zinc, iron, arsenic, titanium, manganese, sulfur, potassium, and calcium. These heavy metals precipitate as the pH is increased which accounts for low concentrations in water samples from Indian Creek. Analysis of substrate materials from the unmixed station (Station 4) showed high concentrations of heavy metals, as in Table 7. One suggested mechanism is precipitation of various heavy metals from the AMD as pH is raised according to equilibrium relationships of each metal ion. In addition, precipitation of FeOH flocs also remove metal ions in the floc matrix. In Indian Creek the greatest concentration of precipitated heavy metals based on pH values should be near the unmixed station, but precipitation could occur downstream due to changes in conditions. Thus secondary biological stress may occur due to heavy metal toxicity, which may be due to stream discharge AMD volume relationships that control pH or floc accumulation.

Stream discharge data are of specific importance in studying the recovery of the stream biological system from the effects of any stress. Unfortunately, discharge data were available only for Poplar Run. To accurately extrapolate these discharge values to various sub-basins in the Indian Creek watershed, the Stanford Watershed Model (Crawford and Linsley, 1966) was used to estimate stream discharge on a daily basis for the period of the study (See Appendix I). These estimates, although not completely reliable, do give an indication of trends occurring in the hydrologic environment of the watershed. In addition to daily discharge estimates, the model was used to predict storm hydrographs for the two major floods which occurred in the watershed on September 14, 1971 and June 23, 1972. The September 1971 flood had a major effect on the stream substrate materials, severely scouring

## Table 6

Water Quality Analyses of AMD From Gob Pile,
Melcroft Mines, Pennsylvania

| | Alkalinity | Acidity ppm | Sulfate ppm | Zinc ppm | Copper ppm |
|---|---|---|---|---|---|
| Gob Pile No. 1 | 0 | 1,000+ | 15,500 | 5.1 | 2.6 |
| Gob Pile No. 2 | 0 | 500+ | 2,050 | 1.4 | .15 |
| Gob Pile Runoff | 0 | 56 | 71.8 | .1 | – |

## Table 7

### Atomic Absorption Analysis of Substrate Samples at Station 4

| Element | mg/g dry weight | mg/g ash free weight |
|---|---|---|
| Lead | 0.017 | 0.022 |
| Iron | 58.5 | 73.5 |
| Copper | 0.017 | 0.022 |
| Zinc | 0.47 | 0.59 |

the streambed in the mainstem of Indian Creek below Champion Run. To gain an appreciation of the magnitude of this physical alteration, scour due to high flow was related to particle size movement at the peak flow (Table 8). These results were obtained from stage and velocity information developed from the Water Surface Profile Program (Shanholtz and Holtan, 1965). Figures 9 and 10 show particle size movement as related to depth (stage) and discharge. The diameter of particles moved during the flood was as large as 0.5 ft (15 cm). To verify this value, a comparison was made with mean rock size recorded at the mainstem stations, Table 4. Although it is difficult to relate the long and short dimension measures (area) with diameter (volume), the average long dimension varied from 3 to 4.5 in. (7.7 to 11.3 cm) within the range of calculations for the largest particle moved. In addition to particle size movement by peak flow during a severe flood, the particle size movement for several lower stage and discharge conditions was calculated. The estimated stage and discharge for the mean annual flood was determined from channel morphometry (lowest channel bank height) and values supplied by hydrologic simulation. The particle size moved by the mean annual flood was generally less than 1.2 in. (3 cm). This value has significance not only from the aspect of physical alteration (i.e., substrate movement), but also the biological impact produced by the removal of both fine particles (i.e., suspended solids) and biota (i.e., drift). This relationship between the onset of particle movement of a specified size and the recurrence interval of flow producing movement will be discussed in following sections as it relates to the stream biological system.

In addition to estimates of stream discharge and its effect on the physical environment, a model was developed to explore the relationship between stream discharge and chemical characteristics in the mainstem of Indian Creek. Because sulfate concentration is a good indicator of both AMD presence and concentration, a model was developed to predict sulfate concentration based on AMD input and stream discharge estimates from the Stanford Model (Appendix I-b). Figure 11 relates sulfate concentration to stream discharge. Although the relationship between AMD volume (i.e., sulfate concentration) and discharge is very complicated, the simplification shown in Figure 11 is useful because it represents average conditions over a long period of time. The effects of highly concentrated AMD on a small stream is shown by Champion Run (Station 3). Concentrations may fluctuate over a large range depending on discharge. The opposite is the case for the recovery station (Station 10). Over a wide discharge range, the sulfate values remain in a rather narrow range (20 ppm). The intermediate stations, Indian Head Nos. 1 and 2 (Stations 5 and 7) show sulfate concentration ranges between these two extremes. In general, sulfate concentrations are lower at

# Table 8

## Particle Size Which May Have Moved at the Storm Peak
September 14, 1971

| Station Number | Depth (ft) | Q (cfs) | Diameter Inches<br>$\gamma = 2.2$ | 2.4 | 2.6 |
|---|---|---|---|---|---|
| 2a | 12.86 | 9009 | 2.0 | 1.8 | 1.5 |
| 4 | 15.52 | 12584 | 1.1 | 0.96 | 1.5 |
| 5 | 15.64 | 13701 | 2.0 | 1.8 | 0.84 |
| 7 | 14.07 | 16431 | 3.9 | 3.2 | 2.9 |
| 8 | 22.44 | 20115 | 0.8 | 0.7 | 0.6 |
| 10 | 14.72 | 23692 | 7.1 | 6 | 5.3 |
| 10a | 13.20 | 26139 | 1.3 | 1.1 | 0.9 |

Figure 9

Particle Size Movement as Related to Flow Depth Obtained from Water Surface Profile Flood Flow Estimates for Indian Creek

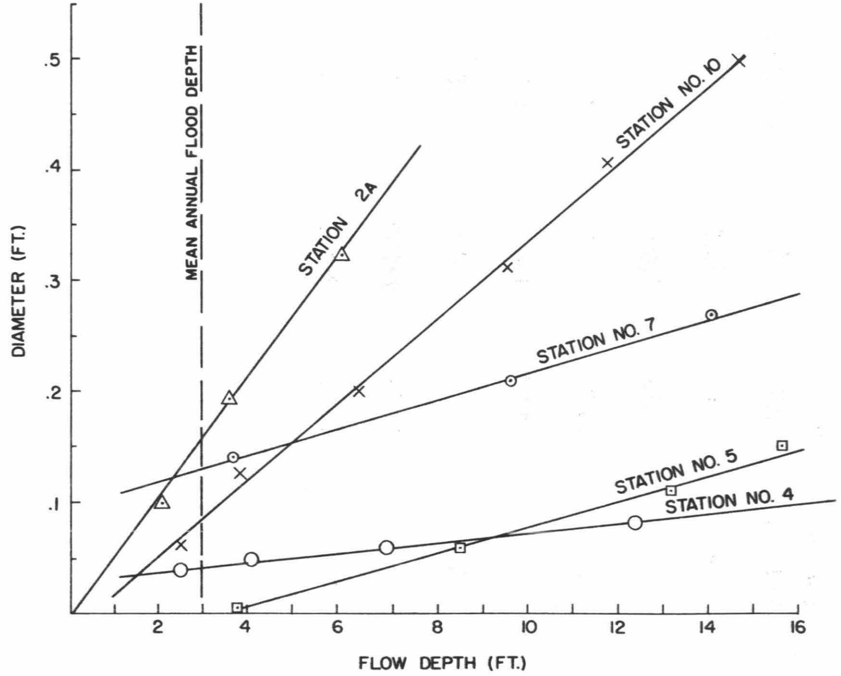


Figure 10

Particle Size Movement as Related to Discharge as Determined by Water Surface Profile Program for Indian Creek

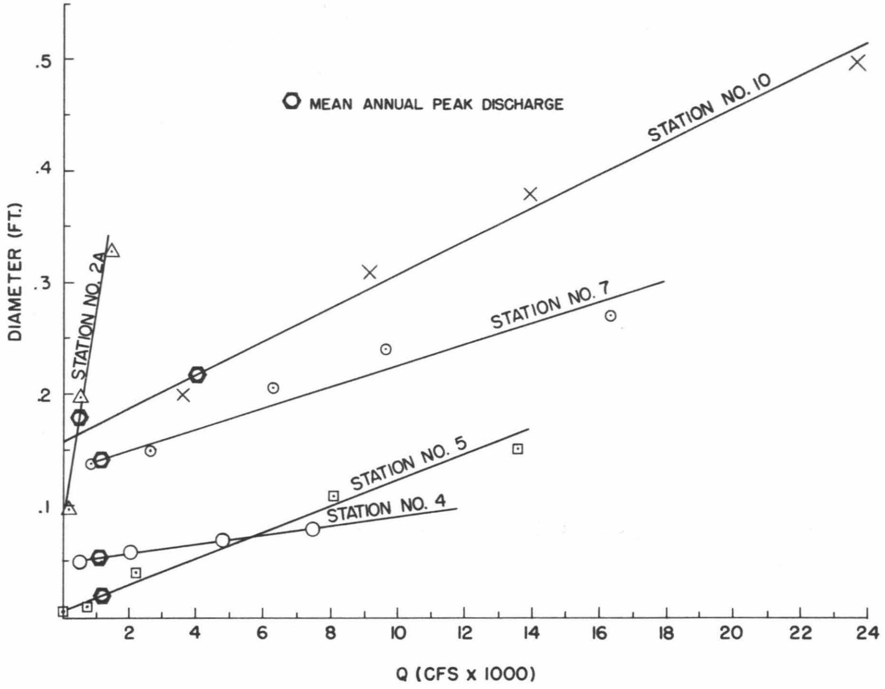
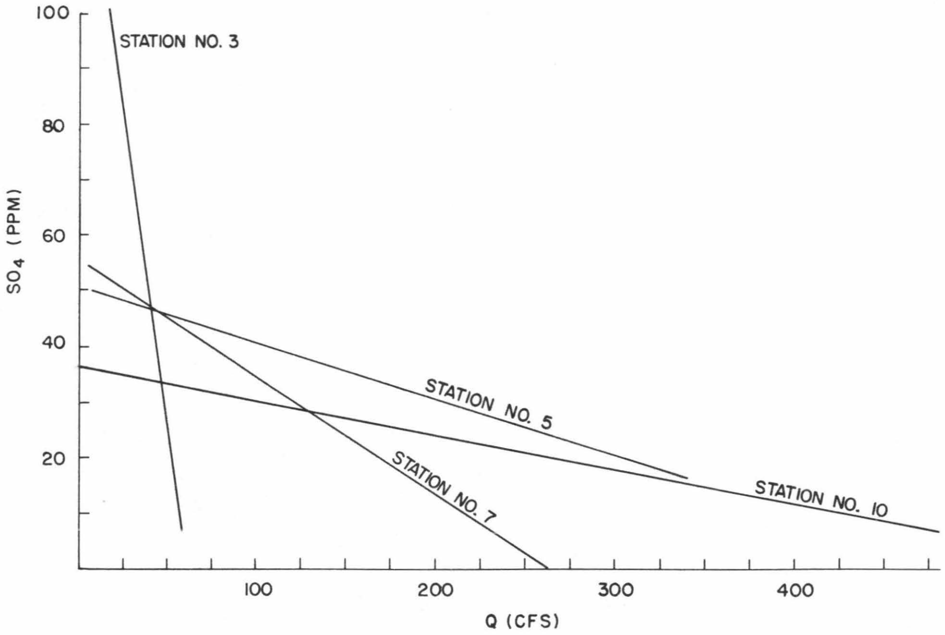


Figure 11

Sulfate Concentration as Related to Discharge for Selected Stations on Indian Creek



these stations due to increased discharge (i.e., dilution) of AMD from a constant source.

3. The Biological System. Table 9 lists all taxa collected in the Indian Creek watershed during the recovery study. Each taxa is keyed with a number which is used in the rank-abundance tabulation (Table 10). Roback and Richardson (1969) recognize Ephemeroptera, Odonata, and Plecoptera as non-tolerant taxa, and representatives of the Chironomidae as tolerant. Reference to the rank-abundance tabulation (Table 10) indicate *Hydropsyche sp.* occurred with regularity in collections from high stress stations. *Hydropsyche sp.* will also be considered tolerant.

The changes produced by Champion Run in the water quality of Indian Creek were reflected in the results of the biological sampling. The reference stations were consistently healthy during all sampling periods. This was indicated by high diversity values (above 3.0), normal density (above 100 organisms/ft$^2$), and the macrobenthos dominated by non-tolerant organisms (Ephemeroptera, Odonata, and Plecoptera) (Roback and Richardson, 1969). Although low diversity occurred on occasion (June and October 1972), non-tolerant organisms were present in high numbers during all sampling periods. Station 1 was used as the overall reference station. Figure 12 shows the mean and range of the diversity values calculated for each station during all sampling periods. Station 1 (upstream reference station) had the highest mean diversity of the mainstem stations with a narrow range. Density values from 70 to 300 organisms/ft$^2$ were recorded, and the community was well balanced with non-tolerant or moderately tolerant organisms present in greatest numbers.

Conditions at two of the reference stations, Riffle's place and Melcroft, were more variable. Riffle's place had a lower mean diversity than the two upstream reference stations. The normal collection area was located downstream from a deep pool, and portions of the riffle section dried up during low flow which restricted the sampling effort and probably contributed to lower diversity and the low density. The Melcroft station also had a lower mean diversity when compared with the upstream reference station, and the range of values was much greater. The acid bog downstream from Riffle's place probably had some effect on the diversity at Melcroft. Water quality analyses showed periodic high sulfate concentrations which indicate acid mine drainage, which in turn may have limited the bottom fauna community under certain conditions (i.e., low flow). A second probable cause of decreased diversity was organic pollution. Isolated sewer discharges along Indian Creek, one of which was located immediately upstream from the

## Table 9

## Taxonomic List of Organisms Collected in Indian Creek

### I. COLEOPTERA

Cyrinidae

1. *Dineutus sp*

Haliplidae

2. *Haliplus sp*

Psephenidae

3. *Psephenus sp*
4. *Ectopria sp*

Hydrophilidae

5. *Helophorus sp*

Elmidae

6. *Cleptelmis sp* # 1
7. *Cleptelmis sp* # 2
8. *Dubiraphia sp*
9. *Optioserus sp*
10. *Promoresia sp*

Ptilodactylidae

11. *Anchytarsus sp*
12. Unidentified

### II. TRICHOPTERA

Philopotamidae

13. *Chimarra sp*
14. *Wormaldia sp*

Psychomyiidae

15. *Polycentropus sp*
16. *Phylocentropus sp*
17. *Neureclipsis sp*
18. *Pschomyiid sp*
19. *Psychomyia sp*

Hydropsychidae

20. *Hydropsyche sp # 1*
21. *Hydropsyche sp* # 2
22. *Chumatopsyche sp*

Rhyacophilidae

23. *Rhyacophilia sp* # 1
24. *Rhyacophilia sp* # 2

Glossosomatidae

25. *Glossosoma sp*
26. *Agapetus sp*

Table 9
(Continued)

Hydroptilidae

27. *Leucotrichia sp*
28. *Orthotrichia sp*

Limnephilidae

29. *Neophylax sp*
30. *Radema sp*
31. *Drusinus sp*
32. *Pycnopsyche sp*
33. Unidentified

Lepidostomatidae

34. *Lepidostoma sp*
35. *Berea sp*
36. Unidentified
37. Unidentified

III. EPHEMEROPTERA

Ephemeridae

38. *Ephemera sp* #1
39. *Ephemera sp* # 2

Heptageniidae

40. *Stenonema sp* # 1
41. *Stenonema sp* # 2
42. *Stenonema sp* # 3
43. *Cinygma sp*
44. *Iron sp* # 1

Baetidae

45. *Isonychia sp* # 1
46. *Isonychia sp* # 2
47. *Isonychia sp* # 3

Leptophelebiinae

48. *Paraleptophlebia sp*

Baetiscinae

49. *Baetisca sp*

Ephemerellinae

50. *Ephemerella sp* # 1
51. *Ephemerella sp* # 2
52. *Ephemerella sp* # 3
53. *Ephemerella sp* # 4
54. *Ephemerella sp* # 5

Caeninae

55. *Caenis sp*

Baetinae

56. *Baetis sp* # 1
57. *Baetis sp* # 2
58. *Pseudocloeon sp*
59. *Cloeon sp*
60. Unidentified

## Table 9
(Continued)

IV. DIPTERA

Tipulidae

61. *Antocha sp*
62. *Pedicia sp*
63. *Eriocera sp*
64. *Hexatoma sp*# 1
65. *Hexatoma sp*# 2
66. *Tipula sp*

Ptchopteridae

67. *Ptychoptera sp*

Blepharoceridae

68. *Blepharocera sp*
69. *Philorus sp*

Simuliidae

70. *Simulium sp*# 1
71. *Simulium sp*# 2

Rhagionidae

72. *Atherix sp* # 1
73. *Atherix sp* # 2

Tabanidae

74. *Tabanus sp*

Empididae

75. *Hemerodromia sp*

Anthomyiidae

76. *Limnophora sp*

Heleidae

77. *Palpomyia sp*

Chironomidae

Taynpodinae

78. Chironomidae # 2

Chironominae

79. Chironomidae # 1
80. Chironomidae # 3
81. Chironomidae # 4
82. Chironomidae # 5
83. Unidentified # 1
84. Unidentified # 2

V. NEUROPTERA

Sialidae

85. *Sialis sp*

Corydalidae

86. *Corydalus sp*
87. *Chauloides sp*
88. *Nigronia sp*

VI. ODONATA

Calopterygidae

## Table 9
(Continued)

89. *Calopteryx sp*
90. *Hetaerina sp*

Gomphidae

91. *Octogomphus sp*
92. *Gomphus sp*

Aeshnidae

93. *Anax sp*
94. *Boyeria sp*

Cordulegastridae

95. *Cordulegaster sp*

Macromiidae

96. *Macromia sp*

Libelluidae

97. *Somatochlora sp*

VII. PLECOPTERA

Pteronarcidae

98. *Pteronarcys sp* # 1
99. *Pteronarcys sp* # 2
100. *Pteronarcys sp* # 3

Peltoperlidae

101. *Peltoperla sp*

Perlidae

102. *Perla sp* # 1
103. *Atoperla sp*
104. *Perlesta sp*
105. *Acroneuria sp* # 1
106. *Acroneuria sp* # 2
107. *Acroneuria sp* # 3
108. *Paragnetina sp*

Chloroperlidae

109. *Paraperla sp*
110. *Hastaperla sp*

Perlopidae

111. *Isoperla sp* # 1
112. *Isoperla sp* # 2
113. *Clioperla sp* # 1
114. *Clioperla sp* # 2

Nemouridae

115. *Nemoura sp*
116. *Taeniopteryx sp* # 1
117. *Taeniopteryx sp* # 2

Table 9
(Continued)

VIII. MOLLUSCA

Lymnaeidae

118. *Lymnaea sp* # 1
119. *Lymnaea sp* # 2

Anyclidae

120. *Ferrissia sp*

# Table 10

Rank-Abundance Tabulation — Indian Creek

|  |  | Station Numbers |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Rank | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| October 1970 | 1 | — | — | 20* | 79* | 20* | 20* | — | — | — | — | 20* |
|  | 2 | — | — | 22 | 20* | 79* | 79* | — | — | — | — | 22 |
|  | 3 | — | — | 41** | — | — | 92 | — | — | — | — | 80 |
|  | 4 | — | — | 101 | — | — | 17 | — | — | — | — | 41** |
|  | 5 | — | — | 61 | — | — | 75 | — | — | — | — | 79* |
| May 1971 | 1 | 79* | 51** | — | 115* | 51** | 51** | 58** | 79* | 20* | 58** | 20* |
|  | 2 | 50** | 79* | — | 88 | 79* | 20* | 61 | 51** | 79* | 50** | 79* |
|  | 3 | 61 | 20* | — | — | 20* | 80* | 79* | 58** | 51** | 20* | 51** |
|  | 4 | 20* | 22 | — | — | 58** | 115 | 6 | 20* | 88 | 44** | 59** |
|  | 5 | 59** | 58** | — | — | 44** | 22 | 51* | 6 | 113 | 6 | 23 |

## Table 10
(Continued)

| Date | Rank | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Station Number | | | | | | | | | | |
| June 1971 | 1 | 81* | – | – | No Dominant | 51** | 80* | 56** | 79* | 79* | 79* | 20* |
| | 2 | 56** | – | – | | 20* | 81* | 79* | 80* | 22 | 56** | 79* |
| | 3 | 6 | – | – | – | 56** | 79* | 52** | 56** | 56** | 25 | 22 |
| | 4 | 79* | – | – | – | 79* | 56** | 70 | 7 | 81* | 6 | 56** |
| | 5 | 81* | – | – | – | 22 | 20* | 61 | 51** | 113 | 113 | 81* |
| July 1971 | 1 | 79* | 79* | 61 | 79* | 79* | 79* | 25 | 79* | 79* | 20* | 20* |
| | 2 | 22 | 22 | 20* | – | 110 | 88 | 20* | 20* | 56** | 25 | 22 |
| | 3 | 61 | 20* | 79* | – | 20* | 85* | 6 | 22 | 20* | 79* | 79* |
| | 4 | 51** | 61 | 22 | – | 6 | 22 | 79* | 6 | 55** | 6 | 56** |
| | 5 | 20* | 42** | 6 | – | 83 | 66 | 110 | 25 | 58** | 22 | 57** |
| August 1971 | 1 | 80* | 79* | 79* | 64 | 20* | 20* | 6 | 79* | 20* | 20* | 79** |
| | 2 | 22 | 22 | 61 | 20* | 79* | 79* | 22 | 20* | 50** | 79* | 20 |
| | 3 | 20* | 41** | 6 | 79* | 22 | 22 | 20* | 22 | 81* | 20 | 20 |
| | 4 | 70 | 6 | 20* | 51** | 6 | 9 | 79* | 6 | 79* | 6 | 69 |
| | 5 | 41** | 20* | 22 | – | 88 | 56** | 56** | 70 | 22 | 25 | 41** |

## Table 10
(Continued)

|  |  | Station Number |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Rank | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| September 1971 | 1 | – | – | – | 20* | 20* | – | – | – | 20* | – | 20* |
|  | 2 | – | – | – | 79* | 79* | – | – | – | 79* | – | 22 |
|  | 3 | – | – | – | 80* | 41** | – | – | – | 6 | – | 41** |
|  | 4 | – | – | – | 46** | 6 | – | – | – | 22 | – | 79* |
|  | 5 | – | – | – | 6 | 20 | – | – | – | 81 | – | 56** |
| October 1971 | 1 | 79* | 41** | 79* | 84 | 20* | 20* | 79* | 20* | 20* | 51** | 20* |
|  | 2 | 20* | 20* | 41** | 79* | 41** | 79* | 20* | 42** | 79* | 20* | 79* |
|  | 3 | 22 | 22 | 20* | – | 46** | 21* | 22 | 56** | 41** | 22 | 41** |
|  | 4 | 41** | 79* | 61 | – | 6 | 22 | 51** | 41** | 6 | 79* | 22 |
|  | 5 | 81* | 60 | 88 | – | 21 | 66 | 41** | 20 | 22 | 41** | 85* |
| December 1971 | 1 | 20* | – | – | 80* | 48** | – | – | 54** | 20 | – | 79* |
|  | 2 | 22 | – | – | – | 81* | – | – | 46** | – | – | 20* |
|  | 3 | 41** | – | – | – | 20* | – | – | 79* | – | – | 81* |
|  | 4 | 13 | – | – | – | 23 | – | – | 81* | – | – | 85* |
|  | 5 | 79* | – | – | – | – | – | – | 20* | – | – | 73 |

## Table 10
(Continued)

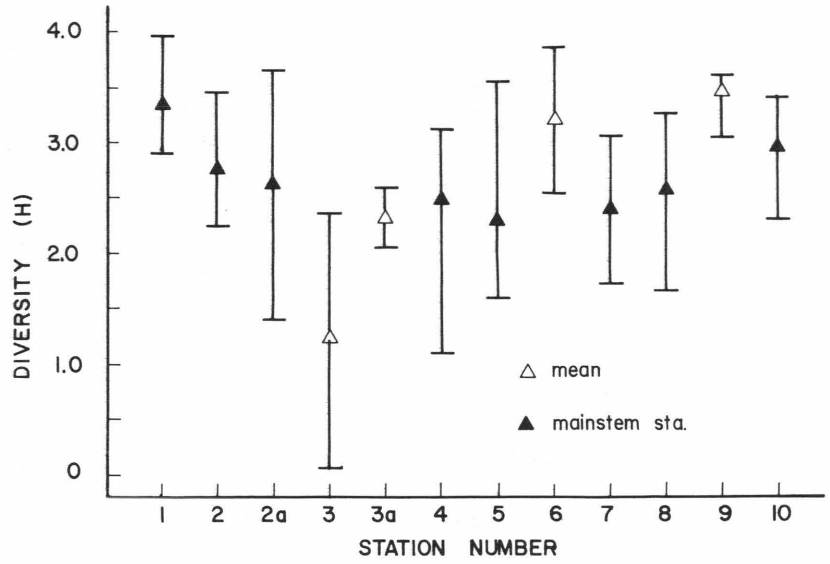
| | | Station Number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Rank | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| March 1972 | 1 | 79* | – | – | – | 79* | 79* | 54** | 54** | – | 54** | 79* |
| | 2 | 22 | – | – | – | 56** | 20* | 56** | 79* | – | 56** | 20* |
| | 3 | 20* | – | – | – | 57** | 81* | 79* | 20* | – | 79* | 54** |
| | 4 | 56** | – | – | – | 115 | 98 | 20* | – | – | 44** | 56** |
| | 5 | 115 | – | – | – | 54** | – | 48** | – | – | 20* | 22 |
| May 1972 | 1 | 54** | 54** | 54** | – | – | 54** | 54** | 79* | – | – | 54** |
| | 2 | 20* | 41** | 20* | – | – | 79* | 57** | 54** | – | – | 56** |
| | 3 | 22 | 20* | 43** | – | – | 85* | 79* | 52** | – | – | 44** |
| | 4 | 79* | 22 | 111 | – | – | 88 | 52** | 113 | – | – | 20* |
| | 5 | 41** | 26 | 106 | – | – | – | 42** | 20* | – | – | 79* |
| June 1972 | 1 | 79* | 53** | 54** | 79* | 54** | 20* | 79* | 79* | 79* | 56** | 56** |
| | 2 | 54** | 20* | 79* | 56** | 79* | 22 | 55** | 54** | 56** | 14 | 79* |
| | 3 | 22 | 79* | 56** | – | 56** | 23 | 14 | 56** | 57** | 79* | 20* |
| | 4 | 14 | 56** | 81* | – | 20* | 79* | 56** | 20* | – | 52** | 70 |
| | 5 | 20* | 41** | 15 | – | 22 | 54** | 52** | 22 | – | 54** | 115 |

## Table 10
(Continued)

| Date | Rank | Station Number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| July 1972 | 1 | 20* | — | 20* | No Dominant | 56** | 79* | 56** | 113 | — | 52** | 51** |
| | 2 | 25 | — | 79* | | 79* | 20* | 15 | 56** | — | 56** | 20* |
| | 3 | 79* | — | 56** | — | 20* | — | 52** | 52** | — | 73 | 76 |
| | 4 | 56** | — | — | — | 46** | — | 79* | 18 | — | 42** | — |
| | 5 | 84 | — | — | — | 113 | — | 72 | — | — | 69 | — |
| October 1972 | 1 | 40** | 41** | 41** | 79* | 20* | 20* | 20* | 20* | — | 20* | 79* |
| | 2 | 22 | 20* | 20* | 81* | 79* | 79* | 13 | 22 | — | 13 | 20* |
| | 3 | 20* | 22 | 22 | 20* | 41** | 13 | 22 | 79* | — | 25 | 14 |
| | 4 | 61 | 47** | 47** | — | 22 | 22 | 41** | 13 | — | 47** | 16 |
| | 5 | 6 | 13 | 79* | — | 43** | 14 | 79* | 7 | — | 79* | 56** |

Figure 12

Mean and Range of Diversity Values Recorded During the Indian Creek Study



Melcroft station, probably contributed to the occurrence of large numbers of caddis larvae (*Hydropsyche sp.*) which reduced diversity.

Results obtained for the mouth of Champion Run were inconclusive due to variable sample size. The mean diversity was low (1.25) and the range of values varied considerably (Figure 12). There was little reproducibility in sampling due to frequent changes in acid drainage volume and stream discharge relations. The similarity between collections from October 1970 and October 1972 (Appendix II-A, Tables 26 and 37) suggests that a pattern exists in the use of Champion Run by Chironomidae adults depositing eggs in this high stress environment, and larva surviving for some time when stress conditions are reduced by increased dilution. In general, both the total number of organisms collected at this station and diversity varied considerably. Non-tolerant organisms occurred in several collections, but these are considered accidental occurrences due mainly to downstream drift from upstream portions of the stream. Station 4 (unmixed station) also showed variable results due in part to the incomplete mixing of the AMD from Champion Run in the mainstem of Indian Creek. The mean diversity value was slightly lower than Melcroft or Riffle's place, but considerably lower than the upstream reference station. In addition, the range was large (between 1.1 and 3.2). The station was severely disturbed by channelization after the first major flood in September 1971. The channel was widened and streamflow was changed; the majority of the flow was contained along the right bank while the left bank was slightly elevated and was covered with water only during high streamflow periods. The left bank of this station, before channelization, was relatively unaffected by acid drainage during high flow conditions due to incomplete mixing. Transect sampling across the stream revealed severe reduction in numbers from the left bank to the right, with many non-tolerant organisms found in samples from the left bank. After channelization, the left bank was isolated from normal low streamflow, and collections in this region produced few organisms.

Results from analysis of samples from Indian Head No. 1 indicated the most severe stress conditions existed in the stream reach between the unmixed station and Back Creek. The mean diversity value for Indian Head No. 1 was the lowest of any mainstem station. By the time water reached Indian Head No. 1, the AMD was well mixed. The combined effect of no major tributaries to dilute the AMD from Champion Run and generally poor water quality made this reach unsuitable for the development of stable macrobenthic communities. Faunal instability was probably due to three factors: (1) periodic changes in the relationship between AMD volume and the discharge volume of Indian Creek which caused overall environmental conditions to vary widely, (2) residual materials resulting from "plating" or deposition (i.e., FeOH floc, or heavy metals which made the reach unsuitable for recolonization), and (3) severe stress conditions upstream from this station due to AMD from Champion Run which may effectively reduce the survival of drifting organisms which might otherwise recolonize this reach.

Below the confluence of Back Creek and Indian Creek recovery of the macrobenthic communities began. The tributary Back Creek had a high mean diversity, near that of the upstream reference station. The density was also similar to the upstream reference station, and the community was regularly dominated by non-tolerant organisms. Indian Head No. 2 showed improved conditions in the mainstem of Indian Creek. Improvement was probably due to the restoration of suitable habitat in the mainstem by unpolluted tributary water, and the drift of organisms from Back Creek which recolonized these habitats. The community at Indian Head No. 2 was generally dominated by tolerant organisms, but non-tolerant organisms occurred in collections consistently (Table 10). Taxa which dominated the collection from Back Creek often dominated the collection from Indian Head No. 2 (Table 13, May 1971, June 1971, August 1971, October 1971, March 1972, May 1972, June 1972, July 1972, and October 1972). This indicates the influence of a healthy tributary on the community downstream. Often the similar taxa were organisms which are common to drift fauna, thus establishing a relationship between organism supply, drift, and restoration. Density and total number of organisms collected varied widely at Indian Head No. 2, due in part to variable water quality depending on AMD volume from Champion Run, and the dilution and neutralization capacity of upstream Indian Creek and Back Creek.

Conditions at Saltlick were more variable. Although the mean diversity value was higher than Indian Head No. 2, the range of values was greater. AMD from Poplar Run periodically reduced the water quality at Saltlick. The station was normally dominated by tolerant organisms, but non-tolerant organisms occurred with some regularity due mainly to high streamflow which contributed to extensive drift distances and moderately good water quality which provided suitable habitats for recolonization. The fauna at Saltlick were often similar to Indian Head No. 2.

Laurel Run was another healthy tributary. The mean diversity value was the highest of any station sampled, and the range of values was narrow. Density values were also high, and non-tolerant organisms dominated the macrobenthic community at this station. The recovery station was located approximately 0.75 miles (1.2 km) below the confluence of Laurel Run with Indian Creek. The mean diversity values were the highest of any mainstem station with the exception of the upstream reference station. The range was also less than any mainstem station below Champion Run. The macrobenthic community was regularly dominated by tolerant organisms, but the total of non-tolerant and moderately tolerant organisms exceeded the total number of tolerant organisms during May, June, and July 1972 and non-tolerant organisms dominated the community. The number of organisms was high during all sampling periods, and moderate to high densities indicated a large established macrobenthic community at this station. Although the possibility of AMD from Poplar Run affecting this station existed, stream volume and the capacity of Laurel Run to buffer any additional acid loading provided stable environmental conditions at the recovery station. Stable conditions contributed to a bottom fauna community well balanced with tolerant and non-tolerant organisms (present in approximately equal numbers) while moderately tolerant organisms dominated the community.

In addition to changes in the biological community downstream from AMD discharges, changes occurred at each station related to other factors. Possibly the most profound changes occurred seasonally due both to (1) changes in the biological system (i.e., maturation and emergence of aquatic insects), and (2) variation in the physical system (i.e., streamflow temperature, etc.) During the spring months of March through June the stream exhibited overall good health. Diversity generally was high. At the upstream reference station and the unpolluted tributaries, Back Creek and Laurel Run, the diversity varied between 2.9 and 3.5, and between 28 and 46 taxa were collected. The dominant taxa during these periods were non-tolerant Ephemeroptera, *Ephemerella sp.* and *Baetis sp.*. A review of hydrologic simulation data for these spring months indicates that the EADD was generally high (100 to 300 cfs). The net effects of dominance of Ephemeroptera (one of the most common drifting groups) (Waters, 1962) and high stream discharge was distribution of these non-tolerant taxa throughout the mainstem of Indian Creek. Evidence of drift was even shown in Champion Run, the tributary most severely affected by AMD. Although the number of organisms collected at Champion Run was small, taxa common in drift were collected, probably due to the influence of upstream unpolluted sections acting as a source of drifting organisms. In the mainstem of Indian Creek, increases in density and diversity were recorded after confluence with unpolluted tributaries [density increased from 11 organisms/ft$^2$ at Indian Head No. 1 to 60 organisms/ft$^2$ at Indian Head No. 2 in May 1971 (Appendix II-A, Table 27)]. The recovery station during these spring months was dominated by a variety of taxa, *Hydropsyche sp., Ephemerella sp., Cloeon sp., Baetis sp.,* and *Iron sp.*; all except *Hydropsyche sp.* are non-tolerant taxa. Although density was sometimes low, probably related to spring emergence, the number of taxa collected remained high as did the total number of organisms collected.

The months of July and August were generally periods of decreased diversity indicating a deterioration in stream conditions. Although the upstream reference station maintained a high diversity (3.16 to 3.59), downstream mainstem stations generally showed lower diversity (1.80 to 3.23). The lower diversity was due in part to two factors. The first was streamflow AMD volume relationships, relating to concentration differences and dilution. A review of EADD values for the period of summer sampling indicated generally low stream discharge values (20 to 130 cfs). The decreased stream discharge during this period reduced the assimilative capacity of Indian Creek and decreased water quality due to higher AMD concentration in the mainstem. The net effect was increased stress on the macrobenthic community in the stream reach below Champion Run. The second factor was that physical and biological factors may have been combined to give an indication of increased stress. Because AMD from underground sources is poorly oxidized during the summer low flow, low infiltration months (Appalachian Reg. Comm., 1969), the discharge of this waste in the stream can create oxygen stress conditions due to its high oxygen demand. In the stream reach immediately below Champion Run, including Indian Head No. 1, this effect would be most severe. A reduction in the diversity value may also be caused by the dominance of the bottom fauna community by one or two taxa. The collections from the summer months were dominated by Chironomidae, and *Hydropsyche sp.* Their dominance may be related in part to food resources. Higher water temperatures may cause a shift from diatom-dominated producer community to an algae- and vascular plant-dominated community. These food resources were noted in great abundance in Indian Creek during the summer months. Mecon (1972) reported that for the trichopteran *Hydropsyche sp.* ingestion of detritus, vascular plants, and other algae occurred at the greatest level in the late spring and summer months. Johansen (1934) reported similar food sources for Chironomidae. The dominance of *Hydropsyche sp.* and Chironomidae may in part be related to tolerance and availability of food resources which encourage development of high numbers of organisms. The end result was a decrease in diversity for these months.

During the late summer and fall months, the stream showed improvement in diversity (mainstem values 2.17 to 3.40). The bottom fauna community throughout the mainstem was still dominated by *Hydropsyche sp.*, but several non-tolerant taxa occurred with regularity, particularly at the recovery station. The hydrologic simulation for this period indicated an increase in the EADD when compared with the summer months (15 to 300 cfs). The combined effect of increasing stream discharge, decreased AMD concentration, and dominance of non-tolerant or moderately tolerant organisms indicated a recovery from the high stress conditions of the summer months.

The pattern of recovery, including seasonal variations, through the reach of the stream below the AMD source was interrupted by two floods which occurred on September 14, 1971, and on June 23, 1972. The EADD for those dates exceeded 4500 cfs at the recovery station. The total effect of the September 14 flood was most severe, although major physical and biological alterations were limited to the stream reach below Champion Run. The hydrograph was relatively short with one peak. Severe scouring occurred moving large substrate materials, food resources, and bottom fauna. Calculations based on estimated peak flow indicated particle sizes as large as 0.5 in. (15.2 cm) were moved (Table 8). Although diversity remained relatively high in samples collected three weeks after the flood, density in the mainstem values were very low, 2 to 9 organisms/ft$^2$. The secondary effects of channelization of the stream near the unmixed station have been discussed. The second flood, which occurred on June 23, 1972, had a more extended hydrograph with two peaks, and effects were noted at the upstream reference station. Bottom fauna samples collected two weeks after the flood indicated trends similar to the September 1971 flood, but diversity values were low, and the total number of organisms collected at the mainstem stations was less than 100 with the exception of the upstream reference station.

These short term physical phenomena may be examined in relation to the recovery time necessary after stress. After the September 1971 flood, recovery was slow. Bottom fauna collections from December 1971 (3 months), and March 1972 (6 months) indicated poor bottom fauna development which was due to several factors. The most important was the removal of food resources by the flooding. Low water temperatures due to seasonal influence reduced biological activity, and even though high stream discharge and suitable habitats were available, the development of producer communities was restricted, limiting the bottom fauna community until food resources became available (i.e., in May and June 1972). Another factor which must be considered is the increased stress from AMD caused by flooding. Field observations after the September 1971 flood revealed several small AMD sources which were not noted before. These discharge sources were short lived, probably dependent on the higher water table caused by the flood. The overall effect of these discharge sources was limitation of recolonization in the mainstem of Indian Creek. While mainstem density values were below 10 organisms/ft$^2$, unpolluted tributaries showed relatively high density, 34 to 53 organisms/ft$^2$. The higher tributary density was due to good water quality with no secondary stress from AMD, and a reduced flood impact because heavily forested watersheds retained some rainfall, reducing flood peaks and the associated scouring and removal of energy sources.

Recovery from the June 1972 flood was relatively rapid. Sampling in October 1972 indicated bottom fauna communities similar to collections in October 1970. Density was high; 100 to 1000 organisms were collected from mainstem stations. This improved recovery rate (3 months versus 6 to 9 months) may also be related in part to food resources. The high water temperatures of the late summer months promote increased biological activity. Diatom (and in particular algal) growth was noted in the July sample. The end result was a more rapid recovery of the bottom fauna community due to a rapid restoration of food resources.

A secondary cause may be related to stream physical conditions—even though peak discharges were similar for the two floods, the scouring noted after the June 1972 flood was less, since the stream channel had been modified by the September 1971 flood, in effect, to carry the high discharge.

Additional community analyses were made using both correlation matrices and cluster analysis. These analytical techniques are useful tools for community analysis because individual taxa maintain identity in the analytical procedure (i.e., providing information at a specific taxonomic level) unlike a community diversity index where all taxa are grouped together losing taxa identity. The correlation matrices (Appendix II-A, Tables 39 through 51) and cluster analysis based on presence/abundance matrices (i.e., distance clusters, Appendix II-A, Figures 1 through 10) have error introduced by negative match correlation. This difficulty is overcome by use of the Jaccard coefficient and presence/absence data matrices.

Correlation matrices revealed relationships between stations through the reach of the stream studied and identified the relationships between the stations sampled during different sampling periods. In general, the upstream reference stations and the unpolluted tributaries were highly correlated indicating a similar fauna in the healthy sections of the stream. The unpolluted tributaries were often correlated with the downstream confluence indicating a similarity of fauna which may be attributed to the effect of the fauna from the unpolluted tributary on the mainstem station. In a similar way, upstream mainstem stations were often highly correlated with mainstem stations immediately downstream, which is especially true of the Melcroft station, and the unmixed station where the influence of the relatively healthy upstream community could be noted during high discharge months (Appendix II-A, Tables 39, 40, and 49). Champion Run was poorly correlated with most stations, but during low discharge periods (Appendix II-A, Tables 42 and 43) higher correlation values with mainstem stations downstream resulted, probably due to elimination of non-tolerant taxa by higher AMD concentration and dominance of Chironomidae, and *Hydropsyche sp.* During October 1970 and October 1971 (Appendix II-A, Tables 39 and 45), the upstream reference station and the recovery station were highly correlated. Although the flood of September 1971 undoubtedly affected the October sample, the continued dominance of *Hydropsyche sp.* may have produced these similarities.

The result of cluster analysis of all stations collected during one sampling period are summarized in Table 11. Ten of the twelve sampling periods were analyzed in this manner, dendrograms for October 1971 and October 1972 were not available because of programming difficulty. As an indication of closeness of fit between the two-dimensional dendrogram and the n-dimensional mathematical placement of clusters, the cophenetic correlation coefficients for the dendrograms were 0.87 to 0.99. All clusters with the exception of August 1971 correlated at the level of 0.94 or higher.

In general, the results of cluster analysis point out the changes in the fauna of Indian Creek produced by AMD. On seven occasions, Station 1 was clustered alone with the upstream reference stations. The bottom fauna at these stations were similar throughout the study. In a similar manner, the mainstem stations exclusive of the reference stations were contained in the same large cluster on seven occasions. For the most part this grouping occurred during high discharge periods, or during seasons when similar taxa dominated the bottom fauna community throughout the stream (i.e., Ephemeroptera drift in the spring, and *Hydropsyche sp.* dominance in the late summer). The healthy tributaries were often clustered together, and on seven occasions were either clustered alone, or with the upstream reference stations, indicating a similarity of fauna in healthy areas of the watershed. Similarly, the tributaries and mainstem stations most severely affected by AMD were clustered together on six occasions revealing the similarity of fauna in these high stress regions of the stream. Two other important relationships were revealed by cluster analysis. The healthy tributaries and the mainstem station immediately downstream were clustered together in several dendrograms. The periods of greatest similarity were during high discharge periods when drift was increased, (i.e., March and May) or early in the summer (i.e., June and July) when water quality was maintained in the mainstem of Indian Creek by the tributary waters providing suitable habitat for organisms drifting from the tributaries.

## Table 11

### Occurrence of Cluster Groupings from Cluster Analysis of Distance Matrices, Each Sampling Period Clustered Alone

I. Mainstem stations with the exception of upstream reference stations

1971 May, June, July, December
1972 March, May, June, July

II. Upstream reference stations occurring alone or cluster together

1971 May, July, December
1972 March, May, June, July

III. Healthy tributaries occurring alone, healthy tributaries occurring with reference stations, or healthy tributaries and reference stations occurring with recovery stations

1970 October
1971 June, July, August
1972 March, May, June

IV. AMD affected areas, Champion Run, Indian Head No. 1, and Saltlick occurring together

1971 May, June, July, December
1972 June, July

V. Back Creek and Indian Head No. 2 together

1971 May, July
1972 March

VI. Laurel Run and recovery station occurring together

1971 June, July

In addition to cluster analysis of all stations sampled during one sampling period, cluster analysis was performed on all stations sampled during one season utilizing the Jaccard coefficient to eliminate the difficulties produced by negative matches. The dendrogram (Figure 13) contains the cluster of 57 stations collected during May through October 1971, and Figure 14 contains the cluster of 53 stations collected during March through October 1972. Analysis of the dendrograms is dependent on selection of a level of similarity which defines the extent of cluster formation. At a limit of similarity of 0.0, one large cluster of all stations is formed, at a level of similarity of 1.0, all stations are clustered apart from each other. Because the statistical reliability of cluster analysis cannot be rigorously proved, the information the dendrogram supplies is a qualitative description of sample groupings. The level of similarity can be arbitrarily selected which allows ease of description of the clusters formed in ecological terms. A level of similarity of 0.4 was selected. This divided the 1971 dendrogram into 5 cluster groups of 8, 9, 14, 7, and 19 stations and the 1972 dendrogram into 5 cluster groups of 13, 3, 5, 10, and 22 stations.

The dendrogram for 1971 collections may best be interpreted in light of seasonal differences. The first cluster included only stations sampled in May 1971, a high discharge period. Although stations 3 and 8 (Champion Run and Saltlick) were not included in the cluster, all remaining stations were clustered together. The second cluster contained either upstream reference stations or tributary stations collected during July and October. During these months, *Hydropsyche sp.* and Chironomidae were present in large numbers throughout the watershed. The fact that non-tolerant organisms occurred with these more tolerant forms made healthy unstressed stations very similar. The third cluster contained stations sampled in June, July, and August where again seasonal differences were revealed. One grouping in this cluster contained upstream reference stations and healthy tributaries from June and August. A second grouping contained mainstem stations downstream from Melcroft (Station 2a), and a third grouping included the upstream reference stations from July and August. Stream discharge during this period was low. The emergence of Ephemeroptera in the early spring and dominance of *Hydropsyche sp.* and Chironomidae contributed to the similarity of collections. The grouping together of mainstem stations from August may be attributed in part to dominance of tolerant taxa, and additionally to increased effect of AMD from discharges near Riffle's place which stressed the fauna at Melcroft (Station 2a). Cluster four contained the Melcroft station, Saltlick (Station 8) and the recovery station from July and August. The final cluster was made up of 19 stations separated at a low limit of similarity. Samples from all months were represented in this cluster, the basis

Figure 13

Dendrogram of Stations Collected 1971

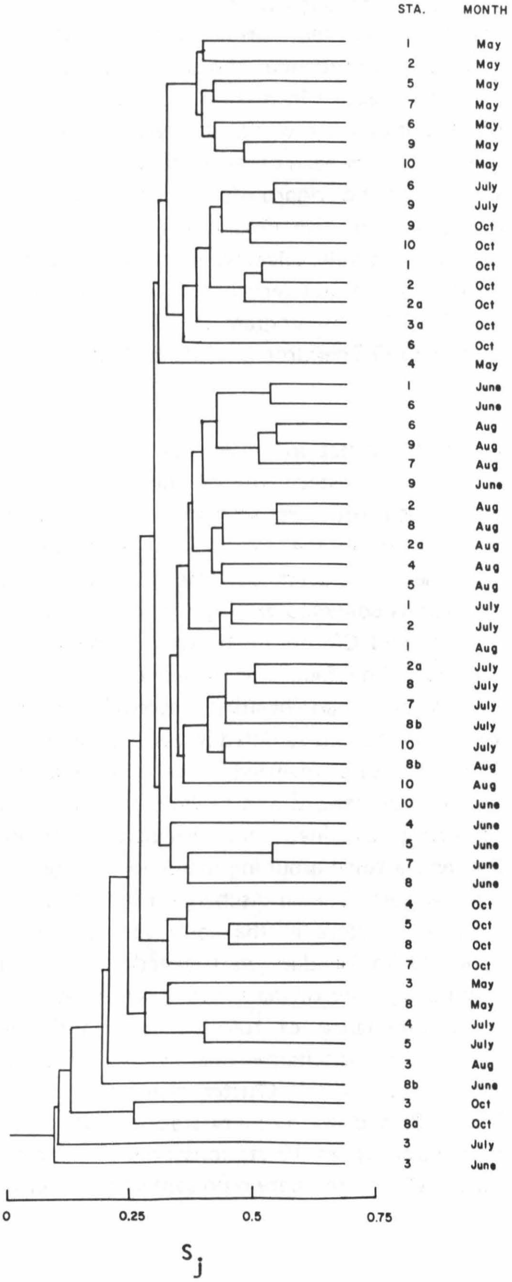
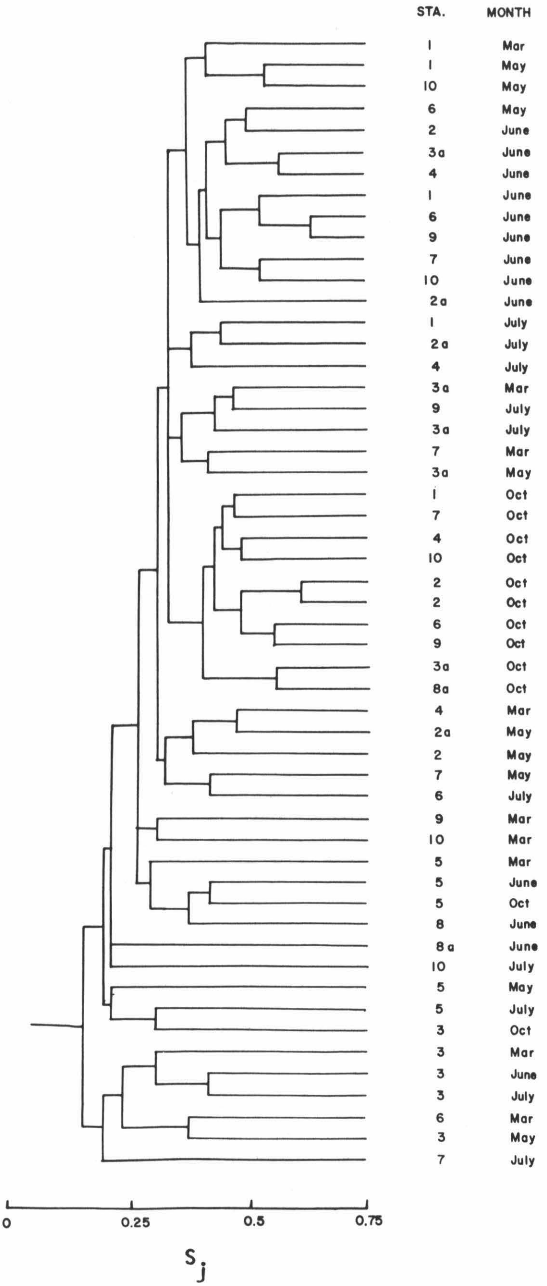


Figure 14

Dendrogram of Stations Collected 1972



of similarity was AMD influence. Neither reference, tributary nor recovery stations were contained in this cluster. The effect of low discharge grouped together the unmixed station (Station 4) and Indian Head No. 1 (Station 5) during July. The stations most severely damaged by the September 14 flood were all clustered together.

The dendrogram produced for 1972 sampling showed similar results. Upstream reference stations and healthy tributaries were grouped together in the first cluster. In addition, the upstream reference station and the recovery station from samples collected in May (a high discharge period) were clustered together. Tributary and mainstem stations from June were grouped together in this same cluster further revealing the separation of high discharge periods from other samples.

The second cluster showed some effects of flooding in late June. The upstream reference station, Melcroft, and the unmixed station were clustered together. The third cluster contained healthy tributary stations from March, July, and May. The fourth cluster was made up of 10 samples from October, but samples from Champion Run and Indian Head No. 1 were missing from the cluster. The interpretation of this grouping includes recovery from the flood effects of late June, and the normalization of conditions in the stream after the flood of June 26. The upstream reference station was grouped with the unmixed station, Indian Head No. 2, and the recovery station; evidence of similar conditions throughout the mainstem with the exception of Champion Run and Indian Head No. 1 where the AMD had not been sufficiently assimilated and stress effects were still pronounced. The fifth cluster was again made up of samples from all months. Important differentiations between stations with AMD effect can be noted with Champion Run and Indian Head No. 1 from several dates clustered together. Similarly, mainstem stations from high discharge periods were grouped together. Tributary stations from March and July occurred in this grouping. Both of these periods were preceded by high discharge periods, the March fauna still being affected by the September 1971 flood.

## II. Little Scrubgrass Creek

The recovery processes occurring through distance may be improved if poor water quality is restored by artificial means. Improved water quality enhances conditions for recolonization; recovery may then occur rapidly if sources of recolonizing organisms are available. Acid mine drainage in the headwaters of

Little Scrubgrass Creek, Venango County, Pennsylvania, was treated by lime neutralization, artificially restoring water quality in the stream. The recovery processes in this stream were studied both as related to distance from the point of restoration and as a function of time from the onset of neutralization plant operation.

## A. History

Mining operations began in the Little Scrubgrass basin in the early 1900's. A total of 11 deep mines were operated in the area, all had been abandoned by 1950. Surface mining operations began in the late 1940's and continued sporadically until 1960. Six surface mines in the headwaters area were sealed, and the six surface mines were backfilled to original contour between 1965 and 1972. Although water quality improved somewhat, acid conditions remained (Pennsylvania Fish Commission, 1949 and 1968). In an effort to further improve water quality, an automatic lime neutralization plant was installed on the stream in 1965 (Maneval, 1968). Pre-operational biological surveys of Little Scrubgrass Creek indicated poor faunal development and white precipitates in the stream below unpolluted tributaries (Pennsylvania Fish Commission, 1949). Biological surveys conducted after neutralization plant installation and operation (Pennsylvania Fish Commission, 1968) listed poor faunal development throughout the stream. Reports of samples of bottom fauna collected in January and September 1968 identified the cause of the poor faunal development as a white precipitate, $Al(OH)_3$ floc. In late 1969, a settling pond was constructed below the treatment plant and normal streamflow was diverted through this pond. The pond provided a reaction and settling basin to reduce the $Al(OH)_3$ floc in the stream. An overflow canal to accommodate high flows paralleled the original streambed. All sampling for this study occurred after settling pond construction.

## B. Environmental Conditions

1. Physiography. Little Scrubgrass Creek is a tributary of the Allegheny River in northwestern Pennsylvania (Figure 15). Mainstem reach length is 7.5 miles (12 km) with a drainage area of approximately 15 $mi^2$ (24 $km^2$). Physiographically, the Little Scrubgrass basin lies in the Appalachian Plateau Province, Allegheny High Plateau Section. The topography of the basin is divided into two regions. The upstream portion of the stream, above the confluence with the South Fork, is typified by low hills and wide meandering stream valleys with average local relief of 200 ft (61 m). Average gradient for this section of the stream is 52 ft/mi (9.8 m/km). The lower portion of the basin from the confluence with the South Fork to the Allegheny River,

consists of a deeply incised valley with a total relief of 660 ft (201 m). Stream gradient in this reach is 120 ft/mi (22 m/km). Land use patterns follow the same divisions. The upper valley is predominately cleared farm land with scrub or light forest cover in the stream valley. This area was extensively disturbed by surface mining; operating permits were granted in 1950, 1952, and 1960. The lower stream valley was heavily forested while surrounding high ground had been cleared and contained open grassland or light forest. Surface mining operations were active in this region during the study.

The Little Scrubgrass watershed lies on sedimentary formations of Pennsylvanian age that are part of the Allegheny formation. In general, the Allegheny formation consists of sandstones, thin-bedded shales, siltstones, limestone, and several coal seams. The strata are nearly horizontal, dipping slightly to the southeast. The stream valley is also divided into two regions based on rock type. The upstream portion of the basin lies in the Pottsville formation, dominated by sandstone with large shale lenses and thin coal seams (Shaw and Munn, 1971). The coal mined in the area is the Middle Kittanning.

2. Location and Description of Sampling Areas. Eight sampling stations were initially located on Little Scrubgrass Creek, seven above the confluence with the South Fork, and one below in the high gradient section of the stream. Stream physical characteristics, by station, are listed in Table 12.

Station 1 was located 100 yd (92 m) above the neutralization plant. The upstream (headwaters) region was severely disturbed by surface mining.

Station 5 was located on an unnamed tributary which entered Little Scrubgrass 100 yd (92 m) below Station 4. Upstream from the riffle collected was a 3-ft dam with a pool behind. Along the left bank was a marshy area which was poorly drained because of the pool level.

Three stations were collected on only one occasion. Station 9 was located on the North Fork and Station 10 was located on the South Fork, both station descriptions would follow Station 7. Station 8a was located on an unnamed tributary to Little Scrubgrass near the intersection of State Route 208 and a country road near the Westminister Highlands Camp. Average width for this station was 10 ft (3 m) with shallow riffles and pools.

Because no gaging stations were located on the watershed, flow conditions were not available for periods prior to sampling, but conversations with residents indicated moderate flows before sampling in October 1970 and May

## Table 12

### Station Physical Characteristics

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Location (Stream miles, km) | .75 | .85 | 1.6 | 2 | – | 2.5 | 4.1 | 5.6 |
| (km) | 1.2 | 1.3 | 2.5 | 3.2 | – | 4 | 6.6 | 9.0 |
| Banks (max. height ft/m) | – | 3/.9 | 3/.9 | 3/.9 | 10/3 | 2/.9 | 20/6.1 | Steep Valley |
| Surroundings* | 2 + 3 | 3 | 2 + 4 | 2 + 4 | 1 + 4 | 1 + 4 | 2 + 5 | 1 + 4 |
| Substrate** | A | B | B + C | B + C | B + C | C + D | C + D | D + C |
| Average Width (ft) | 4–7 | 4–7 | 6–10 | 15–20 | 5–15 | 15–25 | 20–25 | 25–30 |
| Average Depth (ft) | .25–1 | .25–2 | .5–2 | .5–3 | .5–2 | .75–2 | .5–3 | .5–2 |

Table 12
(Continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Average Gradient (ft/100 ft) | .01–.05 | .05–.25 | .05–.25 | .1–1 | .1–1 | .1–1 | 1–3 | 1–3 |
| Estimated Average Velocity (ft/sec) | 0.5–1.0 | 1–2 | 1–2 | 1–3 | 1–3 | 1–3 | 1–3 | 2–5 |

*(I) forest, (2) light forest, (3) cleared land, (4) undeveloped area, (5) developed area

**(A) silt-sand, (B) gravel .5–3 in., (C) cobbles 3 in. – 12 in., (D) small boulders > 12 in.

1971. Low flows were reported before July 1971 sampling, and two periods of extremely high flow occurred in June and September 1972, preceding November sampling.

3. Water Chemistry—Previous Work. Water analyses in the Little Scrubgrass watershed were available from the Pennsylvania Fish Commission and the Pennsylvania Department of Mines and Mineral Industries. Analyses carried out in March of 1949 (Appendix II-C, Table 1) indicated acid conditions (pH 3.2 to 5.4)in the upper portion of the stream with moderation to pH values near 7.0 in the downstream sections. Both downstream tributaries maintained a neutral pH (7.0 and 6.9) and showed little acidity.

Several water analyses were made in 1967 to determine the effect of the lime neutralization plant on water quality (Appendix II-C, Table 2). Samples were collected above the limer, Station 1, and at several stations below the plant; the final sampling point was near Station 6 of this study. Water quality above the plant was consistently poor, low pH (4.5 or less), no alkalinity, and high concentrations of aluminum (1.8 to 14.6 ppm) and sulfates (245 to 430 ppm). Liming immediately raised the pH (7.9 to 11.7), but maintained high concentrations of aluminum (1.5 to 11.4) and sulfate (279 to 475 ppm). The pH values as well as aluminum and sulfate concentrations showed significant reductions by Station 6 (pH 6.8 to 8.2), aluminum (0 to 1.04 ppm), and sulfate (127 to 225 ppm). Aluminum concentrations at Station 6 were the highest of any sample in November 1967 even though sulfate concentrations were low.

Water analyses performed by the Pennsylvania Fish Commission (Appendix II-C, Table 3) are in general agreement with the results reported by Maneval (1969) and were useful in determining trends in water quality. Analysis of samples collected in January 1968 showed increased sulfate concentration throughout the watershed, greater than 400 ppm for upstream stations, and near 200 ppm for downstream stations. Iron concentrations increased downstream. The pH value was 7.2 or greater throughout the stream. Note should be made of water quality in tributary Station 9. Water quality declined from the 1949 analysis; the pH value was lower (6.5 vs. 7.0), and with the acidity/alkalinity ratio between 0.5 and 1. The final analyses provided by the Pennsylvania Fish Commission in September 1968 showed a similar trend to that found in earlier sampling. Downstream from the plant, the pH values were 7.5 or above; sulfate values were high in the upstream portion of the watershed decreasing in downstream areas, while iron concentrations increased after the treatment plant and remained greater than 0.5 ppm throughout the stream.

4. Biological Results–Previous Work. The first biological survey on Little Scrubgrass Creek occurred in March 1949 (Pennsylvania Fish Commission, unpublished report). No fish food organisms were found above Station 7, and only a few caddis larvae were found in the downstream tributaries, the North Fork and the South Fork at stream mile 2.5 (4 m). Sampling of the unidentified tributary, Station 5, revealed acid conditions and no biological organisms were found.

Additional biological sampling began with the installation of the lime neutralization plant in late 1966. Biological sampling in July 1967 involved Stations 3, 5, 6, 7, and 8 (Pennsylvania Fish Commission, unpublished report). No collections were obtained from Station 3 because of thick floc. A few bottom organisms were collected at Stations 6, 7, and 8, mainly tolerant or resistent species. The tributary Station 5 was classified as ". . . good, but small stream based on the occurrence of non-tolerant organisms."

A report of sampling in January 1968 (Pennsylvania Fish Comm., unpublished report, January 1968) provided a list of bottom fauna present. Collections from Stations 6 and 7 contained representatives of Ephemeroptera and Diptera. The mayfly *Heptagenia sp.* was found in abundance at Station 8 while one representative was found at Stations 6 and 7. The midge *Chironomus sp.* was the most abundant organism at Stations 6 and 7, and another Diptera, *Simulium sp.* was found at Station 8. In addition, the Megaloptera, *Sialis sp.* and the Plecoptera, *Isoperla sp.* were found at Station 7. The Trichopteran *Hydropsyche sp.* was found in relatively high numbers at Stations 7 and 8.

Additional sampling in May 1968 (Pennsylvania Fish Comm., unpublished report, May 1968) revealed no benthic organisms at Station 3. The tributary Station 5 had abundant benthic fauna including Diptera, Trichoptera, Plecoptera, Ephemeroptera, and Decapoda. Station 6 had a similar fauna; in addition Odonata were present. The benthic fauna were reduced at Station 7, the only reported occurrence was for Trichoptera.

An additional biological survey was made by the Pennsylvania Fish Commission in September 1968. At this time, Station 4 produced one Trichoptera, *Hydropsyche sp.* and one Diptera, *Tipula sp.* Station 6 produced three taxa, all present in low numbers, *Hydropsyche sp., Simulium sp.,* and *Palpomyia sp.* Three taxa were also present in relatively high numbers at Station 7; these include: *Hydropsyche sp., Ameletus sp.,* and Tenedepedidae. Four taxa were reported at Station 8, *Hydropsyche sp., Ameletus sp., Simulium sp.*, and Ténedepedidae. Density ranged from 2 organisms/ft$^2$

(0.1 $m^2$) at Station 4, to 40 organisms/$ft^2$ or greater for Stations 6, 7, and 8 (Pennsylvania Fish Comm., unpublished report, September 1968).

### C. Results and Discussion

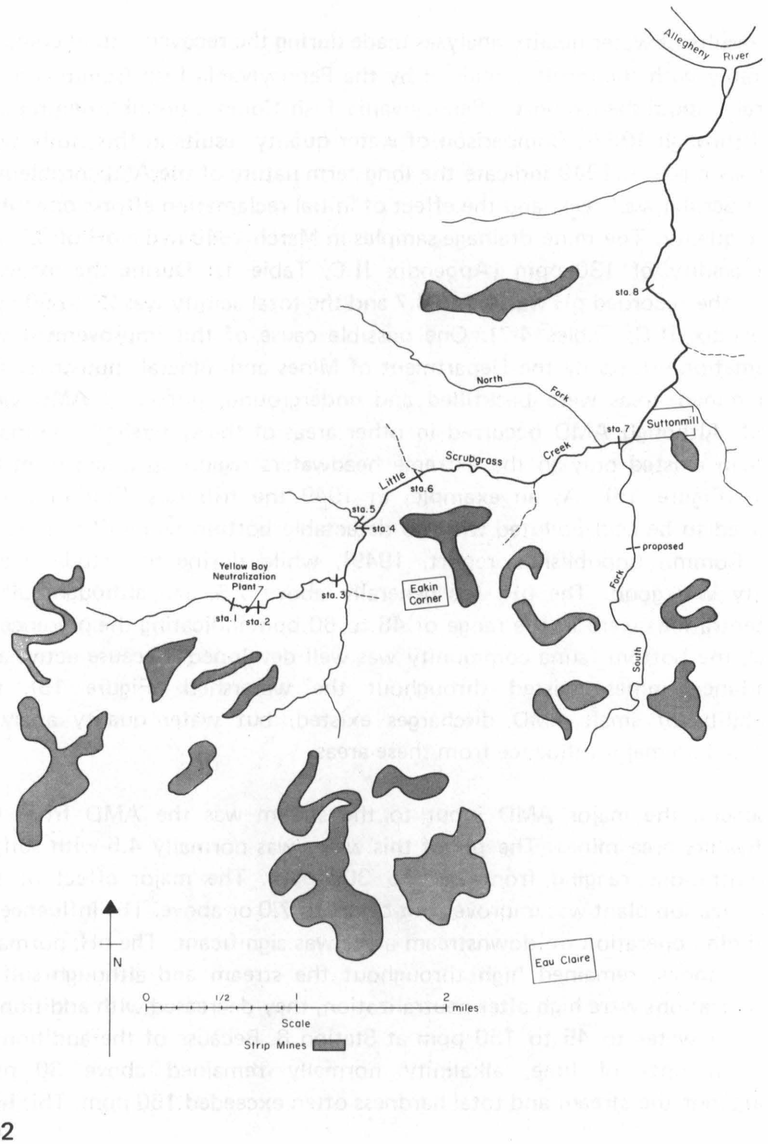
1. Water Quality. The results of water quality analyses are contained in Appendix II-C, Tables 1 through 7.

The results of water quality analyses made during the recovery study compare favorably with the results obtained by the Pennsylvania Fish Commission in several unpublished reports (Pennsylvania Fish Comm., unpublished reports 1949 through 1969). Comparison of water quality results in this study with analyses made in 1949 indicate the long term nature of the AMD problem in Little Scrubgrass Creek, and the effect of initial reclamation efforts on stream water quality. The mine drainage samples in March 1949 had a pH of 3.2 and total acidity of 130 ppm (Appendix II-C, Table 1). During the recovery study, the recorded pH was 4.5 to 4.7 and the total acidity was 24 to 60 ppm (Appendix II-C, Tables 4-7). One possible cause of this improvement was reclamation efforts by the Department of Mines and Mineral Industries. The strip mined areas were backfilled and underground sources of AMD were sealed. Although AMD occurred in other areas of the watershed, the major problem existed only in the extreme headwaters region upstream from the limer (Figure 15). As an example, in 1949 the tributary Station 5 was reported to be acid polluted with no detectable bottom fauna (Pennsylvania Fish Comm., unpublished report, 1949), while during this study, water quality was good. The pH was generally above 7.5, and although sulfate concentrations were in the range of 48 to 60 ppm indicating the presence of AMD, the bottom fauna community was well developed. Because active and abandoned mines existed throughout the watershed (Figure 15), the possibility of small AMD discharges existed, but water quality analyses indicated no major influence from these areas.

In general the major AMD input to the stream was the AMD from the headwaters area mines. The pH of this water was normally 4.5 with sulfate concentrations ranging from 250 to 300 ppm. The major effect of the neutralization plant was improvement of pH to 7.0 or above. The influence of the liming operation on downstream areas was significant. The pH, normally 7.0 or above, remained high throughout the stream and although sulfate concentrations were high after neutralization, they decreased with addition of tributary water to 45 to 150 ppm at Station 8. Because of the addition of large amounts of lime, alkalinity normally remained above 30 ppm throughout the stream and total hardness often exceeded 150 ppm. This high

Figure 15

Stream Map with Station Locations
Little Scrubgrass Creek, Venango Co., Pa.



alkalinity may have assimilated any AMD from areas downstream from the limer.

Seasonal fluctuations in water quality did occur. In May 1971, high flow from the headwaters was diverted around the treatment plant. The pH of Station 2 was 5.0 and the sulfate concentration was 243 ppm (Appendix II-C, Table 5). This untreated AMD was quickly neutralized by substrate deposits (excess lime deposited between Stations 2 and 3) and diluted by increased streamflow from tributaries. The pH was 7.0 at Station 3 and 6.5 or above in the remainder of the stream. Sulfate concentrations in the downstream areas showed a decrease to 58 ppm at Station 8, the lowest value recorded during the study. Extreme low flow conditions were not observed during sampling.

The effect of the neutralization plant on stream physical conditions was a severe disruption of biological activity due to deposition of floc materials. Floc which occurred throughout the stream on several occasions destroyed the normal habitat of bottom fauna. Initial note of this problem was made in the reports of the Pennsylvania Fish Commission (Pennsylvania Fish Comm., unpublished reports, 1967 and 1968). The floc was due to a combination of factors. The first was high aluminum concentrations in the AMD entering Little Scrubgrass Creek; the second was the use of poor quality lime which had a high aluminum content. The hydroxide floc ($Al(OH)_3$) produced by the liming operation blanketed the bottom throughout the stream making it unsuitable for fish and bottom fauna.

This study was initiated after a settling pond was installed and floc deposits eliminated downstream from the limer. October 1970 and May 1971 collections found little floc in the stream. A short visit to the stream in July 1971 revealed heavy floc accumulations throughout the stream. The settling pond was full and unsettled floc materials overflowed the weir of the settling pond. Sampling in July 1972 occurred after hurricane Agnes and high streamflow caused by heavy rainfall. The settling pond was again functional, probably due to flushing by flood flows and little floc was noted in the stream. The sampling in November 1972 indicated conditions similar to July 1972, although there were small accumulations of floc along the banks in slow or standing water.

2. The Biological System. The results of biological sampling and analysis are contained in Appendix II-C, Tables 8 through 11. Rank-abundance tabulations (Table 13) were keyed to a list of all organisms collected during the study (Table 14).

## Table 13

Rank-Abundance Tabulation – Little Scrubgrass Creek

| | | Station Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Rank | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| October 1970 | 1 | 62* | 56 | 48 | 48* | 14 | 14 | 14 | 34** | – | – |
| | 2 | 48* | 53 | 62* | 14 | 29** | 13* | 13* | 13* | – | – |
| | 3 | 10 | 45 | 10 | 49* | 68** | 29** | – | 37** | – | – |
| May 1971 | 1 | 48* | 12 | 48* | 13* | 48* | 48* | 66** | 29** | 48* | 37** |
| | 2 | 62* | 56 | 45 | 48* | 54 | 13* | 13* | 13* | 32** | 66** |
| | 3 | 12 | – | 14 | 45 | 66** | 14 | 48* | 48* | 38** | 13* |

See footnotes on page 95.

## Table 13
(Continued)

| | | Station Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Rank | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| July 1972 | 1 | 56 | 56 | 62* | — | 14 | 13* | — | 13* | — | — |
| | 2 | 32** | 22 | 14 | — | 43 | 48* | — | 37** | — | — |
| | 3 | 48* | 62* | 48* | — | 67** | 14 | — | 28* | — | — |
| | 4 | — | — | — | — | — | — | — | — | — | — |
| | 5 | — | — | — | — | — | — | — | — | — | — |
| November 1972 | 1 | — | 13* | 14 | — | 14 | 13* | — | 13* | — | — |
| | 2 | — | 14 | 13* | — | 48* | 14 | — | 34** | — | — |
| | 3 | — | 56 | 45 | — | 29** | 62* | — | 14 | — | — |
| | 4 | — | — | — | — | — | — | — | — | — | — |
| | 5 | — | — | — | — | — | — | — | — | — | — |

*tolerant taxa
**non-tolerant taxa
underlined: number present = 2 x next rank's abundance

## Table 14

### Taxonomic List of Organisms Collected in Little Scrubgrass Creek

I. COLEOPTERA

Psephenidae

1. *Ectopria sp*

Dytiscidae

2. *Dytiscus sp*

Hydrophilidae

3. *Hydrophilus sp*
4. *Hydrobius sp*
5. *Tropisternus sp*

Elmidae

6. *Cleptelmis sp*
7. *Dubiraphia sp*
8. *Tropisternus sp*

II. TRICHOPTERA

Philopotamidae

9. *Chimarra sp*

Psychomyodae

10. *Polycentropus sp*
11. *Psychonyiid sp*
12. *Lype sp*

Hydropsychidae

13. *Hydropsyche sp*
14. *Cheumatopsyche sp*

Rhyacophilidae

15. *Rhyacophila sp* # 1
16. *Rhyacophila sp* # 2

Glossosomatidae

17. *Glossosoma sp*

Hydroptilidae

18. *Hydroptila sp*

Phryganeidae

19. *Banksiola sp*
20. *Eubasilissa sp*

Limnephilidae

21. *Radema sp*
22. *Drusinus sp*
23. *Limnephilus sp*

Lepidostomatidae

24. *Lepidostoma sp*

## Table 14
(Continued)

Odontoceridae

25. *Psilotreta sp*
26. Unidentified

III. EPHEMEROPTERA

Ephemeridae

27. *Ephemera sp*
28. *Pentagenia*

Hepiageniidae

29. *Stenonema sp* # 1
30. *Stenonema sp* # 2
31. *Stenonema sp* # 3

Baetidae

Siphlonurinae

32. *Isonychia sp*

Leptophlebiinae

33. *Paraleptophlebia sp*

Ephemerellinae

34. *Ephemerella sp* # 1
35. *Ephemerella sp* # 2

Caeninae

36. *Caenis sp*

Baetinae

37. *Baetis sp* # 1
38. *Baetis sp* # 2
39. *Pseudocloeon sp*
40. Unidentified

IV. DIPTERA

Tipulidae

41. *Pseudolimnophila sp* # 11
42. *Dicranota sp* # 10
43. *Hexatoma sp*# 9
44. *Antocha sp*
45. *Tipula sp* # 1
46. *Tipula sp* # 2
47. *Holorusia sp*

Chironomidae

48. Chironomidae # 1
49. Chironomidae # 2
50. Chironomidae # 3
51. Chironomidae # 4

Simuliidae

52. *Simulium sp*

Tabanidae

53. *Tabanus sp*

Anthomyiidae

54. *Limnophora sp*

## Table 14
(Continued)

Heleidae

55. *Palpomyia sp*
56. Unidentified
57. Unidentified

V. NEUROPTERA

58. *Chauliodes sp*
59. *Nigronia sp*

VI. ODONATA

Aeshnidae

60. *Aeshna sp*

Cordulegasteridae

61. *Cordulegaster sp*

VII. PLECOPTERA

Peltoperlidae
62. *Peltoperla sp*

Perlidae

63. *Acroneuria sp*

Nemouridae

64. *Nemoura sp*

Chloroperlidae

65. *Hastaperla sp*
66. *Alloperla sp*

Perlodidae

67. *Isoperla sp*
68. *Clioperla sp*

VIII. MOLLUSCA

Physidae

69. *Physa sp*

Lymnaeidae

70. *Lymnaea sp* #1
71. *Lymnaea sp* #2

The initial effect of the treatment plant as reported by the Pennsylvania Fish Commission was restoration of water quality and recovery of stream fish and fish food organisms (Maneval, 1968). When $Al(OH)_3$ floc built up, bottom fauna were virtually eliminated from upstream sections of the stream (i.e., Stations 2, 3, 4, and 7) and downstream areas were dominated by tolerant organisms.

After installation of the settling pond, recovery of stream bottom fauna communities began again. Recovery progressed until the settling pond's capacity was exceeded, and floc materials began to build up in downstream areas. Periodic high water, such as floods produced by hurricane Agnes, removed the floc blanket, and recovery processes could begin again, but floc accumulations could occur again if the settling capacity of the pond is not maintained. From previous experience, severe degradation of the bottom fauna community could occur in a matter of months.

A review of the results of biological collections illustrates general recovery processes and community development after stress. Even though Station 1 was a low pH area, fauna adapted to the station's environmental conditions and flourished. The bottom fauna community was dominated by the midge larvae Chironomidae, and the Odonata *Aeschna sp.* Habitats at the station included fine substrate materials and rich aquatic and submerged vegetation. *Aeschna sp.* is a weed dwelling dragonfly, and several species are classed as acid water organisms (Corbet, 1960).

Faunal development at Station 2 was limited by variable environmental conditions. During high flow (for example, May 1971) the bypass canal carried acid water around the treatment plant and the pH was reduced at Station 2. During low flow conditions constant lime additions at the plant in excess of acid requirements increased the pH of the pond effluent to as high as 11.7 (Maneval, 1969).

Stations 3 and 4 had improved fauna, but the communities at these stations were still dominated by tolerant organisms (Appendix II-C, Tables 8 through 11). Communities at both stations were alternately dominated by Chironomidae, *Hydropsyche sp.,* or *Chuematopsyche sp.* Organisms of frequent occurrence at Station 3 included *Aeschna sp.,* and *Tipula sp.* both adapted to pool or slow water habitats found at Station 3. Only two occurrences of Ephemeroptera or Plecoptera were noted at Station 3. The fauna at Station 4 showed the effect of both improved environmental conditions and a well developed riffle habitat. The faunal list for Station 4 included several taxa of Trichoptera, additional Diptera taxa, and the

Plecoptera *Hastaperla sp.* Diversity was variable at both stations and the number of taxa collected varied, as few as five or as many as fourteen occurred in collections from different dates.

Stations 5 and 6 will be considered together due to the influence of the tributary Station 5 on the mainstem downstream Station 6. The tributary Station 5 maintained a consistently high diversity, 2.95 to 3.57, and the number of taxa collected ranged from 23 to 33. Although the fauna was often dominated by Chironomidae, *Hydropsyche sp.* or *Cheumatopsyche sp.*, intolerant taxa were often co-dominant or present in large numbers (Table 13). Station 6 showed the same pattern, although dominance by tolerant organisms was more pronounced. As an example, in October 1970 *Stenonema sp.* was the second most abundant taxon at Station 5, and the third most abundant taxon at Station 6. No *Stenonema sp.* were collected at Station 4 on this date. Similar correspondences occurred in this and other collections which led to the recognition of the effects tributaries have on the mainstem. In this case, water quality was restored by the treatment plant, but sources of non-tolerant organisms were not available in other upstream areas. A healthy tributary such as Station 5 supplied recolonizing organisms resulting in restoration of bottom fauna communities in downstream areas.

Station 7 showed patterns of community structure similar to Station 6; i.e., dominance by tolerant organisms, but 7 taxa of Ephemeroptera.

Station 8 showed consistent good health based on the occurrence and dominance of non-tolerant taxa. Although the diversity values (2.36 to 2.57) were not high, non-tolerant organisms were well represented in each collection. The low diversity results were in part due to sampling problems presented by the substrate materials of Station 8. The current was very swift, and bottom materials were large cobbles to small boulders making both qualitative and quantitative sampling very difficult and somewhat non-representative of actual faunal occurrence. In October 1970 and May 1971, the collections were dominated by *Ephemerella sp.* and *Stenonema sp.* Although the number of taxa present was lower than at Stations 5 or 6, this difference in composition may be attributed to difficulties in sampling.

The general results of this study revealed a recovery from long term stress based on restoration of water quality and availability of recolonizing organisms. Although water quality was restored by the neutralization plant, communities with a high diversity and regular occurrence of non-tolerant taxa did not occur until the confluence with a healthy tributary. Communities in sections of the stream under variable or moderate stress were dominated by tolerant organisms; e.g., Stations 2, 3, and 4. With stress reduction, suitable habitat, and the source of recolonizing organisms, non-tolerant taxa were established as permanent members of the bottom fauna community indicating recovery; e.g., Station 8.

Superimposed on this overall recovery pattern was the effect of short term stress. Using October 1970 samples as an approximate baseline for stream conditions, the samples collected in May 1971 showed the effect of a short term low pH stress. Because AMD was diverted around the treatment plant by high flows, the upstream stations on Little Scrubgrass showed stress conditions with lowered diversity and reduced bottom fauna abundance. The AMD which bypassed the neutralization plant severely affected Station 2 and reduced diversity as far as Station 6. Stream conditions were improved at Stations 7 and 8 due in part to the neutralization of AMD by deposited lime between Stations 2 and 3, and higher discharges from all tributaries which diluted the AMD and increased drift from healthy tributaries. The stress conditions extended as far downstream as Station 6, 2.5 miles (4 km) downstream from the neutralization plant.

Another short term recovery pattern was illustrated in collections from July and November 1972. In May 1971, floc materials were beginning to build up throughout the stream. High streamflow in June 1972 evidently scoured the bottom and removed the floc. Samples from July 1972, 15 days after the Agnes flooding, showed decreased diversity and reduced bottom fauna abundance at all stations. In addition to scouring floc blankets, some bottom fauna organisms were evidently swept away. The combined effect was development of suitable habitat, removal of organisms, and insufficient time for well developed bottom fauna communities to develop through recolonization. A secondary effect of this high flow and heavy rainfall was increased acid loading throughout the stream indicated by high sulfate concentrations (Appendix II-C, Table 6). Even Station 5 had a high sulfate concentration, 62 ppm. By November 1972, approximately 120 days after the July 1972 sample, the tributary Station 5 had returned to normal levels of bottom fauna abundance, and Stations 6 and 8 showed major improvement with dominance by the tolerant *Hydropsyche sp.*, but non-tolerant Ephemeroptera were the next most abundant taxa. Because floc materials were removed, water quality was maintained, and sources of recolonizing organisms were available, recovery occurred within 120 days.

# CONCLUSIONS

The recovery of stream macrobenthic communities is governed by a host of physical, chemical, and biological factors which acting alone or in concert bring about reduction or removal of the stress, effect restoration of damaged habitat and produce recovery of the biotic system.

The primary effects of acid mine drainage on the water quality of a receiving stream are: reducing pH; increasing dissolved solids load; decreasing alkalinity, with a corresponding increased acidity; and introducing high toxic heavy metals. Several secondary effects also occur. A residual toxicity may be produced by the precipitation of various heavy metals, floc accumulations may build up in areas of the stream where the acid mine drainage is neutralized, and localized reduction in stream dissolved oxygen may occur if incompletely oxidized acid mine drainage is discharged in the stream. In general, water quality is reduced and severe damage to the biological system may occur if acid mine drainage is discharged into a stream.

The ability of a stream or river to assimilate acid mine drainage depends on several factors, the most important of which are streamflow (dilution capacity) and total alkalinity (neutralization capacity). Acid mine drainage occurs from both surface and subsurface sources. Subsurface sources of acid mine drainage are related to groundwater flow and maintain relatively constant discharge volumes, although the intensity of the mine drainage changes seasonally (Appalachian Reg. Comm., 1969). Surface sources of acid mine drainage are more variable. Runoff from surface exposures of pyritic material may vary with season and mine drainage concentration may vary widely from day to day. During cold winter months, temperatures restrict the chemical and biological reactions which form acid mine drainage at this time. During the warm summer months, the speed of reactions which form acid mine drainage are increased and large quantities of oxidation end products may be produced. These accumulations are flushed off the surface site with the initiation of runoff in a high intensity slug discharge. After initial flushing, continued runoff may have low concentrations of acid mine drainage and may actually contribute to dilution of other mine drainage.

Related to variable acid mine drainage discharge volumes and intensity are stream conditions which change seasonally. Stream discharge is related to rainfall and to several biotic-climatic factors, such as evapotranspiration, infiltration rates, and groundwater flow. Highest stream discharges usually occur in the spring months. Because infiltration may be reduced by saturated ground conditions, streamflow during the spring may be predominantly direct surface runoff. During the late spring and summer months, streamflow decreases. Rainfall amounts are usually less, and infiltration is reduced by vegetative cover. In constantly flowing streams, discharge may be low and groundwater rather than surface runoff is the major source of streamflow.

The assimilative capacity of a stream is related to these acid mine drainage streamflow interrelationships. The recovery of stream macrobenthic communities is dependent on good water quality and suitable habitat for growth and reproduction. Two models were proposed for recovery of streams from the effects of acid mine drainage, recovery through time and recovery through distance.

### I. Recovery Through Time

The model of recovery through time was verified by the experimental studies and results obtained from observational studies; when short term stress occurred, communities were restored in a short time. Recovery through time occurs when stress conditions are of short duration or when stress conditions which have been long term or chronic are removed. Although damage to the biotic system may have occurred, stress is removed and habitats are restored, providing sites for recolonization leading to recovery of normal community structure and function. In the experimental acid stress experiments, stress intensity was high, but of short duration. The damage to the community was reduction in numbers of organisms present, reduction of community diversity, and damage to food resources which limited recolonization until food chains could be reconstructed. Recovery began immediately after the stress was removed. Drift-borne sources of recolonizing organisms were greatest immediately after the stress, which may have occurred for a number of reasons (e.g., changes in flow encouraging drift). After damage, diversity and density may further decrease because food resources are limited. As habitat restoration occurs, density and diversity increase. The community in the experimental section at this time was dominated by *Cleptelmis sp.*; this taxon probably survived the stress. Those organisms which survive the stress conditions usually increase in numbers because competition for available resources is decreased. Recolonization by other organisms may be rapid or slow, depending on the nature of physical conditions after the stress, and the likelihood that an organism will be transported to the damaged area. As the damaged area is restored through time, density increases and diversity rises. Competition for available resources is greater and no single taxon dominates the community. Normal community structure and function are restored when diversity and density values are similar to pre-stress levels. Community structure may be changed by the appearance of new species, the same taxa may not occur after the stress (Cairns, 1965).

This pattern found in experimental studies was also evident in observational studies on both Indian Creek and Little Scrubgrass Creek. After flooding and the associated scouring of high flow, bottom fauna communities in the eastern tributaries and the downstream portion of the mainstem of Indian Creek were much reduced. After the September 1971 flood, food resources were severely limited, and recovery did not occur until late spring when algal and diatom growth provided sufficient energy sources for a well developed bottom fauna community. After the June 1972 flood, recovery was rapid because food sources were reestablished very quickly; normal diversity and density values were recorded approximately 12 weeks after the flood.

Recovery through time on Little Scrubgrass Creek occurred after heavy floc accumulations were removed by settling pond construction and high streamflow. Recovery was dependent on restored habitat. As soon as suitable conditions existed, organisms from healthy tributaries recolonized the mainstem of Little Scrubgrass Creek. Restoration was fairly rapid. High streamflow occurred in late June 1972, and the samples collected in mid-July 1972 indicated recovery had already begun.

### II. Recovery Through Distance

The model of recovery through distance may be applied to the observational sites. A chronic stress conditon exists in the upstream portion. These stress conditions are moderated through distance, and stream recovery occurs as suitable habitat is restored.

The recovery processes are related to distance from the source of stress and the stability of environmental conditions downstream. Recovery in Indian Creek had occurred by Station 10; macrobenthos at this station were well established. The community was dominated by moderately tolerant organisms, but non-tolerant forms occurred regularly. Diversity values were somewhat lower than upstream reference stations, but density values were almost equal on several occasions and the recovery station was often clustered with upstream reference stations. The community at the recovery station was well developed because the acid mine drainage stress had been reduced and sufficient buffer capacity of upstream tributaries maintained high water quality.

Bottom fauna communities in the remainder of the stream were not as stable. Rather than recovery, we might speak of conditions in this section of the stream as bottom fauna "accommodation" to conditions. During high discharge periods, bottom fauna communities were similar throughout the stream. It was at this time that the acid mine drainage was very dilute, and high streamflows distributed organisms throughout the stream, probably due mainly to drift. During low discharge periods, acid mine drainage intensity was high, and there was little dilution of the mine drainage. The effect of these changes in flow was increased stress throughout the middle section of the stream, and elimination of many taxa of bottom fauna which could not tolerate the increased stress. Diversity and density decreased during these periods.

Superimposed on these general patterns associated with low and high flow conditions were the effects of scour from the floods, periodic slug loads of acid mine drainage occurring as highly concentrated runoff from the gob piles along Champion Run during intense rain, and the interrelationship of streamflow and groundwater flow which during certain periods of the year reduce the dilution capacity of the stream system, but increase neutralization capacity of the tributaries.

The recovery through distance on Little Scrubgrass Creek occurred in a similar manner. The downstream station which was buffered against large fluctuations in environmental conditions maintained moderately healthy communities with high diversity and dominance by non-tolerant organisms. Stations in the mid-portion of the stream again were subject to variable environmental conditions. The bottom fauna communities in these sections of the stream were also "accommodated" but not actually established. Restoration of benthic communities began after each tributary. These tributaries did not have the primary function of restoring water quality, but acted as sources of recolonizing organisms to aid the recovery of downstream areas.

Summarizing, the conclusions drawn are restated below:

1. Recovery after short term stress with no residual toxicity is rapid. Experimental acid stress on a healthy stream resulted in recovery in 19 to 28 days.

2. Recovery may be related to downstream drift of recolonizing organisms. Those organisms most common in drift samples after acid stress were the dominant members of the bottom fauna community following recovery.

3. Recovery through distance occurs when environmental conditions are sufficiently stable to allow development of healthy macrobenthic communities.

4. Recovery from acid mine drainage is dependent on the maintenance of good water quality which is closely related to stream discharge—acid mine drainage volume relationships.

5. Recovery of macrobenthic communities after water quality has been restored artificially may occur rapidly. Secondary stress effects such as heavy floc accumulations may severely limit bottom fauna.

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# APPENDIX I-A

# WATERSHED MODELING

The production and eventual impact of acid mine drainage is dependent on interrelationships between physical and biological systems. The most useful physical parameter with which to estimate biological impact is stream discharge. Unfortunately, stream discharge values were not available for all mainstem and tributary stations in the observational studies. To overcome this difficulty in the Indian Creek study area a series of computer simulation models were adapted to the watershed to predict stream discharge in several sub-basins of the watershed, and provide a basis for water quality models of acid drainage.

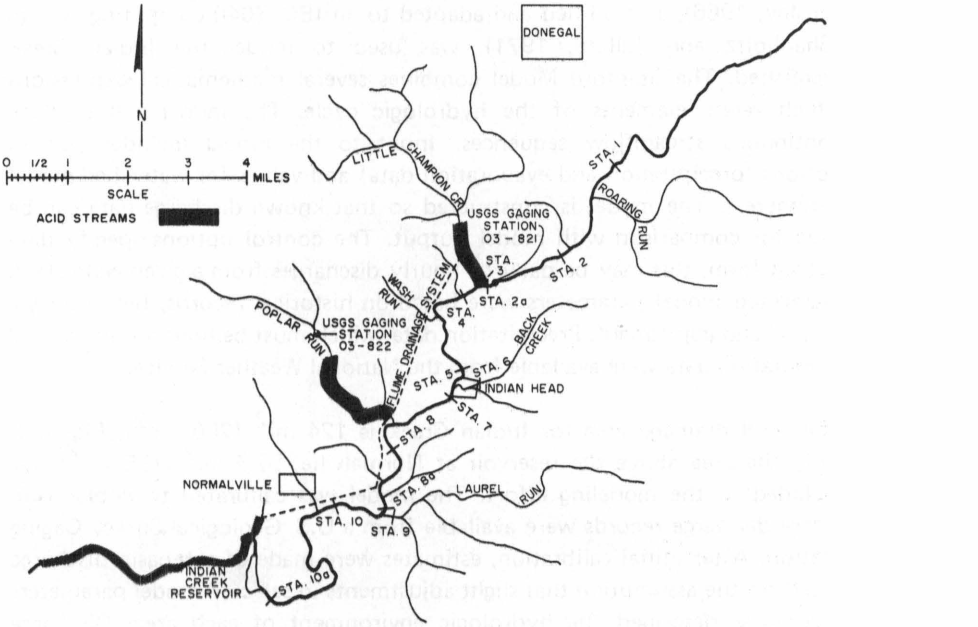
The Stanford Watershed Model, without snowmelt provisions (Crawford and Linsley, 1966), as modified and adapted to an IBM 7040 computing system (Shanholtz and Lillard, 1971), was used to model the Indian Creek watershed. The Stanford Model combines several mathematical expressions which relate elements of the hydrologic cycle. The model will produce continuous streamflow sequences. Input to the model includes control options (precipitation and evaporation data) and values for watershed model parameters. The model is constructed so that known discharge data can be used for comparison with model output. The control options specify data output form, this may be daily or hourly discharges from a given watershed. Watershed model parameters were based on historical records, field surveys, or trial and adjustment. Precipitation data, which must be hourly rainfall, and evaporation data were available from the National Weather Service.

The total drainage area for Indian Creek is 124 mi$^2$ (200 km$^2$), Figure 1. Only the area above the reservoir at Normalville, 97.4 mi$^2$ (155 km$^2$) was included in the modeling effort. The model was calibrated to Poplar Run where discharge records were available from a U.S. Geological Survey Gaging Station. After initial calibration, estimates were made of sub-basin discharge based on the assumption that slight adjustments in selected model parameters accurately described the hydrologic environment of each area. Discharge values were estimated for seven sub-basins: Indian Creek (upstream from Champion Run), Champion Run, Back Creek, Indian Creek (upstream from Poplar Run), Poplar Run, Laurel Run, and Indian Creek (upstream from the reservoir at Normalville).

Control parameters were specified to provide daily discharge estimates. After the model was calibrated, as above, two storm sequences were selected for modeling, and a series of 288 hourly discharge values were generated to estimate the storm hydrograph.

Figure 1

Stream Map with Station Locations
Indian Creek, Fayette County, Pa.



Precipitation data were obtained from the U.S. Weather Service. Hourly rainfall records were obtained for Connelsville, 7 mi (11.2 km) west of Normalville, and Confluence, 13 mi (21 km) southeast of Normalville. Daily rainfall records were available at these stations and at Donegal, located in the northwestern quarter of the Indian Creek watershed (Figure 1). Because hourly rainfall values were necessary for the model, initial attempts at model calibration used hourly precipitation from the Connelsville station. Comparisons with known discharge values for Poplar Run produced very poor correlations. A closer examination of the daily values from Connelsville revealed that Donegal had a higher mean number of rainy days per year than Connelsville. Alternative techniques were then explored to distribute the daily rainfall available for Donegal in hourly periods.

The initial distribution technique uniformly distributed daily rainfall in one 6-hour period on the day of occurrence beginning at 1100 hours and terminating at 1600 hours. This approach seemed justified because initial requirements were to produce sound estimates of water yields over a 7- to 10-day period. The fit between estimated and observed discharge values using this technique was quite close.

To further refine rainfall input data and achieve more accurate estimates of daily water yields, a second technique of rainfall distribution was employed. Because rainfall occurs randomly and the corresponding daily flows fluctuate in a similar manner, a scheme of random distribution of rainfall would more closely parallel nature and should produce more accurate estimates of water yield. To randomly distribute daily rainfall amounts, a frequency of occurrence table was developed for different rainfall amounts occurring during four periods of a day. Hourly data from Connelsville were used for this purpose. It was assumed that a ten-year analysis period and the proximity of Connelsville to Donegal would accurately indicate the time of day distribution of rainfall at Donegal. The day was broken into four six-hour periods beginning at 2400 hours (midnight). The frequency with which rainfall occurred in each of these periods was determined for four rainfall amount classes: 0.25 in. (0.6 cm), 0.5 in. (1.2 cm), 0.75 in. (1.8 cm), 1.0 in. (2.4 cm), Table 1. Based on this frequency distribution, daily rainfall amounts at Donegal falling in each amount class were randomly placed in one six-hour period and uniformly distributed within that period. If rainfall amounts exceeded one inch, the rainfall amount was divided into one-inch increments, each inch randomly placed, and uniformly distributed. Any rainfall amount (less than one inch) remaining after this distribution was placed according to the frequency of occurrence of its amount class and uniformly distributed in that day period. All assignments to one day period

## Table 1

### Percentage Estimates of Time of Day Distribution of Rainfall by Class Amounts

| Rainfall Amount (Inches) | 2400 - 0600 hrs | 0600 - 1200 hrs | 1200 - 1800 hrs | 1800 - 2400 hrs |
|---|---|---|---|---|
| 0.25 | .20 | .27 | .23 | .30 |
| 0.50 | .23 | .25 | .27 | .25 |
| 0.75 | .31 | .30 | .24 | .14 |
| 1.00 | .35 | .24 | .12 | .29 |

were combined and the total of all four periods equalled the daily rainfall. A comparison of simulated flows for the Poplar Run watershed showed some attentuation of peak flows, but water yield estimates were quite close.

Other climatic variables which influence both biotic and abiotic systems and may affect model calibration and performance are potential evapotranspiration and mean number of rainy days/year. Pan evaporation values were obtained from the U.S. Weather Service Climatological Data for Pennsylvania, and annual lake evaporation values were obtained from Kohler, Nordenson, and Daker (1959). These values were entered in the program and calculations were made of potential evapotranspiration for the model. Final adjustments of potential evapotranspiration and mean number of rainy days/year were made through use of an optimization technique (Liou and Iuan, 1970).

Watershed parameters were considered in two categories: physiographic parameters, non-variable within the watershed, and parameters which may vary within the watershed. Non-variable parameters include: watershed area, stream gradient, stream length, stream surface area, and mean overland flow distance. These values were obtained from U.S. Geological Survey 7.5-minute topographic maps using techniques described by Shanholtz and Lillard (1971). A time area histogram was developed relating watershed area associated with equal flow time increments.

Variable physiographic parameters included analysis of land use and vegetative cover. Estimates were made of total impervious area draining directly into the stream. Manning roughness coefficients were estimated for overland flow on pervious and impervious surfaces. Maximum interception rates were estimated using the percentage of the watershed in grassland, moderate forest cover, or heavy forest cover. An estimate of lower zone moisture loss by evaporation was made by estimation of watershed fractions of open land, grassland, light forest cover, or heavy forest cover. With this basic information for each sub-basin, the model was adapted to the hydrologic characteristics of each area. A list of all values used for model parameters is contained in Table 2.

Calibration of the model was carried out on Poplar Run (Figure 1) using discharge data obtained from the U.S. Geological Survey Gaging Station 03-822. Discharge records were available for the 10-year period of 1962-1972. Because an intensive sampling effort was made during 1971, this year's data were used in the calibration. Table 3 shows statistics for the calibration period by month. Good fits were obtained for monthly flows and

## Table 2

### Summary of Parameters with Algorithms Required for the Stanford Watershed Model

| Parameter | Description |
|---|---|
| FLZS | Current lower zone soil moisture storage |
| GWS | Current ground water slope index and gives an indication of antecedent moisture conditions |
| RI | Discharge rate at the end of the previous day |
| SGW | Ground water moisture storage |
| UZS | Current upper zone moisture storage |
| AREA | Watershed area (square miles) |
| C | Time delay histogram |
| ETL | Fraction of area in stream surface |
| FIA | Fraction of area having impervious area draining directly into a stream |
| FK24EL | Ground water evaporation parameter. Equal to the fraction of area having water loss due to phreatophytes |
| LENGTH | Average length of travel for overland flow (ft) |

Table 2
(Continued)

| | |
|---|---|
| MANI | Average Mannings roughness coefficient for impervious surfaces |
| MANP | Average Mannings roughness coefficient for pervious surfaces |
| S | Average watershed slope (ft/ft) |
| CSSR | Stream flow channel routing parameter |
| EPXM | Maximum interception rate for a dry watershed (in/hr) |

## Table 3

Table of Summary Values from Model Calibration
Poplar Run 1970–71

| | Statistics for Water Year 70–71 | | | | | |
|---|---|---|---|---|---|---|
| | Mean | | | | | |
| Summary for: | EST | OBS | R | A | B | N |
| Daily Flows | | | | | | |
| October | 13.86 | 5.13 | 0.68 | 4.41 | 1.84 | 31. |
| November | 14.06 | 11.47 | 0.73 | 7.49 | 0.57 | 28. |
| December | 33.89 | 36.60 | 0.96 | 9.68 | 0.66 | 31. |
| January | 25.15 | 29.38 | 0.81 | 14.24 | 0.37 | 30. |
| February | 39.60 | 50.30 | 0.64 | 18.97 | 0.41 | 31. |
| March | 26.49 | 30.06 | -0.00 | 26.56 | - 0.00 | 30. |
| April | 7.01 | 11.12 | 0.93 | - 5.71 | 1.14 | 31. |
| May | 26.97 | 31.78 | 0.98 | 1.75 | 0.79 | 31. |
| June | 34.83 | 11.72 | 0.59 | 2.47 | 2.76 | 30. |
| July | 15.48 | 4.13 | 0.44 | 12.05 | 0.83 | 31. |
| August | 21.11 | 21.13 | 0.16 | 18.63 | 0.12 | 30. |
| Water Year | 26.89 | 24.98 | 0.72 | 13.66 | 0.53 | 365. |

## Table 3
(Continued)

Statistics for Water Year 70-71

|  | Mean |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Summary for: | EST | OBS | R | A | B | N |
| Monthly Flows | 3.28 | 3.05 | 0.84 | 1.01 | 0.74 | 12. |
| Monthly Peaks | 137.67 | 173.41 | 0.77 | 74.80 | 0.36 | 12. |
| Flow Duration (% of Amt) | 12.33 | 12.77 | 1.00 | - 0.50 | 1.00 | 21. |
| Flow Duration (% of Time) | 29.33 | 33.45 | 0.99 | - 2.84 | 0.96 | 21. |

# Table 4

Table of Summary Values from Model Calibration 10% High

Poplar Run 1970–71

|  | Statistics for Water Year 1970–71 |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Mean |  |  |  |  |  |
| Summary for: | EST | OBS | R | A | B | N |
| Daily Flows |  |  |  |  |  |  |
| October | 18.64 | 5.13 | 0.62 | 5.90 | 2.48 | 31. |
| November | 17.68 | 11.47 | 0.80 | 7.68 | 0.87 | 28. |
| December | 39.30 | 36.60 | 0.97 | 8.34 | 0.85 | 31. |
| January | 28.02 | 29.38 | 0.82 | 14.61 | 0.46 | 30. |
| February | 44.51 | 50.30 | 0.63 | 20.71 | 0.47 | 31. |
| March | 29.58 | 30.06 | -0.00 | 29.68 | - 0.00 | 30. |
| April | 8.21 | 11.12 | 0.93 | - 6.75 | 1.35 | 31. |
| May | 32.70 | 31.78 | 0.97 | 1.67 | 0.98 | 31. |
| June | 44.22 | 11.72 | 0.53 | 6.76 | 3.20 | 30. |
| July | 22.74 | 4.13 | 0.76 | 12.95 | 2.37 | 31. |
| August | 27.64 | 21.13 | 0.22 | 23.44 | 0.20 | 30. |
| September | 73.18 | 55.35 | 0.84 | 40.13 | 0.60 | 31. |
| Water Year | 32.32 | 24.98 | 0.72 | 16.25 | 0.64 | 365. |

## Table 4
(Continued)

Statistics for Water Year 1970-71

| Summary for: | Mean<br>EST | <br>OBS | R | A | B | N |
|---|---|---|---|---|---|---|
| Monthly Flows | 3.94 | 3.05 | 0.78 | 1.57 | 0.78 | 12. |
| Monthly Peaks | 176.25 | 173.41 | 0.76 | 100.21 | 0.44 | 12. |
| Flow Duration (% of Amt) | 10.88 | 12.77 | 0.99 | -1.54 | 0.97 | 21. |
| Flow Duration (% of Time) | 25.83 | 33.45 | 0.98 | -5.07 | 0.92 | 21. |

monthly peaks (r values of 0.84 and 0.77, respectively). Computed and actual flow duration curves showed extremely close fit (r values 0.99 and 1.0). The fit between actual and computed daily flows showed a wide variation. All months except March, July, and August showed r values near to or greater than 0.6. Because the model does not include snowmelt provisions, the poor fit for March may be explained by delays between recording precipitation and actual runoff. Poor fits for July and August are probably due to high evaporation rates which are difficult to model.

Probable sources of error in model results include both model parameter errors and errors in climatological input data. An accepted error for rain gaging stations is 10%. To test the effect of this potential error on model output, runs were made adjusting input rainfall, and evaporation either high or low by 10%. High values were obtained by increasing precipitation while decreasing potential evapotranspiration—this process was reversed for low values. Results of model runs with these values are contained in Tables 4 and 5. Correlations between daily flows were poorer in each case.

After initial calibration, data were prepared to model stream discharge for Poplar Run during the 10-year period 1962-1972. Table 6 lists the observed and estimated annual discharge for the period of simulation. All values were within 20% of actual values except for water years 1964 and 1972. Monthly yield estimates for the period (Table 7) show large water yield values for the early spring months for 1964 and 1972 which may have produced model inconsistencies due to snowmelt.

The calibration model was then used to estimate discharge in the other sub-basins of the Indian Creek watershed. Adjustments to non-variable and variable physiographic parameters were made according to values listed in Table 8. Flow duration summaries are presented for each sub-basin, Tables 9 to 15.

## Table 5

### Table of Summary Values from Model Calibration 10% Low Poplar Run 1970–71

| Statistics for Water Year 70–71 | | | | | | |
|---|---|---|---|---|---|---|
| | Mean | | | | | |
| Summary for: | EST | OBS | R | A | B | N |
| Daily Flows | | | | | | |
| October | 4.95 | 5.13 | 0.84 | 0.79 | 0.81 | 31. |
| November | 9.21 | 11.47 | 0.69 | 5.38 | 0.33 | 28. |
| December | 26.41 | 36.60 | 0.90 | 9.26 | 0.47 | 31. |
| January | 21.45 | 29.38 | 0.76 | 13.54 | 0.27 | 30. |
| February | 34.09 | 50.30 | 0.64 | 17.71 | 0.33 | 31. |
| March | 23.32 | 30.06 | 0.00 | 23.26 | 0.00 | 30. |
| April | 6.08 | 11.12 | 0.91 | - 3.39 | 0.85 | 31. |
| May | 20.09 | 31.78 | 0.98 | 1.37 | 0.59 | 31. |
| June | 24.42 | 11.72 | 0.64 | 2.63 | 1.86 | 30. |
| July | 8.43 | 4.13 | -0.16 | 9.00 | -0.14 | 31. |
| August | 12.07 | 21.13 | 0.09 | 11.20 | 0.04 | 30. |
| September | 41.35 | 55.35 | 0.66 | 28.47 | 0.23 | 31. |
| Water Year | 19.39 | 24.98 | 0.65 | 11.59 | 0.31 | 365. |

Table 5

(Continued)

| | Statistics for Water Year 1970-71 | | | | | |
|---|---|---|---|---|---|---|
| | Mean | | | | | |
| Summary for: | EST | OBS | R | A | B | N |
| Monthly Flows | 2.36 | 3.05 | 0.91 | 0.48 | 0.62 | 12. |
| Monthly Peaks | 82.69 | 173.41 | 0.66 | 52.23 | 0.18 | 12. |
| Flow Duration (% of Amt) | 14.47 | 12.77 | 0.99 | 1.09 | 1.05 | 21. |
| Flow Duration (% of Time) | 36.45 | 33.45 | 1.00 | 4.45 | 0.96 | 21. |

## Table 6

### Observed and Estimated Annual Discharge for Period 1962-72 — Poplar Run

| Water Year | Annual Discharge | | Error | |
|---|---|---|---|---|
| | OBS | EST | | |
| | Inches | Inches | Inches | (%) |
| 1962-63 | 22.88 | 18.87 | 4.01 | 17.53 |
| 1963-64 | 25.65 | 32.38 | -6.73 | -26.24 |
| 1964-65 | 23.19 | 23.67 | -0.48 | - 2.07 |
| 1965-66 | 18.79 | 21.29 | -2.50 | -13.30 |
| 1966-67 | 23.51 | 21.89 | 1.62 | 6.89 |
| 1967-68 | 19.57 | 20.58 | -1.01 | - 5.16 |
| 1968-69 | 20.73 | 17.79 | 2.97 | 14.18 |
| 1969-70 | 27.06 | 27.78 | -0.72 | - 2.66 |
| 1970-71 | 34.08 | 35.97 | -1.89 | - 5.55 |
| 1971-72 | 37.53 | 30.04 | 7.49 | 19.96 |

## Table 7

### Observed and Estimated Monthly Water Yield Estimates, Poplar Run

### Water Yield and Error Summary for Period

| Water Year | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1962-63 | 1.43 | 2.12 | 1.64 | 3.07 | 1.81 | 8.92 | 1.15 | 0.66 | 0.87 | 1.05 | 0.06 | 0.10 | 22.88 |
| | 1.32 | 1.60 | 2.67 | 1.77 | 3.17 | 5.14 | 1.70 | 0.37 | 0.61 | 0.50 | 0.02 | 0.00 | 18.87 |
| | 0.11 | 0.52 | -1.03 | 1.30 | -1.36 | 3.78 | -0.55 | 0.29 | 0.26 | 0.55 | 0.04 | 0.10 | 4.01 |
| 1963-64 | 0.04 | 1.40 | 1.44 | 3.69 | 1.69 | 8.25 | 6.06 | 1.46 | 1.07 | 0.22 | 0.20 | 0.13 | 25.65 |
| | 0.01 | 2.62 | 3.18 | 3.76 | 3.46 | 5.80 | 8.41 | 2.30 | 2.56 | 0.22 | 0.02 | 0.04 | 32.38 |
| | 0.03 | -1.22 | -1.74 | -0.07 | -1.77 | 2.45 | -2.35 | -0.84 | -1.49 | 0.00 | 0.18 | 0.09 | -6.73 |
| 1964-65 | 0.22 | 2.10 | 4.18 | 4.68 | 2.52 | 4.36 | 3.00 | 1.63 | 0.33 | 0.04 | 0.04 | 0.09 | 23.19 |
| | 0.33 | 1.81 | 4.09 | 4.81 | 2.58 | 3.76 | 3.49 | 2.32 | 0.44 | 0.01 | 0.03 | 0.03 | 23.67 |
| | -0.08 | 0.29 | 0.09 | -0.13 | -0.06 | 0.60 | -0.49 | -0.69 | -0.11 | 0.03 | 0.01 | 0.06 | -0.48 |

## Table 7
(Continued)

### Water Yield and Error Summary for Period

| Water Year | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1966-67 | 0.09 | 0.78 | 2.01 | 0.90 | 1.91 | 9.05 | 3.06 | 4.87 | 0.35 | 0.22 | 0.09 | 0.18 | 23.51 |
| | 0.08 | 0.70 | 2.28 | 0.60 | 2.03 | 7.68 | 3.31 | 4.70 | 0.36 | 0.06 | 0.06 | 0.03 | 21.89 |
| | 0.01 | 0.08 | -0.27 | 0.30 | -0.12 | 1.37 | 0-0.25 | 0.17 | -0.01 | 0.16 | 0.03 | 0.15 | 1.62 |
| 1967-68 | 0.87 | 1.81 | 1.66 | 2.40 | 1.73 | 3.04 | 1.43 | 5.14 | 1.30 | 0.02 | 0.13 | 0.04 | 19.57 |
| | 0.67 | 1.88 | 2.20 | 2.52 | 1.58 | 3.06 | 1.43 | 5.73 | 1.47 | 0.01 | 0.02 | 0.01 | 20.58 |
| | 0.20 | -0.07 | -0.54 | -0.12 | 0.15 | -0.02 | 0.00 | -0.59 | -0.17 | 0.01 | 0.11 | 0.03 | -1.01 |
| 1968-69 | 0.05 | 1.85 | 3.50 | 2.51 | 1.57 | 1.44 | 4.90 | 1.63 | 0.36 | 0.95 | 1.61 | 0.36 | 20.73 |
| | 0.01 | 0.88 | 2.33 | 1.99 | 1.57 | 0.75 | 3.78 | 1.81 | 0.51 | 0.81 | 3.18 | 0.17 | 17.79 |
| | 0.04 | 0.97 | 1.17 | 0.52 | 0.00 | 0.69 | 1.12 | -0.18 | -0.15 | 0.14 | -1.57 | 0.19 | 2.94 |

## Table 7
(Continued)

### Water Yield and Error Summary for Period

| Water Year | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1969-70 | 0.62 | 2.20 | 3.11 | 3.97 | 3.19 | 4.54 | 3.98 | 2.11 | 1.04 | 1.23 | 0.75 | 0.32 | 27.06 |
| | 0.44 | 2.04 | 5.40 | 5.20 | 2.91 | 2.95 | 3.29 | 2.40 | 2.16 | 0.20 | 0.27 | 0.52 | 27.78 |
| | 0.18 | 0.16 | -2.29 | -1.23 | 0.28 | 1.59 | 0.69 | -0.29 | -1.12 | 1.03 | 0.48 | -0.20 | -0.72 |
| 1970-71 | 0.59 | 1.36 | 4.19 | 3.34 | 5.68 | 3.43 | 1.23 | 3.68 | 1.31 | 0.48 | 2.43 | 6.36 | 34.08 |
| | 1.65 | 1.65 | 4.03 | 2.87 | 4.43 | 3.01 | 0.73 | 3.15 | 3.46 | 1.47 | 2.10 | 7.42 | 35.97 |
| | -1.06 | -0.29 | 0.16 | 0.47 | 1.25 | 0.42 | 0.50 | 0.53 | -2.15 | -0.99 | 0.33 | -1.06 | -1.89 |
| 1971-72 | 0.35 | 1.33 | 3.31 | 3.06 | 2.76 | 8.29 | 5.39 | 2.34 | 7.11 | 3.12 | 0.38 | 0.09 | 37.53 |
| | 0.35 | 1.01 | 2.73 | 3.21 | 5.13 | 4.65 | 4.00 | 1.32 | 6.41 | 1.19 | 0.02 | 0.02 | 30.04 |
| | 0.00 | 0.32 | 0.58 | -0.15 | -2.37 | 3.64 | 1.39 | 1.02 | 0.70 | 1.93 | 0.36 | 0.07 | 7.49 |

## Table 8

### Values Used for Variable Watershed Parameters

| | Area Associated with Flow Time from Headwater Watershed Boundary | | | | | | |
|---|---|---|---|---|---|---|---|
| Time Area Histogram | Indian Creek above Champion Run | Champion Run | Back Creek | Indian Creek above Poplar Run | Poplar Run | Laurel Creek | Indian Creek above Reservoir |
| Time (min) | | | | | | | |
| 0 | 33.5 | 14.2 | 11.5 | 63.9 | 9.9 | 12.2 | 97.5 |
| 60 | 19.5 | 9.2 | 8.9 | 48.1 | 8.8 | 1.7 | 23.6 |
| 90 | – | 2.5 | – | – | 1.2 | – | – |
| 120 | 8.0 | – | – | 20.1 | – | – | 12.2 |
| 180 | 2.3 | – | – | 11.8 | – | – | 21.9 |
| 240 | – | – | – | 2.7 | – | – | 8.0 |
| 300 | – | – | – | – | – | – | 13.7 |
| 360 | – | – | – | – | – | – | 14.07 |
| ETL | .01 | .001 | .001 | .01 | .001 | .001 | .01 |
| MANP | .37 | .30 | .375 | .34 | .25 | .370 | .34 |
| MANI | .02 | .05 | .005 | .02 | .001 | .005 | .02 |
| FIA | .01 | .15 | – | .03 | – | .005 | .03 |

Table 8
(Continued)

| Time Area Histogram | Indian Creek above Champion Run | Champion Run | Back Creek | Indian Creek above Poplar Run | Poplar Run | Laurel Creek | Indian Creek above Reservoir |
|---|---|---|---|---|---|---|---|
| EXPM | .16 | .135 | .17 | .15 | .16 | .18 | .15 |
| FK3 | .272 | .254 | .276 | 2.62 | .27 | .289 | 2.62 |
| LENGTH | 900 | 800 | 800 | 900 | – | 800 | 1000 |
| % oper. | 30 | 50 | 20 | 40 | 20 | 10 | 40 |
| % light forest | 20 | 30 | 20 | 20 | 20 | 20 | 20 |
| % heavy forest | 50 | 20 | 60 | 40 | 60 | 70 | 40 |
| % open | 10 | 15 | 10 | 20 | 10 | 2 | 10 |
| % grassland | 20 | 35 | 10 | 20 | 10 | 8 | 30 |
| Slope (ft/ft) | 1/83.0 | 1/116 | 1/26.2 | 1/83.0 | 1/76.0 | 1/29.5 | 1/107.9 |

## Table 9

### Streamflow Simulation — Indian Creek Above Champion Run

### Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulation Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 — 0.10 | 0.00 | 0.01 | 10. | 211. |
| 0.10 — 0.20 | 0.00 | 0.01 | 5. | 77. |
| 0.20 — 0.30 | 0.01 | 0.02 | 26. | 60. |
| 0.30 — 0.50 | 0.04 | 0.03 | 90. | 80. |
| 0.50 — 0.75 | 0.08 | 0.05 | 109. | 75. |
| 0.75 — 1.00 | 0.04 | 0.05 | 41. | 51. |
| 1.00 — 1.50 | 0.16 | 0.09 | 119. | 65. |
| 1.50 — 2.00 | 0.09 | 0.10 | 47. | 52. |
| 2.00 — 4.00 | 0.74 | 0.46 | 230. | 143. |
| 4.00 — 5.00 | 0.37 | 0.30 | 73. | 60. |
| 5,00 — 5.50 | 0.34 | 0.15 | 59. | 26. |
| 5.50 — 6.00 | 0.13 | 0.13 | 20. | 20. |
| 6.00 — 6.50 | 0.20 | 0.19 | 29. | 28. |
| 6.50 — 7.00 | 0.33 | 0.16 | 45. | 21. |
| 7.00 — 10.00 | 1.50 | 1.24 | 161. | 133. |
| 10.00 — 15.00 | 3.39 | 2.21 | 246. | 160. |
| 15.00 — 20.00 | 3.60 | 2.41 | 187. | 124. |
| 20.00 — 25.00 | 4.81 | 2.70 | 193. | 109. |
| 25.00 — 30.00 | 5.57 | 3.66 | 183. | 120. |
| 30.00 — 40.00 | 13.48 | 8.51 | 342. | 220. |
| 40.00 — | 236.59 | 252.10 | 1438. | 1818. |

## Table 9
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Data (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.27 | 0.00 | 5.78 | 0.00 |
| 0.10 – 0.20 | 0.41 | 0.00 | 7.88 | 0.01 |
| 0.20 – 0.30 | 1.12 | 0.00 | 9.53 | 0.01 |
| 0.30 – 0.50 | 3.59 | 0.02 | 11.72 | 0.03 |
| 0.50 – 0.75 | 6.57 | 0.05 | 13.77 | 0.05 |
| 0.75 – 1.00 | 7.69 | 0.06 | 15.17 | 0.06 |
| 1.00 – 1.50 | 10.95 | 0.12 | 16.94 | 0.09 |
| 1.50 – 2.00 | 12.24 | 0.15 | 18.37 | 0.13 |
| 2.00 – 4.00 | 18.53 | 0.43 | 22.28 | 0.30 |
| 4.00 – 5.00 | 20.53 | 0.56 | 23.93 | 0.41 |
| 5.00 – 5.50 | 22.15 | 0.69 | 24.64 | 0.46 |
| 5.50 – 6.00 | 22.69 | 0.74 | 25.18 | 0.51 |
| 6.00 – 6.50 | 23.49 | 0.81 | 25.95 | 0.58 |
| 6.50 – 7.00 | 24.72 | 0.93 | 26.53 | 0.63 |
| 7.00 – 10.00 | 29.13 | 1.48 | 30.17 | 1.08 |
| 10.00 – 15.00 | 35.86 | 2.73 | 34.55 | 1.89 |
| 15.00 – 20.00 | 40.98 | 4.06 | 37.94 | 2.77 |
| 20.00 – 25.00 | 46.26 | 5.83 | 40.93 | 3.75 |
| 25.00 – 30.00 | 51.27 | 7.88 | 44.21 | 5.09 |
| 30.00 – 40.00 | 60.64 | 12.84 | 50.23 | 8.19 |
| 40.00 – | 100.00 | 100.01 | 100.00 | 100.01 |

## Table 10

### Streamflow Simulations — Champion Run

### Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulated Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 — 0.10 | 0.00 | 0.02 | 22. | 318. |
| 0.10 — 0.20 | 0.04 | 0.02 | 109. | 52. |
| 0.20 — 0.30 | 0.03 | 0.03 | 42. | 41. |
| 0.30 — 0.50 | 0.17 | 0.07 | 173. | 67. |
| 0.50 — 0.75 | 0.11 | 0.09 | 72. | 54. |
| 0.75 — 1.00 | 0.18 | 0.10 | 80. | 44. |
| 1.00 — 1.50 | 0.43 | 0.24 | 134. | 74. |
| 1.50 — 2.00 | 0.55 | 0.25 | 117. | 55. |
| 2.00 — 4.00 | 2.29 | 1.64 | 295. | 214. |
| 4.00 — 5.00 | 1.29 | 1.16 | 109. | 99. |
| 5.00 — 5.50 | 0.94 | 0.56 | 69. | 41. |
| 5.50 — 6.00 | 0.66 | 0.60 | 44. | 40. |
| 6.00 — 6.50 | 0.88 | 0.64 | 54. | 39. |
| 6.50 — 7.00 | 0.94 | 0.76 | 53. | 43. |
| 7.00 — 10.00 | 5.96 | 4.62 | 267. | 209. |
| 10.00 — 15.00 | 13.28 | 10.06 | 407. | 307. |
| 15.00 — 20.00 | 14.90 | 12.83 | 324. | 281. |
| 20.00 — 25.00 | 11.90 | 14.26 | 199. | 242. |
| 25.00 — 30.00 | 10.38 | 15.09 | 144. | 210. |
| 30.00 — 40.00 | 23.37 | 31.47 | 258. | 347. |
| 40.00 — | 183.25 | 190.75 | 681. | 876. |

## Table 10
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Data (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.60 | 0.00 | 8.71 | 0.01 |
| 0.10 – 0.20 | 3.59 | 0.02 | 10.13 | 0.01 |
| 0.20 – 0.30 | 4.74 | 0.03 | 11.25 | 0.02 |
| 0.30 – 0.50 | 9.47 | 0.09 | 13.09 | 0.05 |
| 0.50 – 0.75 | 11.44 | 0.13 | 14.56 | 0.08 |
| 0.75 – 1.00 | 13.63 | 0.20 | 15.77 | 0.11 |
| 1.00 – 1.50 | 17.30 | 0.36 | 17.79 | 0.20 |
| 1.50 – 2.00 | 20.50 | 0.56 | 19.30 | 0.29 |
| 2.00 – 4.00 | 28.58 | 1.40 | 25.16 | 0.86 |
| 4.00 – 5.00 | 31.56 | 1.88 | 27.87 | 1.27 |
| 5.00 – 5.50 | 33.45 | 2.23 | 28.99 | 1.47 |
| 5.50 – 6.00 | 34.66 | 2.47 | 30.08 | 1.68 |
| 6.00 – 6.50 | 36.13 | 2.79 | 31.15 | 1.90 |
| 6.50 – 7.00 | 37.59 | 3.14 | 32.33 | 2.17 |
| 7.00 – 10.00 | 44.89 | 5.33 | 38.05 | 3.79 |
| 10.00 – 15.00 | 56.04 | 10.22 | 46.45 | 7.32 |
| 15.00 – 20.00 | 64.91 | 15.71 | 54.15 | 11.81 |
| 20.00 – 25.00 | 70.35 | 20.09 | 60.77 | 16.81 |
| 25.00 – 30.00 | 74.30 | 23.91 | 66.52 | 22.10 |
| 30.00 – 40.00 | 81.36 | 32.52 | 76.02 | 33.14 |
| 40.00 – | 100.00 | 100.01 | 100.00 | 100.02 |

## Table 11

### Streamflow Simulations — Back Creek

### Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulated Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 — 0.10 | 0.01 | 0.03 | 41. | 458. |
| 0.10 — 0.20 | 0.05 | 0.04 | 114. | 83. |
| 0.20 — 0.30 | 0.09 | 0.05 | 116. | 63. |
| 0.30 — 0.50 | 0.16 | 0.10 | 126. | 83. |
| 0.50 — 0.75 | 0.21 | 0.12 | 97. | 62. |
| 0.75 — 1.00 | 0.25 | 0.17 | 84. | 62. |
| 1.00 — 1.50 | 0.53 | 0.32 | 130. | 80. |
| 1.50 — 2.00 | 0.68 | 0.44 | 120. | 79. |
| 2.00 — 4.00 | 3.09 | 2.05 | 324. | 219. |
| 4.00 — 5.00 | 2.21 | 1.12 | 151. | 77. |
| 5.00 — 5.50 | 0.77 | 0.55 | 45. | 33. |
| 5.50 — 6.00 | 1.22 | 0.74 | 66. | 40. |
| 6.00 — 6.50 | 1.18 | 0.78 | 58. | 39. |
| 6.50 — 7.00 | 0.93 | 0.74 | 42. | 34. |
| 7.00 — 10.00 | 9.36 | 5.31 | 340. | 195. |
| 10.00 — 15.00 | 18.35 | 12.72 | 449. | 317. |
| 15.00 — 20.00 | 15.45 | 15.91 | 267. | 284. |
| 20.00 — 25.00 | 14.31 | 17.99 | 193. | 249. |
| 25.00 — 30.00 | 13.70 | 19.52 | 153. | 221. |
| 30.00 — 40.00 | 22.25 | 38.22 | 196. | 341. |
| 40.00 — | 166.75 | 155.66 | 541. | 634. |

# Table 11
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Data (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 1.12 | 0.00 | 12.54 | 0.01 |
| 0.10 – 0.20 | 4.24 | 0.02 | 14.81 | 0.03 |
| 0.20 – 0.30 | 7.42 | 0.06 | 16.53 | 0.05 |
| 0.30 – 0.50 | 10.87 | 0.12 | 18.81 | 0.08 |
| 0.50 – 0.75 | 13.52 | 0.20 | 20.50 | 0.13 |
| 0.75 – 1.00 | 15.82 | 0.29 | 22.20 | 0.19 |
| 1.00 – 1.50 | 19.38 | 0.48 | 24.39 | 0.31 |
| 1.50 – 2.00 | 22.67 | 0.73 | 26.55 | 0.47 |
| 2.00 – 4.00 | 31.54 | 1.87 | 32.55 | 1.23 |
| 4.00 – 5.00 | 35.67 | 2.69 | 34.66 | 1.64 |
| 5.00 – 5.50 | 36.90 | 2.97 | 35.56 | 1.84 |
| 5.50 – 6.00 | 38.71 | 3.42 | 36.65 | 2.11 |
| 6.00 – 6.50 | 40.30 | 3.85 | 37.72 | 2.40 |
| 6.50 – 7.00 | 41.45 | 4.20 | 38.65 | 2.67 |
| 7.00 – 10.00 | 50.75 | 7.65 | 43.99 | 4.62 |
| 10.00 – 15.00 | 63.04 | 14.40 | 52.67 | 9.29 |
| 15.00 – 20.00 | 70.35 | 20.09 | 60.44 | 15.12 |
| 20.00 – 25.00 | 75.64 | 25.36 | 67.26 | 21.72 |
| 25.00 – 30.00 | 79.82 | 30.41 | 73.31 | 28.88 |
| 30.00 – 40.00 | 85.19 | 38.60 | 82.64 | 42.91 |
| 40,00 – | 100.00 | 100.01 | 100.00 | 100.01 |

## Table 12

## Streamflow Simulations — Indian Creek Above Poplar Run

### Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulated Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 — 0.10 | 0.00 | 0.00 | 10. | 145. |
| 0.10 — 0.20 | 0.00 | 0.00 | 0. | 50. |
| 0.20 — 0.30 | 0.00 | 0.01 | 2. | 42. |
| 0.30 — 0.50 | 0.01 | 0.01 | 21. | 60. |
| 0.50 — 0.75 | 0.03 | 0.02 | 68. | 60. |
| 0.75 — 1.00 | 0.02 | 0.02 | 36. | 47. |
| 1.00 — 1.50 | 0.09 | 0.06 | 112. | 81. |
| 1.50 — 2.00 | 0.05 | 0.06 | 46. | 62. |
| 2.00 — 4.00 | 0.25 | 0.19 | 158. | 111. |
| 4.00 — 5.00 | 0.22 | 0.10 | 86. | 40. |
| 5.00 — 5.50 | 0.05 | 0.05 | 16. | 16. |
| 5.50 — 6.00 | 0.13 | 0.04 | 39. | 12. |
| 6.00 — 6.50 | 0.09 | 0.07 | 25. | 19. |
| 6.50 — 7.00 | 0.13 | 0.04 | 34. | 11. |
| 7.00 — 10.00 | 0.66 | 0.46 | 131. | 94. |
| 10.00 — 15.00 | 1.24 | 0.87 | 172. | 120. |
| 15.00 — 20.00 | 1.46 | 1.13 | 142. | 112. |
| 20.00 — 25.00 | 1.63 | 1.28 | 124. | 97. |
| 25.00 — 30.00 | 1.85 | 1.15 | 116. | 72. |
| 30.00 — 40.00 | 4.10 | 2.89 | 202. | 142. |
| 40.00 — | 259.55 | 268.10 | 2113. | 2260. |

## Table 12
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Data (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.27 | 0.00 | 3.97 | 0.00 |
| 0.10 – 0.20 | 0.27 | 0.00 | 5.34 | 0.00 |
| 0.20 – 0.30 | 0.33 | 0.00 | 6.49 | 0.00 |
| 0.30 – 0.50 | 0.90 | 0.00 | 8.13 | 0.01 |
| 0.50 – 0.75 | 2.76 | 0.01 | 9.77 | 0.02 |
| 0.75 – 1.00 | 3.75 | 0.02 | 11.06 | 0.03 |
| 1.00 – 1.50 | 6.82 | 0.05 | 13.28 | 0.05 |
| 1.50 – 2.00 | 8.08 | 0.07 | 14.97 | 0.07 |
| 2.00 – 4.00 | 12.40 | 0.16 | 18.01 | 0.14 |
| 4.00 – 5.00 | 14.75 | 0.24 | 19.11 | 0.18 |
| 5.00 – 5.50 | 15.19 | 0.26 | 19.55 | 0.19 |
| 5.50 – 6.00 | 16.26 | 0.31 | 19.87 | 0.21 |
| 6.00 – 6.50 | 16.94 | 0.34 | 20.39 | 0.23 |
| 6.50 – 7.00 | 17.88 | 0.39 | 20.70 | 0.25 |
| 7.00 – 10.00 | 21.46 | 0.63 | 23.27 | 0.41 |
| 10.00 – 15.00 | 26.17 | 1.09 | 26.55 | 0.73 |
| 15.00 – 20.00 | 30.06 | 1.63 | 29.62 | 1.14 |
| 20.00 – 25.00 | 33.45 | 2.23 | 32.27 | 1.60 |
| 25.00 – 30.00 | 36.63 | 2.91 | 34.25 | 2.02 |
| 30.00 – 40.00 | 42.16 | 4.42 | 38.13 | 3.06 |
| 40.00 – | 100.00 | 100.01 | 100.00 | 100.01 |

## Table 13

### Simulation Studies on Poplar Run, Pennsylvania

### Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulated Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.03 | 0.05 | 101. | 515. |
| 0.10 – 0.20 | 0.10 | 0.06 | 139. | 108. |
| 0.20 – 0.30 | 0.10 | 0.06 | 96. | 60. |
| 0.30 – 0.50 | 0.13 | 0.15 | 84. | 93. |
| 0.50 – 0.75 | 0.30 | 0.20 | 122. | 82. |
| 0.75 – 1.00 | 0.39 | 0.25 | 111. | 70. |
| 1.00 – 1.50 | 0.66 | 0.60 | 131. | 121. |
| 1.50 – 2.00 | 1.10 | 0.53 | 155. | 77. |
| 2.00 – 4.00 | 3.89 | 2.72 | 327. | 231. |
| 4.00 – 5.00 | 3.31 | 1.49 | 184. | 82. |
| 5.00 – 5.50 | 0.72 | 1.03 | 34. | 49. |
| 5.50 – 6.00 | 2.14 | 0.90 | 92. | 39. |
| 6.00 – 6.50 | 1.30 | 1.03 | 52. | 41. |
| 6.50 – 7.00 | 2.36 | 1.06 | 87. | 39. |
| 7.00 – 10.00 | 14.24 | 7.52 | 407. | 219. |
| 10.00 – 15.00 | 20.25 | 17.39 | 393. | 347. |
| 15.00 – 20.00 | 17.84 | 21.55 | 248. | 306. |
| 20.00 – 25.00 | 16.10 | 22.99 | 177. | 256. |
| 25.00 – 30.00 | 14.53 | 24.74 | 130. | 224. |
| 30.00 – 40.00 | 23.16 | 40.54 | 165. | 291. |
| 40.00 – | 148.89 | 123.81 | 418. | 403. |

## Table 13
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Data (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 2.76 | 0.01 | 14.10 | 0.02 |
| 0.10 – 0.20 | 6.57 | 0.05 | 17.05 | 0.04 |
| 0.20 – 0.30 | 9.20 | 0.09 | 18.70 | 0.06 |
| 0.30 – 0.50 | 11.50 | 0.13 | 21.24 | 0.12 |
| 0.50 – 0.75 | 14.84 | 0.24 | 23.49 | 0.19 |
| 0.75 – 1.00 | 17.88 | 0.39 | 25.40 | 0.28 |
| 1.00 – 1.50 | 21.46 | 0.63 | 28.72 | 0.51 |
| 1.50 – 2.00 | 25.70 | 1.04 | 30.82 | 0.71 |
| 2.00 – 4.00 | 34.66 | 2.47 | 37.15 | 1.72 |
| 4.00 – 5.00 | 39.69 | 3.69 | 39.39 | 2.27 |
| 5.00 – 5.50 | 40.62 | 3.95 | 40.73 | 2.66 |
| 5.50 – 6.00 | 43.14 | 4.74 | 41.80 | 2.99 |
| 6.00 – 6.50 | 44.57 | 5.22 | 42.92 | 3.37 |
| 6.50 – 7.00 | 46.95 | 6.09 | 43.99 | 3.77 |
| 7.00 – 10.00 | 58.09 | 11.33 | 49.99 | 6.57 |
| 10.00 – 15.00 | 68.85 | 18.79 | 59.49 | 13.04 |
| 15.00 – 20.00 | 75.64 | 25.36 | 67.86 | 21.06 |
| 20.00 – 25.00 | 80.48 | 31.29 | 74.87 | 29.62 |
| 25.00 – 30.00 | 84.04 | 36.65 | 81.00 | 38.83 |
| 30.00 – 40.00 | 88.56 | 45.18 | 88.97 | 53.92 |
| 40.00 – | 100.00 | 100.01 | 100.00 | 100.01 |

# Table 14

## Streamflow Simulations — Laurel Run

## Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulated Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.01 | 0.03 | 33. | 462. |
| 0.10 – 0.20 | 0.05 | 0.04 | 108. | 82. |
| 0.20 – 0.30 | 0.09 | 0.05 | 115. | 65. |
| 0.30 – 0.50 | 0.14 | 0.10 | 116. | 80. |
| 0.50 – 0.75 | 0.15 | 0.12 | 81. | 64. |
| 0.75 – 1.00 | 0.20 | 0.15 | 98. | 58. |
| 1.00 – 1.50 | 0.45 | 0.31 | 127. | 80. |
| 1.50 – 2.00 | 0.70 | 0.43 | 131. | 82. |
| 2.00 – 4.00 | 2.71 | 1.88 | 303. | 211. |
| 4.00 – 5.00 | 2.01 | 1.06 | 147. | 77. |
| 5.00 – 5.50 | 0.82 | 0.48 | 51. | 30. |
| 5.50 – 6.00 | 1.11 | 0.60 | 63. | 34. |
| 6.00 – 6.50 | 0.93 | 0.55 | 49. | 29. |
| 6.50 – 7.00 | 1.10 | 0.84 | 54. | 41. |
| 7.00 – 10.00 | 8.52 | 4.82 | 325. | 186. |
| 10.00 – 15.00 | 15.80 | 11.02 | 414. | 292. |
| 15.00 – 20.00 | 16.15 | 15.46 | 300. | 292. |
| 20.00 – 25.00 | 13.91 | 16.63 | 199. | 241. |
| 25.00 – 30.00 | 11.78 | 17.75 | 140. | 212. |
| 30.00 – 40.00 | 22.79 | 35.70 | 216. | 337. |
| 40.00 – | 172.06 | 162.81 | 583. | 698. |

## Table 14
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Data (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.90 | 0.00 | 12.65 | 0.01 |
| 0.10 – 0.20 | 3.86 | 0.02 | 14.89 | 0.03 |
| 0.20 – 0.30 | 7.01 | 0.05 | 16.67 | 0.04 |
| 0.30 – 0.50 | 10.18 | 0.10 | 18.86 | 0.08 |
| 0.50 – 0.75 | 12.40 | 0.16 | 20.61 | 0.12 |
| 0.75 – 1.00 | 15.08 | 0.25 | 22.20 | 0.18 |
| 1.00 – 1.50 | 18.56 | 1.43 | 24.39 | 0.30 |
| 1.50 – 2.00 | 22.15 | 0.69 | 26.64 | 0.46 |
| 2.00 – 4.00 | 30.44 | 1.69 | 32.41 | 1.15 |
| 4.00 – 5.00 | 34.46 | 2.43 | 34.52 | 1.54 |
| 5.00 – 5.50 | 35.86 | 2.73 | 35.34 | 1.72 |
| 5.50 – 6.00 | 37.59 | 3.14 | 36.27 | 1.94 |
| 6.00 – 6.50 | 38.93 | 3.48 | 37.07 | 2.14 |
| 6.50 – 7.00 | 40.41 | 3.89 | 38.19 | 2.45 |
| 7.00 – 10.00 | 49.30 | 7.03 | 43.28 | 4.23 |
| 10.00 – 15.00 | 60.64 | 12.84 | 51.27 | 8.30 |
| 15.00 – 20.00 | 68.85 | 18.79 | 59.27 | 14.01 |
| 20.00 – 25.00 | 74.30 | 23.91 | 65.86 | 20.15 |
| 25.00 – 30.00 | 78.13 | 28.25 | 71.67 | 26.71 |
| 30.00 – 40.00 | 84.04 | 36.65 | 80.89 | 39.89 |
| 40.00 – | 100.00 | 100.01 | 100.00 | 100.01 |

## Table 15

### Streamflow Simulations — Indian Creek Above the Reservoir at Normalville

### Flow Duration Summary — 1961-1972

| Flow Rate (cfs) | Actual Discharge (in.) | Simulated Discharge (in.) | Number of Days (act) | Number of Days (syn) |
|---|---|---|---|---|
| 0.00 — 0.10 | 0.00 | 0.00 | 10. | 107. |
| 0.10 — 0.20 | 0.00 | 0.00 | 0. | 52. |
| 0.20 — 0.30 | 0.00 | 0.00 | 0. | 34. |
| 0.30 — 0.50 | 0.00 | 0.01 | 2. | 43. |
| 0.50 — 0.75 | 0.01 | 0.01 | 21. | 44. |
| 0.75 — 1.00 | 0.01 | 0.02 | 16. | 47. |
| 1.00 — 1.50 | 0.04 | 0.03 | 88. | 67. |
| 1.50 — 2.00 | 0.02 | 0.03 | 36. | 45. |
| 2.00 — 4.00 | 0.21 | 0.15 | 199. | 142. |
| 4.00 — 5.00 | 0.07 | 0.07 | 42. | 43. |
| 5.00 — 5.50 | 0.06 | 0.04 | 31. | 18. |
| 5.50 — 6.00 | 0.02 | 0.03 | 8. | 13. |
| 6.00 — 6.50 | 0.10 | 0.02 | 41. | 9. |
| 6.50 — 7.00 | 0.02 | 0.04 | 7. | 15. |
| 7.00 —10.00 | 0.40 | 0.22 | 125. | 69. |
| 10.00 — 15.00 | 0.77 | 0.46 | 157. | 97. |
| 15.00 — 20.00 | 0.81 | 0.54 | 120. | 80. |
| 20.00 — 25.00 | 0.76 | 0.70 | 89. | 81. |
| 25.00 — 30.00 | 0.88 | 0.63 | 84. | 61. |
| 30.00 — 40.00 | 2.43 | 1.63 | 183. | 123. |
| 40.00 — | 264.95 | 271.73 | 2394. | 2463. |

## Table 15
(Continued)

| Flow Rate (cfs) | Flow Data (%) Time Base (act) | Flow Date (%) Q Base (act) | Flow Data (%) Time Base (syn) | Flow Data (%) Q Base (syn) |
|---|---|---|---|---|
| 0.00 – 0.10 | 0.27 | 0.00 | 2.93 | 0.00 |
| 0.10 – 0.20 | 0.27 | 0.00 | 4.35 | 0.00 |
| 0.20 – 0.30 | 0.27 | 0.00 | 5.28 | 0.00 |
| 0.30 – 0.50 | 0.33 | 0.00 | 6.46 | 0.00 |
| 0.50 – 0.75 | 0.90 | 0.00 | 7.66 | 0.01 |
| 0.75 – 1.00 | 1.34 | 0.00 | 8.95 | 0.01 |
| 1.00 – 1.50 | 3.75 | 0.02 | 10.70 | 0.03 |
| 1.50 – 2.00 | 4.74 | 0.03 | 12.02 | 0.04 |
| 2.00 – 4.00 | 10.18 | 0.10 | 15.90 | 0.09 |
| 4.00 – 5.00 | 11.33 | 0.13 | 17.08 | 0.12 |
| 5.00 – 5.50 | 12.18 | 0.15 | 17.57 | 0.13 |
| 5.50 – 6.00 | 12.40 | 0.16 | 17.93 | 0.14 |
| 6.00 – 6.50 | 13.52 | 0.20 | 18.18 | 0.15 |
| 6.50 – 7.00 | 13.71 | 0.20 | 18.59 | 0.16 |
| 7.00 – 10.00 | 17.14 | 0.35 | 20.48 | 0.24 |
| 10.00 – 15.00 | 21.43 | 0.63 | 23.13 | 0.41 |
| 15.00 – 20.00 | 24.72 | 0.93 | 25.32 | 0.60 |
| 20.00 – 25.00 | 27.16 | 1.21 | 27.54 | 0.85 |
| 25.00 – 30.00 | 29.46 | 1.53 | 29.21 | 1.08 |
| 30.00 – 40.00 | 34.46 | 2.43 | 32.58 | 1.67 |
| 40.00 – | 100.00 | 100.01 | 100.00 | 100.01 |

# APPENDIX I-B

# CHEMICAL MODELING

An attempt was made to better define chemical conditions in the Indian Creek watershed as they were related to stream discharge. Because sulfate is a conservative compound and is a good indicator of not only acid mine drainage but also mine drainage intensity, a model was developed to predict sulfate concentration in the watershed based on known acid loading and stream discharge.

The model developed was similar to a steady state conservative case model described by Thomann (1972). The basic equation, shown here,

Sulfate Model

$$[C_1]\,Q_1 + [C_2]\,Q_2 = [C_{out}]\,Q_{out}$$

where:

$C$ = $SO_4$ concentration
$Q$ = discharge (cfs)

combines the discharge and sulfate concentration from a tributary with the discharge and sulfate concentration of an upstream confluence. The result is a discharge value and a sulfate concentration immediately downstream from the confluence. Because even unpolluted tributaries have some sulfate in solution, unpolluted tributaries were assigned sulfate concentrations of 20 ppm or less. Because mine drainage loading in acid tributaries is variable, these tributaries were assigned variable sulfate loads based on observed concentrations.

Discharge values from the Stanford Model were used for all sub-basins except Poplar Run, where USGS discharge values were used. Sulfate concentrations were obtained from the Pennsylvania Department of Mines and Mineral Industries (anon. 1969) and adjusted according to values of water quality analyses made during the recovery study. Sulfate loads for Champion Run were reported to be 18,000 lb/day, and Poplar Run loading was 2,000 lb/day.

Field observations indicated that rainfall effects included both increased stream discharge and increased mine drainage. An extensive tailing or gob pile along the north bank of Champion Run produced significant amounts of acid mine drainage and the associated sulfate loading. During dry periods or periods of light rainfall, pyritic materials in the gob pile would oxidize and hydrolize to produce large quantities of acid and sulfate compounds. During high intensity storms, highly concentrated mine drainage flushed off the gob pile in a slug, and residual acid drainage would occur until rainfall ceased. To simulate the effect of these high sulfate slugs, a rainfall trigger was placed in the model. If the daily rainfall exceeded 0.25 inches, an additional sulfate load was included in that days results.

Using these basic assumptions the model was run to determine its validity with these input data. During periods of moderate to high discharge, the model sulfate concentrations compared favorably with values recorded during the recovery study. Low discharge estimates were much higher than recorded sulfaty values, which indicated that groundwater discharge decreased during low flow periods. Sulfate loading was similarly reduced. To account for these low flow changes, all daily discharge values less than 15 cfs received an incremental decrease in sulfate loading which produced acceptable low discharge sulfate values.

The accuracy of model estimates of sulfate loading was good. Regression analysis performed on model value and actual value pairs (Table 1) indicate high correlation (r) values. Two sets of model values were regressed with actual values. Because sampling occurred over a one- to five-day period, model values were selected on the basis of closeness of fit of five values, two on either side of the midpoint, with actual values. Midpoint correlation values varied between 0.35 and 0.74 while best fit values varied between 0.69 and 0.94. Considering the possible sources of error in the hydrologic model and the loading values, model accuracy was quite good.

## Table 1

### Correlation Values for Least Square Regression of $SO_4$ Model and Actual $SO_4$ Value Pairs

| Station | R Midpoint | 5-Day Best Fit |
|---|---|---|
| 3 | 0.69 | 0.94 |
| 4 | 0.74 | 0.89 |
| 7 | 0.50 | 0.84 |
| 10 | 0.35 | 0.69 |

# APPENDIX II-A

## Indian Creek Data

## Table 1

### Water Chemistry and Estimated Average Daily Discharge – October 1970

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2a | 3 | 4R | | 4L | 5 | 7 | 10 |
| Total Alkalinity (ppm) | 40 | 0 | 10 | – | 24 | 16 | NR | 18 |
| Total Acidity | | | | | | | | |
| (Cold) | 6 | 64 | 8 | – | 4 | 4 | NR | 4 |
| (Hot) | 10 | 94 | 10 | – | 4 | 4 | NR | 4 |
| Total Hardness | 67.79 | 193.62 | 103.74 | – | 81.83 | 105.63 | NR | 73.78 |
| Calcium | 49.81 | 113.67 | 67.79 | – | 53.75 | 63.85 | NR | 49.81 |
| Fe | 0 | 1.0+ | .66 | – | .45 | – | – | 0 |
| $SO_4$ | 29.8 | 24.0 | 45.4 | – | 85.0 | 66.4 | NR | 55.2 |
| pH | 7.8 | 3.9 | 6.4 | – | 6.8 | 6.8 | NR | 6.8 |

## Table 1
(Continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2a | 3 | 4R | | 4L | 5 | 7 | 10 |
| | | | Estimated Q (cfs) | | | | | |
| *Sept. – Sept. 29 | – | 21.6 | – | 70.2 | – | – | 87.3 | 111.8 |
| Sept. 30 – Oct. 7 | – | 18.8 | – | 61.2 | – | – | 78.2 | 103.3 |
| Oct. 8 – Oct. 14 | – | 10.8 | – | 31.2 | – | – | 38.6 | 53.4 |
| Oct. 15 – Oct. 21 | – | 30.3 | – | 100.6 | – | – | 123.8 | 157.3 |

*Week of sampling

## Table 2

### High and Low Stream Discharge Estimates Preceding Sampling — October 1970

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge Station 10 | 376.9 | Sept. 20 | 159.3 | Oct. 2 | 73.5 | Oct. 11 | 869.2 | Oct. 21 |
| Low Daily Discharge Station 10 | 16.8 | Sept. 25 | 61.6 | Oct. 7 | 44.9 | Oct. 14 | 27.2 | Oct. 20 |

# Table 3

## Water Chemistry and Stream Discharge Estimates — May 1971

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4R | | 4L |
| Total Alkalinity (ppm) | 18 | 18 | 0 | 12 | — | 14 |
| Total Acidity | | | | | | |
| (Cold) | 2 | 2 | 20 | 4 | — | 4 |
| (Hot) | 0 | 2 | 20 | 4 | — | 0 |
| Total Hardness | 38.02 | 38.02 | 83.71 | 47.76 | — | 37.83 |
| Calcium | 29.78 | 21.91 | 47.76 | 35.78 | — | 27.90 |
| Fe | 0 | 0 | .3 | 0 | — | .1 |
| $SO_4$ | 14.5 | 14.0 | 82 | 41.6 | — | 26.5 |
| pH | 7.0 | 7.0 | 4.0 | 6.8 | — | 5.8 |

Table 3
(Continued)

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4R |  | 4L |
|  |  |  | Estimated Q (cfs) |  |  |  |
| *Apr. 27 – May 5 | – | – | 27.4 | – | – | 45.1 |
| May 6 – May 12 | – | – | 489.0 | – | – | 695.1 |
| May 13 – May 19 | – | – | 198.2 | – | – | 268.4 |
| May 20 – May 26 | – | – | 45.2 | – | – | 68.4 |

*Week of sampling

### Table 3
(Continued)

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 |
| Total Alkalinity (ppm) | 12 | 18 | 14 | 18 | 14 | 12 |
| Total Acidity | | | | | | |
| (Cold) | 2 | 3 | 2 | 2 | 2 | 2 |
| (Hot) | 2 | 0 | 2 | 2 | 0 | 0 |
| Total Hardness | 41.77 | 31.84 | 15.88 | 39.88 | 21.91 | 31.84 |
| Calcium | 29.78 | 23.79 | 27.90 | 27.90 | 15.92 | 25.85 |
| Fe | 0 | 0 | .02 | .09 | 0 | 0 |
| $SO_4$ | 28.2 | 11.5 | 28.8 | 20.0 | 9.5 | 24.0 |
| pH | 6.5 | 7.0 | 6.5 | 6.8 | 7.0 | 6.8 |

Table 3
(Continued)

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 8 | 9 | 10 |
|  | Estimated Q (cfs) |  |  |  |  |  |
| *Apr. 27 – May 5 | – | – | 27.4 | – | – | 45.1 |
| May 6 – May 12 | – | – | 489.0 | – | – | 695.1 |
| May 13 – May 19 | – | – | 198.2 | – | – | 268.4 |
| May 20 – May 26 | – | – | 45.2 | – | – | 68.4 |

*Week of sampling

Table 4

High and Low Stream Discharge Estimates Preceding Sampling — May 1971

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge Station 10 | 184.9 | May 5 | 2146.9 | May 6 | 565.0 | May 13 | 103.4 | May 20 |
| Low Daily Discharge Station 10 | 17.9 | May 4 | 206.9 | May 12 | 123.3 | May 19 | 42.4 | May 26 |

## Table 5

Water Chemistry and Stream Discharge Estimates — June 1971

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4R | | 4L |
| Total Alkalinity (ppm) | 26 | 28 | 24 | 0 | 20 | — | 8 |
| Total Acidity | | | | | | | |
| (Cold) | 2 | 2 | 2 | 20 | 2 | — | 2 |
| (Hot) | 0 | 0 | 0 | 40 | 2 | — | 4 |
| Total Hardness | 39.89 | 45.88 | 47.42 | 109.73 | 55.81 | — | 43.88 |
| Calcium | 27.80 | 27.90 | 31.84 | 67.79 | 39.88 | — | 27.90 |
| Fe | .2 | 0 | 0 | 3.5 | .37 | — | 1 |
| $SO_4$ | 13.1 | 12.3 | 15.1 | 14.08 | 148.5 | — | 48.5 |
| pH | 7.0 | 7.0 | 7.0 | 4.0 | 6.0 | — | 6.75 |

## Table 5
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4R | | 4L |
| | Estimated Q (cfs) | | | | | | |
| *June 3 – June 9 | – | – | – | 92.4 | – | 327.4 | – |
| June 10 – June 16 | – | – | – | 63.0 | – | 189.5 | – |
| June 17 – June 23 | – | – | – | 17.6 | – | 60.8 | – |
| June 24 – June 30 | – | – | – | 73.4 | – | 213.6 | – |

*Week of sampling

Table 5
(Continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10R | | 10L |
| Total Alkalinity (ppm) | 14 | 26 | 14 | 16 | 26 | 12 | — | 16 |
| Total Acidity | | | | | | | | |
| (Cold) | 2 | 2 | 2 | 2 | 2 | 2 | — | 0 |
| (Hot) | 0 | 0 | 0 | 0 | 0 | 2 | — | 2 |
| Total Hardness | 47.76 | 31.84 | 49.81 | 43.82 | 29.78 | 47.76 | — | 43.82 |
| Calcium | 35.78 | 25.89 | 33.89 | 34.84 | 23.79 | 31.89 | — | 29.78 |
| Fe | .25 | 0 | .25 | .25 | 0 | .12 | — | .37 |
| $SO_4$ | 36.3 | 11.8 | 33.6 | 32.8 | 9.9 | 26.2 | — | 29.6 |
| pH | 6.75 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | — | 7.0 |

# Table 5

(Continued)

|  | Station Number |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 8 | 9 | 10R |  | 10L |
|  |  |  | Estimated Q (cfs) |  |  |  |  |  |
| *June 3 – June 9 | – | – | 393.4 | – | – | – | 486.5 | – |
| June 10 – June 16 | – | – | 236.9 | – | – | – | 311.2 | – |
| June 17 – June 23 | – | – | 77.6 | – | – | – | 106.4 | – |
| June 24 – June 30 | – | – | 265.4 | – | – | – | 328.4 | – |

*Week of sampling

## Table 6

### High and Low Stream Discharge Estimates Preceding Sampling — June 1971

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge<br>Station 10 | 1940.7 | June<br>6 | 652 | June<br>14 | 169.6 | June<br>17 | 111.4 | June<br>29 |
| Low Daily Discharge<br>Station 10 | 20.90 | June<br>5 | 105 | June<br>12 | 60.9 | June<br>23 | 33.1 | June<br>27 |

## Table 7

Water Chemistry and Stream Discharge Estimates – July 1971

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4R | | 4L |
| Total Alkalinity (ppm) | 30 | 28 | 34 | 0 | 8 | – | 16 |
| Total Acidity | | | | | | | |
| (Cold) | 2 | 2 | 2 | 52 | 6 | – | 2 |
| (Hot) | 0 | 0 | 0 | 56 | 6 | – | 0 |
| Total Hardness | 59.74 | 51.87 | 59.74 | 173.93 | 81.83 | – | 75.84 |
| Calcium | 49.81 | 39.88 | 51.87 | 105.63 | 57.86 | – | 53.75 |
| Fe | 0 | 0 | .62 | 3 | 1.5 | – | 1.25 |
| $SO_4$ | 12.22 | 15.5 | 27.11 | 195.8 | 65.8 | – | 53.93 |
| pH | 2.3 | 7.0 | 7.0 | 3.8 | 6.5 | – | 6.0 |

### Table 7
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4R | | 4L |
| | Estimated Q (cfs) | | | | | | |
| *July 1 — July 7 | — | — | — | 29.4 | — | 106.5 | — |
| July 8 — July 14 | — | — | — | 41.4 | — | 111.7 | — |
| July 15 — July 21 | — | — | — | 22.2 | — | 70.4 | — |
| July 22 — July 28 | — | — | — | 8.5 | — | 22.7 | — |

*Week of sampling

Table 7
(Continued)

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 |
| Total Alkalinity (ppm) | 12 | 32 | 14 | 14 | 20 | 12 |
| Total Acidity | | | | | | |
| (Cold) | 2 | 2 | 2 | 2 | 2 | 2 |
| (Hot) | 2 | 0 | 0 | 2 | 0 | 0 |
| Total Hardness | 75.84 | 45.88 | 57.86 | 65.74 | 25.85 | 59.74 |
| Calcium | 61.80 | 35.78 | 51.87 | 53.75 | 23.79 | 45.88 |
| Fe | .25 | .12 | .5 | .25 | .12 | .12 |
| $SO_4$ | 59.5 | 8.9 | 49.7 | 48.2 | 7.07 | 41.99 |
| pH | 7.0 | 7.0 | 6.9 | 7.0 | 6.0 | 7.0 |

## Table 7
(Continued)

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 8 | 9 | 10 |
|  |  |  | Estimated Q (cfs) |  |  |  |
| *July 1 – July 7 | – | – | 133.1 | – | – | 167.5 |
| July 8 – July 14 | – | – | 134.0 | – | – | 164.6 |
| July 15 – July 21 | – | – | 86.7 | – | – | 111.0 |
| July 22 – July 28 | – | – | 28.1 | – | – | 39.8 |

*Week of sampling

Table 8

High and Low Stream Discharge Estimates Preceding Sampling — July 1971

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge<br>Station 10 | 284.3 | July<br>1 | 332.2 | July<br>13 | 167.5 | July<br>15 | 52.0 | July<br>22 |
| Low Daily Discharge<br>Station 10 | 91.7 | July<br>7 | 67.6 | July<br>9 | 67.3 | July<br>21 | 27.4 | July<br>28 |

## Table 9

### Water Chemistry and Stream Discharge Estimates — August 1971

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 2a | 3 | 4R |  | 4L |
| Total Alkalinity (ppm) | 30 | 26 | 26 | 0 | 4 | — | 18 |
| Total Acidity |  |  |  |  |  |  |  |
| (Cold) | 2 | 2 | 2 | 10 | 6 | — | .2 |
| (Hot) | 0 | 0 | 0 | 16 | 8 | — | 0 |
| Total Hardness | 55.81 | 47.76 | 53.75 | 59.87 | 51.87 | — | 47.76 |
| Calcium | 45.88 | 35.78 | 41.77 | 47.76 | 35.78 | — | 39.88 |
| Fe | .12 | .12 | .12 | 1.25 | 1.0 | — | .5 |
| $SO_4$ | 14.7 | 17.0 | 26.0 | 53.5 | — | — | — |
| pH | 7.5 | 7.5 | 7.2 | 4.7 | 5.7 | — | 6.8 |

Table 9
(Continued)

Station Number

| | 1 | 2 | 2a | 3 | 4R | | 4L |
|---|---|---|---|---|---|---|---|
| | | | Estimated Q (cfs) | | | | |
| *Aug 5 – Aug 11 | – | – | – | 46.9 | – | 170.9 | – |
| Aug 12 – Aug 18 | – | – | – | 13.9 | – | 48.1 | – |
| Aug 19 – Aug 25 | – | – | – | 22.2 | – | 52.6 | – |
| Aug 26 – Sept 1 | – | – | – | 7.9 | – | 24.6 | – |

*Week of sampling

Table 9
(continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10R | | 10L |
| Total Alkalinity (ppm) | 22 | 18 | 14 | 14 | 20 | 10 | — | 14 |
| Total Acidity | | | | | | | | |
| (Cold) | 2 | 2 | 2 | 2 | 2 | 2 | — | 2 |
| (Hot) | 0 | 0 | 0 | 0 | 0 | 0 | — | 0 |
| Total Hardness | 59.74 | 39.88 | 49.81 | 55.81 | 27.90 | 49.81 | — | 45.88 |
| alcium | 39.88 | 29.78 | 41.77 | 45.88 | 21.91 | 45.88 | — | 37.83 |
| Fe | .5 | .08 | .62 | .12 | 0 | .25 | — | .25 |
| $SO_4$ | — | 13.3 | 35.9 | 38.0 | 9.04 | 35.3 | — | 35.3 |
| pH | 6.9 | 7.5 | 7.2 | 7.2 | 7.5 | 7.2 | — | 7.2 |

## Table 9
(Continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10R | | 10L |
| | | | Estimated Q (cfs) | | | | | |
| *Aug 5 – Aug 11 | – | – | 212.3 | – | – | – | 274.9 | – |
| Aug 12 – Aug 18 | – | – | 60.1 | – | – | – | 79.5 | – |
| Aug 19 – Aug 25 | – | – | 63.0 | – | – | – | 90.7 | – |
| Aug 26 – Sept 1 | – | – | 31.1 | – | – | – | 88.3 | – |

*Week of sampling

# Table 10

## High and Low Stream Discharge Estimates Preceding Sampling — August 1971

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge<br>Station 10 | 475.9 | Aug.<br>5 | 129.0 | Aug.<br>12 | 215.8 | Aug.<br>23 | 186.4 | Aug.<br>28 |
| Low Daily Discharge<br>Station 10 | 189.9 | Aug.<br>11 | 45.1 | Aug.<br>18 | 34.0 | Aug.<br>20 | 36.72 | Sept.<br>1 |

## Table 11

Water Chemistry and Stream Discharge Estimates — October 1971

| | Station Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4R | | 4L | 5 |
| Total Alkalinity (ppm) | 26 | 32 | 22 | 0 | 24 | 8 | — | 20 | 16 |
| Total Acidity | | | | | | | | | |
| (Cold) | 2 | 2 | 2 | 60 | 4 | 8 | — | 4 | 4 |
| (Hot) | 6 | 4 | 4 | 72 | 8 | 10 | — | 6 | 6 |
| Total Hardness | 51.36 | 39.88 | 47.76 | 145.86 | 73.78 | 69.84 | — | 57.74 | 59.74 |
| Calcium | 41.77 | 29.78 | 23.79 | 77.72 | 43.82 | 47.76 | — | 41.77 | 39.88 |
| Fe | 0 | 0 | 0 | 3.7 | 0 | .5 | — | .05 | .5 |
| $SO_4$ | 11.11 | 12.49 | 19.02 | 165.54 | 44.23 | 57.36 | — | 34.23 | 39.30 |
| pH | 7.2 | 7.2 | 7.3 | 3.8 | 7.2 | 6.0 | — | 6.6 | 6.8 |

Table 11
(Continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 8a | 9 | 10R | | 10L |
| Total Alkalinity (ppm) | 26 | 16 | 22 | 4 | 20 | 14 | — | 18 |
| Total Acidity | | | | | | | | |
| (Cold) | 2 | 4 | 4 | 4 | 4 | 2 | — | 2 |
| (Hot) | 6 | 8 | 6 | 8 | 4 | 4 | — | 4 |
| Total Hardness | 37.83 | 57.86 | 57.86 | 73.78 | 25.85 | 47.76 | — | 51.87 |
| Calcium | 27.90 | 43.82 | 49.81 | 54.86 | 17.80 | 41.77 | — | 41.77 |
| Fe | .1 | .5 | .5 | 0 | .1 | 0 | — | .05 |
| $SO_4$ | 10.03 | 37.89 | 40.55 | 65.23 | 8.46 | 35.43 | — | 35.65 |
| pH | 7.4 | 7.2 | 7.2 | 4.7 | 7.4 | 7.2 | — | 7.2 |

Table 11
(Continued)

| | Station Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4R | | 4L | 5 |
| | | | | Estimated Q (cfs) | | | | | |
| *Sept. 23 – Sept. 29 | – | – | – | 62.5 | – | – | 208 | – | – |
| Oct. 1 – Oct. 7 | – | – | – | 17.9 | – | – | 58.8 | – | – |
| Oct. 8 – Oct 14 | – | – | – | 5.8 | – | – | 17.6 | – | – |
| Oct. 15 – Oct. 21 | – | – | – | 1.3 | – | – | 4.7 | – | – |

*Week of sampling

## Table 11
(Continued)

|  | Station Number |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | 6 | 7 | 8 | 8a | 9 | 10R |  | 10L |
|  | Estimated Q (cfs) |  |  |  |  |  |  |  |
| *Sept. 23 – Sept. 29 | – | 259.7 | – | – | – | – | 331.7 | – |
| Oct. 1 – Oct. 7 | – | 73.7 | – | – | – | – | 99.1 | – |
| Oct. 8 – Oct. 14 | – | 22.4 | – | – | – | – | 35.3 | – |
| Oct. 15 – Oct. 21 | – | 6.7 | – | – | – | – | 15.7 | – |

*Week of sampling

## Table 11a

### Hourly Storm Flows for Flood Peak, September 1971

| Sept. 14 | Hour | Q (cfs) |
|---|---|---|
| | 0900 | 47.7 |
| | 1000 | 45.9 |
| | 1100 | 895.1 |
| | 1200 | 3244.6 |
| | 1300 | 3259.4 |
| | 1400 | 3189.5 |
| | 1500 | 3217.0 |
| | 1600 | 3265.7 |
| | 1700 | 894.3 |
| | 1800 | 446.9 |

## Table 12

### High and Low Stream Discharge Estimates Preceding Sampling — October 1971

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge Station 10 | 409.8 | Sept. 26 | 150.7 | Oct. 1 | 54.7 | Oct. 8 | 20.3 | Oct. 15 |
| Low Daily Discharge Station 10 | 219.6 | Sept. 29 | 71.5 | Oct. 7 | 23.0 | Oct. 14 | 12.3 | Oct. 21 |

# Table 13

Water Chemistry and Stream Discharge Estimates — December 1971

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 3 | 4R | 7 | 8a | 10R | | 10L |
| Total Alkalinity (ppm) | 20 | 0 | 6 | 12 | 10 | 12 | — | 10 |
| Total Acidity | | | | | | | | |
| (Cold) | 2 | 26 | 10 | 6 | 4 | 2 | — | 4 |
| (Hot) | 4 | 58 | 12 | 7 | 6 | 4 | — | 5 |
| Total Hardness | 41.77 | 67.79 | 45.88 | 39.88 | 39.88 | 37.83 | — | 35.78 |
| Calcium | 35.78 | 39.88 | 35.78 | 27.90 | 35.78 | 21.91 | — | 23.79 |
| Fe | 0 | 2.5 | 1.5 | .5 | .25 | .25 | — | .25 |
| $SO_4$ | 13.19 | 90.18 | 36.37 | 28.94 | 30.42 | 26.91 | — | 26.20 |
| pH | 7.2 | 4.2 | 5.8 | 6.8 | 6.8 | 7.0 | — | 7.2 |

Table 13
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 3 | 4R | 7 | 8a | 10R | | 10L |
| | | | Estimated Q (cfs) | | | | | |
| *Nov. 26 – Dec. 2 | – | 39.6 | 130.8 | 163.1 | – | – | 247.9 | – |
| Dec. 3 – Dec. 9 | – | 79.4 | 236.4 | 327.5 | – | – | 468.2 | – |
| Dec. 10 – Dec. 16 | – | 37.4 | 137.3 | 173.0 | – | – | 235.4 | – |
| Dec. 17 – Dec. 23 | – | 10.9 | 39.6 | 50.4 | – | – | 77.9 | – |

*Week of sampling

## Table 14

### High and Low Stream Discharge Estimates Preceding Sampling — December 1971

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge<br>Station 10 | 427.2 | Nov.<br>30 | 973.3 | Dec.<br>7 | 372.8 | Dec.<br>10 | 113.8 | Dec.<br>17 |
| Low Daily Discharge<br>Station 10 | 164.8 | Nov.<br>26 | 153.1 | Dec.<br>5 | 134.6 | Dec.<br>16 | 55.3 | Dec.<br>23 |

## Table 15

### Water Chemistry and Stream Discharge Estimates — March 1972

|  | Station Number |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | 1 | 2a | 3 | 3a | 4 | 4R |  | 4L |
| Total Alkalinity (ppm) | 8 | 6 | — | 6 | 0 | 0 | — | 4 |
| Total Acidity |  |  |  |  |  |  |  |  |
| (Cold) | 2 | 2 | — | 2 | 40 | 16 | — | 4 |
| (Hot) | 2 | 2 | — | 4 | 48 | 18 | — | 22 |
| Total Hardness | 29.78 | 23.79 | — | 41.77 | 59.74 | 59.74 | — | 43.82 |
| Calcium | 19.85 | 17.80 | — | 31.84 | 29.78 | 33.89 | — | 27.90 |
| Fe | 0 | 0 | — | NR | 3.0 | 2.0 | — | 0 |
| $SO_4$ | 11.04 | 11.56 | — | 30.26 | 37.37 | 22.27 | — | 16.32 |
| pH | 7.4 | 7.3 | — | 7.0 | 5.0 | 5.2 | — | 6.8 |

### Table 15
(Continued)

Station Number

| | 1 | 2a | 3 | 3a | 4 | 4R | | 4L |
|---|---|---|---|---|---|---|---|---|
| | | | Estimated Q(cfs) | | | | | |
| *Feb. 18 – Feb. 24 | — | — | 134.3 | — | — | — | 447.6 | — |
| Feb. 25 – Mar. 2 | — | — | 49.8 | — | — | — | 168.3 | — |
| Mar. 3 – Mar. 9 | — | — | 62.7 | — | — | — | 220.0 | — |
| Mar. 10 – Mar. 16 | — | — | 88.6 | — | — | — | 287.5 | — |

*Week of sampling

Table 15
(Continued)

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 9 | 10R |  | 10L |
| Total Alkalinity (ppm) | 2 | 4 | 4 | 6 | 4 | — | 6 |
| Total Acidity |  |  |  |  |  |  |  |
| (Cold) | 8 | 2 | 8 | 2 | 4 | — | 4 |
| (Hot) | 10 | 4 | 10 | 6 | 8 | — | 8 |
| Total Hardness | 49.81 | 29.78 | 49.81 | 27.90 | 39.88 | — | 39.88 |
| Calcium | 29.78 | 23.79 | 35.78 | 19.85 | 29.78 | — | 29.78 |
| Fe | 2 | 0 | .75 | 0 | .25 | — | .25 |
| $SO_4$ | 27.62 | 10.54 | 26.52 | 8.16 | 22.69 | — | 23.29 |
| pH | 6.7 | 7.3 | 6.1 | 7.1 | 6.9 | — | 6.8 |

## Table 15
(Continued)

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 9 | 10R |  | 10L |
| *Feb. 18 – Feb. 24 | – | – | 556.2 | – | – | 691.3 | – |
| Feb. 25 – Mar. 2 | – | – | 210.9 | – | – | 382.9 | – |
| Mar. 3 – Mar. 9 | – | – | 274.5 | – | – | 405.6 | – |
| Mar. 10 – Mar. 16 | – | – | 356.9 | – | – | 535.2 | – |

*Week of sampling

## Table 15
(Continued)

Sample Mixing Model Results for March 1972

| Station | Q(cfs) | $SO_4$ conc. |
|---|---|---|
| 3 | 26.8 | 80.7 |
| 4 | 96.9 | 36.5 |
| 7 | 122.2 | 31.7 |
| 9 | 20.1 | 19.5 |
| 10 | 173.9 | 26.3 |

Average daily rainfall 0.012 in.

## Table 16

High and Low Stream Discharge Estimates Preceding Sampling – March 1972

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge | | Feb. | | Mar. | | Mar. | | Mar. |
| Station 10 | 1372.8 | 20 | 587.9 | 2 | 1018.2 | 3 | 1119.5 | 13 |
| Low Daily Discharge | | Feb. | | Feb. | | Mar. | | Mar. |
| Station 10 | 353.3 | 24 | 281.5 | 28 | 205.2 | 9 | 157.0 | 11 |

## Table 17

### Water Chemistry and Estimated Average Daily Discharge — May 1972

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4R | | 4L |
| Total Alkalinity (ppm) | 24 | 18 | 10 | 0 | 16 | 26 | — | 6 |
| Total Acidity | | | | | | | | |
| (Cold) | 6 | 4 | 4 | 24 | 2 | 6 | — | 2 |
| (Hot) | 8 | 4 | 8 | 28 | 6 | 32 | — | 10 |
| Total Hardness | 31.84 | 29.78 | 21.91 | 59.74 | 37.83 | 37.83 | — | 37.83 |
| Calcium | 23.79 | 21.91 | 7.87 | 33.89 | 21.91 | 19.85 | — | 23.79 |
| Fe | .2 | .01 | .1 | .6 | .1 | 1.1 | — | .01 |
| $SO_4$ | 13.48 | 14.63 | — | 49.48 | 27.88 | 40.22 | — | 18.05 |
| pH | 7.2 | 7.2 | 7.0 | 3.9 | 6.8 | 5.4 | — | 7.0 |

Table 17
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4R | 4L |
| | | | Estimated Q (cfs) | | | | |
| *Apr. 21 – Apr. 27 | – | | – | 160.5 | – | | 231.3 |
| Apr. 28 – May 4 | – | | – | 85.5 | – | | 124.0 |
| May 5 – May 11 | – | | – | 185.8 | – | | 274.4 |
| May 12 – May 15 | – | | – | 77.7 | – | | 121.3 |

*Week of sampling

## Table 17
(Continued)

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 5 | 6 | 7 | 9 | 10 |
| Total Alkalinity (ppm) | 12 | 18 | 8 | 14 | 22 |
| Total Acidity | | | | | |
| (Cold) | 6 | 2 | 2 | 2 | 4 |
| (Hot) | 6 | 4 | 2 | 4 | 8 |
| Total Hardness | 37.83 | 29.78 | – | 21.91 | 31.84 |
| Calcium | 23.79 | 19.85 | 23.79 | 15.92 | 21.91 |
| Fe | NR | .1 | .3 | 0 | .2 |
| $SO_4$ | 27.12 | 13.33 | 25.82 | 12.04 | 24.99 |
| pH | 6.2 | 7.2 | 6.8 | 6.8 | 6.8 |

## Table 18

High and Low Stream Discharge Estimates Preceding Sampling — May 1972

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge Station 10 | 335.7 | Apr. 22 | 272.5 | May 4 | 670.0 | May 9 | 185.6 | May 12 |
| Low Daily Discharge Station 10 | 141.2 | Apr. 27 | 83.1 | May 1 | 138.4 | May 8 | 75.7 | May 18 |

## Table 19

Water Chemistry and Stream Discharge Estimates — June 1972

| | Station Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4R | | 4L | 5 |
| Total Alkalinity (ppm) | 22 | 20 | 20 | 0 | 12 | 12 | — | 10 | 14 |
| Total Acidity | | | | | | | | | |
| (Cold) | 2 | 2 | 2 | 32 | 2 | 4 | — | 2 | 2 |
| (Hot) | 6 | 4 | 6 | 48 | 4 | 8 | — | 6 | 6 |
| Total Hardness | 57.86 | 51.87 | 51.87 | 161.44 | 97.75 | 61.80 | — | 51.87 | 63.85 |
| Calcium | 41.77 | 37.49 | 37.83 | 95.70 | 63.85 | 45.88 | — | 41.77 | 45.88 |
| Fe | 0 | NR | NR | 4.2 | .1 | .1 | — | .3 | NR |
| SO4 | 11.80 | 13.02 | 20.79 | 124.32 | 60 | 46.30 | — | 26.81 | 20.26 |
| pH | 7.2 | 7.2 | 7.2 | 3.9 | 7.2 | 6.2 | — | 6.8 | 6.8 |

Table 19
(Continued)

Station Number

|  | 1 | 2 | 2a | 3 | 3a | 4R |  | 4L | 5 |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Estimated Q (cfs) |  |  |  |  |  |
| *May 12 – May 18 | – | – | – | 14.4 | – | – | 60.9 | – | – |
| May 19 – May 25 | – | – | – | 3.8 | – | – | 17.1 | – | – |
| May 26 – June 1 | – | – | – | 1.2 | – | – | 4.9 | – | – |
| June 2 – June 8 | – | – | – | .4 | – | – | 1.5 | – | – |

## Table 19
(Continued)

|  | Station Number |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | 6 | 7 | 8 | 8a | 9 | 10R |  | 10L |
| Total Alkalinity (ppm) | 22 | 12 | 14 | 2 | 22 | 18 | — | 12 |
| Total Acidity |  |  |  |  |  |  |  |  |
| (Cold) | 2 | 2 | 4 | 6 | 2 | 2 | — | 2 |
| (Hot) | 4 | 4 | 6 | 10 | 6 | 4 | — | 6 |
| Total Hardness | 32.82 | 63.85 | 61.80 | 71.73 | 29.78 | 51.87 | — | 49.81 |
| Calcium | 33.89 | 43.82 | 41.77 | 41.77 | 21.91 | 39.88 | — | 39.88 |
| Fe | NR | NR | .1 | .1 | 0 | .1 | — | — |
| $SO_4$ | 8.53 | 33.81 | 35.56 | 65.80 | 7.31 | 30.16 | — | 30.54 |
| pH | 7.3 | 7.2 | — | 4.7 | 7.1 | 7.2 | — | 7.3 |

## Table 19
(Continued)

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 8a | 9 | 10R | | 10L |
| | | | EstimatedQ(cfs) | | | | | |
| *May 12 – May 18 | – | 77.7 | – | – | – | – | 121.3 | – |
| May 19 – May 25 | – | 22.9 | – | – | – | – | 43.8 | – |
| May 26 – June 1 | – | 7.1 | – | – | – | – | 18.2 | – |
| June 2 – June 8 | – | 2.8 | – | – | – | – | 12.2 | – |

*Week of sampling

## Table 20

### High and Low Stream Discharge Estimates Preceding Sampling – June 1972

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge<br>Station 10 | 185.6 | May<br>12 | 63.9 | May<br>19 | 24.3 | May<br>26 | 14.6 | June<br>2 |
| Low Daily Discharge<br>Station 10 | 75.7 | May<br>18 | 27.8 | May<br>25 | 14.5 | June<br>1 | 10.5 | June<br>8 |

## Table 21

Water Chemistry and Stream Discharge Estimates – July 1972

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2a | 3 | 3a | 4R | | 4L |
| Total Alkalinity (ppm) | 20 | 19 | 0 | 14 | 0 | – | 20 |
| Total Acidity | | | | | | | |
| (Cold) | 2 | 2 | 58 | 4 | 16 | – | 4 |
| (Hot) | 6 | 6 | 78 | 10 | 16 | – | 10 |
| Total Hardness | 47.76 | 37.83 | 111.62 | 77.72 | 55.81 | – | 39.88 |
| Calcium | 28.76 | 27.80 | 53.75 | 43.82 | 35.95 | – | 27.90 |
| Fe | 0 | 0 | 1 | 0 | .5 | – | 0 |
| $SO_4$ | 13.64 | 15.54 | 140.7 | 42.81 | 49.66 | – | 16.30 |
| pH | 7.0 | 7.0 | 3.4 | 6.9 | 4.8 | – | 6.8 |

## Table 21
(Continued)

|  | Station Number |  |  |  |  |
|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 9 | 10 |
|  | Estimated Q (cfs) |  |  |  |  |
| *June 16 – June 22 | – | – | 248.4 | – | 330.9 |
| June 23 – June 29 | – | – | 1352.8 | – | 1858.6 |
| June 30 – July 6 | – | – | 233.8 | – | 332.9 |
| July 7 – July 13 | – | – | 89.5 | – | 137.7 |

*Week of sampling

## Table 21
(Continued)

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 5 | 6 | 7 | 9 | 10 |
| Total Alkalinity (ppm) | 7 | 16 | 8 | 10 | 10 |
| Total Acidity | | | | | |
| (Cold) | 6 | 4 | 6 | 4 | 4 |
| (Hot) | 8 | 8 | 10 | 6 | 8 |
| Total Hardness | 53.75 | 37.83 | 51.87 | 21.91 | 41.77 |
| Calcium | 33.89 | 25.85 | 31.84 | 17.80 | 29.78 |
| Fe | .25 | 0 | .25 | 0 | 0 |
| $SO_4$ | 40.52 | 9.60 | 34.13 | 8.84 | 29.86 |
| pH | 5.9 | 7.0 | 7.0 | 7.0 | 6.8 |

Table 21
(Continued)

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 1 | 2a | 3 | 3a | 4R |  | 4L |
|  |  |  | Estimated Q (cfs) |  |  |  |  |
| *June 16 – June 22 | – | – | 68.8 | – | – | 202.5 | – |
| June 23 – June 29 | – | – | 315.5 | – | – | 1087.5 | – |
| June 30 – July 6 | – | – | 63.2 | – | – | 190.5 | – |
| July 7 – July 13 | – | – | 19.9 | – | – | 72.5 | – |

*Week of sampling

## Table 22

High and Low Stream Discharge Estimates Preceding Sampling — July 1972

| | | Date | | Date | | Date | | Date |
|---|---|---|---|---|---|---|---|---|
| High Daily Discharge Station 10 | 1014.3 | June 22 | 4541.0 | June 23 | 430.4 | June 30 | 199.9 | July 7 |
| Low Daily Discharge Station 10 | 100.75 | June 20 | 516.8 | June 29 | 270.6 | July 6 | 76.4 | July 13 |

## Table 23

### Water Chemistry Analysis — October 1972

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4R | 4L |
| Total Alkalinity (ppm) | 32 | 12 | 22 | 0 | 22 | 22 | 2 |
| Total Acidity (Cold) | 2 | 2 | 6 | 182 | 2 | 2 | 16 |
| $SO_4$ (ppm) | 18 | 18 | 28 | 321 | 59 | 25 | 67 |
| pH | 7.0 | 6.4 | 6.8 | 3.4 | 7.0 | 6.9 | 5.0 |
| Zn (ppm) | .1 | — | — | .3 | .05 | — | .11 |

## Table 23
(Continued)

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8a | 9 | 10 |
| Total Alkalinity (ppm) | 10 | 30 | 26 | 2 | 24 | 16 |
| Total Acidity (Cold) | 2 | 2 | 2 | 10 | 2 | 4 |
| $SO_4$ (ppm) | 28 | 12 | 55 | 67 | 8.6 | 43.2 |
| pH | 6.2 | 7.2 | 7.1 | 5.1 | 7.2 | 6.8 |
| Zn (ppm) | .05 | — | — | — | — | — |

## Table 24

Estimated Q (cfs)

| | Station Number | | | |
|---|---|---|---|---|
| | 3 | 4 | 7 | 10 |
| Sept. 22 – 28 | 2.94 | 3.97 | 5.02 | 11.73 |
| High Daily Discharge September 26 | – | – | – | 21.26 |
| Low Daily Discharge September 28 | – | – | – | 7.7 |

## Table 25

Water Quality Analyses Performed by the Pennsylvania Department of Mines and Mineral Industries*
Indian Creek, Pennsylvania

| mg/l | Above Champion Run (Station 2a) | Champion Run (Station 2) | Below Champion Run (Station 4) | Indian Creek into reservoir (Station 10a) |
|---|---|---|---|---|
| Acidity | 1 | 92 | 1 | 2 |
| Alkalinity | 32 | 0 | 48 | 44 |
| Iron | 0.7 | 12.0 | 1.8 | 0.6 |
| $SO_4$ | .8 | 133 | 41 | 34 |
| pH | 7.2 | 3.2 | 6.3 | 6.9 |

*Pennsylvania Department of Mines and Minerals Industries (1969)

## Table 26

Indian Creek Biological Data Summary — October 1970

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 2a | 3 | 4 | 5 | 10 |
| Number of Organisms | 658 | 186 | 57 | 61 | 518 |
| Number of Taxa | 24 | 2 | 8 | 10 | 24 |
| $\bar{d}$ | 2.51 | .04 | 1.31 | 1.94 | 2.98 |
| $\bar{d}$ redundancy | .46 | .99 | .69 | .48 | .35 |
| H | 2.43 | .04 | 1.10 | 1.67 | 2.88 |
| H redundancy | .49 | .99 | .79 | .61 | .38 |
| Density Organisms/ft$^2$ | 30 | – | 11 | 7 | 33 |

## Table 27

Indian Creek Biological Data Summary – May 1971

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Number of Organisms | 1663 | 1084 | 15 | 625 | 175 |
| Number of Taxa | 46 | 40 | 10 | 27 | 23 |
| $\bar{d}$ | 3.55 | 3.23 | 2.99 | 2.70 | 3.01 |
| $\bar{d}$ redundancy | .36 | .40 | – | .45 | .35 |
| H | 3.48 | 3.15 | 2.15 | 2.60 | 2.78 |
| H redundancy | .37 | .42 | .74 | .47 | .43 |
| Density Organisms/$ft^2$ | 226 | 105 | – | 33 | 11 |

Table 27
(Continued)

|  | Station Number |  |  |  |  |
|---|---|---|---|---|---|
|  | 6 | 7 | 8 | 9 | 10 |
| Number of Organisms | 690 | 451 | 196 | 1143 | 698 |
| Number of Taxa | 45 | 28 | 22 | 42 | 38 |
| $\bar{d}$ | 4.01 | 3.05 | 2.94 | 3.71 | 3.34 |
| $\bar{d}$ redundancy | .27 | .38 | .36 | .31 | .37 |
| H | 3.86 | 2.91 | 2.71 | 3.62 | 3.22 |
| H redundancy | .30 | .41 | .43 | .33 | .40 |
| Density Organisms/ft$^2$ | 111 | 60 | 13 | 111 | 38 |

## Table 28

Indian Creek Biological Data Summary — June 1971

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 3 | 4 | 5 | 6 |
| Number of Organisms | 578 | 5 | 315 | 266 | 1024 |
| Number of Taxa | 36 | 5 | 27 | 21 | 43 |
| $\bar{d}$ | 4.07 | 2.32 | 3.20 | 3.65 | 3.87 |
| $\bar{d}$ redundancy | .20 | — | .34 | .14 | .28 |
| H | 3.91 | 1.38 | 3.02 | 3.46 | 3.76 |
| H redundancy | .23 | — | .38 | .19 | .31 |
| Density Organisms/$ft^2$ | 76 | — | 18 | 46 | 123 |

## Table 28
(Continued)

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 7 | 8 | 8b | 9 | 10 |
| Number of Organisms | 310 | 126 | 87 | 981 | 412 |
| Number of Taxa | 22 | 18 | 10 | 36 | 34 |
| $\bar{d}$ | 3.19 | 3.19 | 2.34 | 3.56 | 3.49 |
| $\bar{d}$ redundancy | .28 | .21 | .29 | .31 | .32 |
| H | 3.03 | 2.91 | 2.12 | 3.46 | 3.31 |
| H redundancy | .32 | .31 | .38 | .33 | .36 |
| Density Organisms/ft$^2$ | 34 | 20 | – | 165 | 38 |

## Table 29

Indian Creek Biological Data Summary — July 1971

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4 | 5 |
| Number of Organisms | 2174 | 623 | 703 | 4 | 41 | 114 |
| Number of Taxa | 46 | 34 | 32 | 2 | 14 | 18 |
| $\bar{d}$ | 3.62 | 3.43 | 3.79 | .81 | 3.34 | 3.16 |
| $\bar{d}$ redundancy | .34 | .33 | .23 | 1 | - .09 | .22 |
| H | 3.56 | 3.31 | 3.67 | .5 | 2.77 | 2.85 |
| H redundancy | .36 | .36 | .26 | - .76 | .26 | .33 |
| Density Organisms/$ft^2$ | 406 | 75 | 110 | — | 5 | 14 |

## Table 29
(Continued)

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 6 | 7 | 8 | 8b | 9 | 10 | 10a |
| Number of Organisms | 1396 | 935 | 621 | 567 | 1182 | 1010 | 574 |
| Number of Taxa | 42 | 31 | 28 | 28 | 36 | 28 | 22 |
| $\bar{d}$ | 3.75 | 2.97 | 3.36 | 3.02 | 3.61 | 2.76 | 2.62 |
| $\bar{d}$ redundancy | .30 | .41 | .30 | .38 | .30 | .43 | .42 |
| H | 3.67 | 2.89 | 3.24 | 2.91 | 3.53 | 2.69 | 2.53 |
| H redundancy | .32 | .43 | .33 | .40 | .32 | .45 | .44 |
| Density Organisms/ft$^2$ | 166 | 138 | 79 | — | 150 | 120 | — |

## Table 30

### Indian Creek Biological Data Summary — August 1971

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4 | 5 |
| Number of Organisms | 2378 | 242 | 712 | 30 | 420 | 697 |
| Number of Taxa | 44 | 33 | 31 | 12 | 30 | 22 |
| $\bar{d}$ | 3.20 | 3.74 | 3.37 | 2.95 | 2.42 | 1.87 |
| $\bar{d}$ redundancy | .41 | .25 | .32 | -.03 | .55 | .60 |
| H | 3.16 | 3.47 | 3.26 | 2.36 | 2.29 | 1.80 |
| H redundancy | .42 | .33 | .35 | .45 | .58 | .62 |
| Density Organisms/ft$^2$ | 392 | 35 | 122 | — | 28 | 128 |

## Table 30
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 8a | 9 | 10 | 10a |
| Number of Organisms | 718 | 1244 | 609 | 1338 | 1079 | 1701 | 213 |
| Number of Taxa | 35 | 33 | 32 | 22 | 38 | 40 | 16 |
| $\bar{d}$ | 3.78 | 2.69 | 3.35 | 2.57 | 3.41 | 2.72 | 2.87 |
| $\bar{d}$ | .26 | .48 | .33 | .42 | .35 | .50 | .27 |
| H | 3.65 | 2.63 | 3.23 | 2.52 | 3.32 | 2.66 | 2.71 |
| H redundancy | .29 | .49 | .36 | .44 | .37 | .51 | .33 |
| Density Organisms/ft$^2$ | 113 | 210 | 27 | – | 141 | 205 | – |

## Table 31

Indian Creek Biological Data Summary – September 1971

| | Station Number | | | |
|---|---|---|---|---|
| | 2a | 3 | 8 | 10 |
| Number of Organisms | 340 | 171 | 535 | 616 |
| Number of Taxa | 23 | 16 | 25 | 23 |
| $\bar{d}$ | 3.21 | 2.24 | 2.37 | 2.48 |
| $\bar{d}$ redundancy | .29 | .48 | .51 | .46 |
| H | 3.06 | 2.06 | 2.28 | 2.40 |
| H redundancy | .33 | .54 | .54 | .48 |

## Table 32

### Indian Creek Biological Data Summary — October 1971

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4 | 5 |
| Number of Organisms | 2346 | 993 | 403 | 8 | 573 | 125 | 163 |
| Number of Taxa | 42 | 28 | 24 | 5 | 21 | 23 | 21 |
| $\bar{d}$ | 3.41 | 2.57 | 3.23 | 2.15 | 2.58 | 3.44 | 2.99 |
| $\bar{d}$ redundancy | .37 | .47 | .29 | -1.76 | .42 | .22 | .33 |
| H | 3.36 | 2.50 | 3.09 | 1.46 | 2.50 | 3.11 | 2.76 |
| H redundancy | .38 | .49 | .33 | .57 | .44 | .33 | .40 |
| Density Organisms/ft$^2$ | 318 | 70 | — | — | — | 5 | 9 |

### Table 32
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 8b | 8a | 9 | 10 |
| Number of Organisms | 229 | 40 | 82 | 15 | 86 | 826 | 138 |
| Number of Taxa | 30 | 11 | 15 | 5 | 12 | 36 | 28 |
| $\bar{d}$ | 3.96 | 2.93 | 2.97 | 1.73 | 2.24 | 3.81 | 3.77 |
| $\bar{d}$ redundancy | .16 | .005 | .21 | .11 | .30 | .26 | .18 |
| H | 3.68 | 2.46 | 2.64 | 1.31 | 2.49 | 3.69 | 3.40 |
| H redundancy | .24 | .28 | .35 | .61 | .41 | .28 | .31 |
| Density Organisms/ft$^2$ | 34 | 4 | — | — | — | 53 | 2 |

## Table 33

### Indian Creek Biological Data Summary — December 1971

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 1 | 3 | 4 | 7 | 8b | 10 |
| Number of Organisms | 306 | 10 | 24 | 59 | 10 | 58 |
| Number of Taxa | 29 | 6 | 10 | 11 | 9 | 23 |
| $\bar{d}$ | 3.86 | 2.16 | 2.63 | 2.44 | 3.12 | 4.01 |
| $\bar{d}$ redundancy | .20 | -.77 | .02 | .29 | -7 | -.12 |
| H | 3.59 | 1.48 | 2.05 | 2.13 | 2.07 | 3.35 |
| H redundancy | .25 | 1.00 | .58 | .44 | 1.00 | .26 |

## Table 34

### Indian Creek Biological Data Summary — March 1972

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 3 | 3a | 4 | 5 |
| Number of Organisms | 514 | 1 | 235 | 132 | 70 |
| Number of Taxa | 28 | 1 | 21 | 24 | 13 |
| $\bar{d}$ | 3.64 | 0.00 | 2.75 | 3.32 | 1.94 |
| $\bar{d}$ redundancy | .23 | — | .39 | .28 | .59 |
| H | 3.50 | 0.00 | 2.58 | 2.99 | 1.66 |
| H redundancy | .27 | — | .44 | .39 | .72 |

## Table 34
(Continued)

| | Station Number | | | |
|---|---|---|---|---|
| | 6 | 7 | 9 | 10 |
| Number of Organisms | 71 | 60 | 276 | 83 |
| Number of Taxa | 10 | 13 | 23 | 22 |
| $\bar{d}$ | 2.52 | 2.56 | 3.24 | 3.40 |
| $\bar{d}$ redundancy | .32 | .32 | .33 | .21 |
| H | 2.26 | 2.20 | 3.05 | 2.96 |
| H redundancy | .21 | .49 | .28 | .40 |

## Table 35

### Indian Creek Biological Data Summary – May 1972

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a |
| Number of Organisms | 693 | 258 | 528 | 5 | 220 |
| Number of Taxa | 34 | 20 | 14 | 5 | 15 |
| $\bar{d}$ | 3.17 | 2.44 | 1.56 | 2.32 | 2.51 |
| $\bar{d}$ redundancy | .39 | .47 | .61 | – | .37 |
| H | 3.05 | 2.27 | 1.49 | 1.38 | 2.36 |
| H redundancy | .41 | .51 | .63 | – | .41 |
| Density Organisms/ft$^2$ | 55 | – | – | – | – |

## Table 35
(Continued)

| | Station Number | | | |
|---|---|---|---|---|
| | 5 | 6 | 7 | 10 |
| Number of Organisms | 15 | 482 | 85 | 246 |
| Number of Taxa | 9 | 26 | 14 | 29 |
| $\bar{d}$ | 2.97 | 2.60 | 2.63 | 3.53 |
| $\bar{d}$ redundancy | - 1.1 | .47 | .32 | .27 |
| H | 2.17 | 2.49 | 2.33 | 3.29 |
| H redundancy | .38 | .50 | .44 | .34 |
| Density Organisms/ft$^2$ | — | — | 11 | 2 |

## Table 36

### Indian Creek Biological Data Summary — June 1972

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 1 | 2 | 2a | 3 | 3a | 4 |
| Number of Organisms | 1575 | 572 | 1171 | 11 | 370 | 283 |
| Number of Taxa | 37 | 25 | 27 | 3 | 21 | 25 |
| $\bar{d}$ | 2.97 | 2.74 | 2.06 | 1.09 | 2.18 | 2.70 |
| $\bar{d}$ redundancy | .44 | .42 | .58 | .23 | .53 | .45 |
| H | 2.90 | 2.64 | 2.01 | .81 | 2.06 | 2.52 |
| H redundancy | .45 | .44 | .59 | .68 | .57 | .50 |
| Density Organisms/ft$^2$ | 161 | — | — | — | — | 13 |

## Table 36
(Continued)

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 8a | 9 | 10 |
| Number of Organisms | 41 | 930 | 323 | 24 | 80 | 951 | 341 |
| Number of Taxa | 13 | 37 | 20 | 9 | 10 | 37 | 29 |
| $\bar{d}$ | 2.78 | 3.30 | 1.83 | 2.19 | 2.29 | 3.63 | 2.86 |
| $\bar{d}$ redundancy | .20 | .37 | .63 | .32 | .31 | .30 | .44 |
| H | 2.29 | 3.20 | 1.71 | 1.69 | 2.06 | 3.52 | 2.69 |
| H redundancy | .50 | .39 | .66 | .77 | .41 | .32 | .48 |
| Density Organisms/ft$^2$ | 1 | 138 | 44 | 3 | – | 65 | 45 |

## Table 37

Indian Creek Biological Data Summary – July 1972

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2a | 3 | 3a | 4 |
| Number of Organisms | 238 | 87 | 4 | 279 | 192 |
| Number of Taxa | 26 | 14 | 4 | 21 | 24 |
| $\bar{d}$ | 3.58 | 2.78 | 2.00 | 2.76 | 3.21 |
| $\bar{d}$ redundancy | .22 | .26 | – | .39 | .30 |
| H | 3.35 | 2.44 | 1.14 | 2.62 | 2.97 |
| H redundancy | .29 | .38 | – | .43 | .38 |

## Table 37
(Continued)

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 5 | 6 | 7 | 9 | 10 |
| Number of Organisms | 19 | 84 | 35 | 197 | 25 |
| Number of Taxa | 12 | 14 | 8 | 29 | 12 |
| $\bar{d}$ | 3.43 | 3.10 | 2.36 | 3.89 | 3.07 |
| $\bar{d}$ redundancy | - 1.3 | .13 | .12 | .19 | - .24 |
| H | 2.55 | 2.78 | 1.99 | 3.53 | 2.38 |
| H redundancy | .30 | .26 | .36 | .27 | .48 |

## Table 38

Indian Creek Biological Data Summary — October 1972

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 1 | 2 | 2a | 3 | 3a | 4 |
| Number of Organisms | 2445 | 1010 | 1251 | 136 | 1195 | 245 |
| Number of Taxa | 40 | 24 | 26 | 6 | 26 | 24 |
| $\bar{d}$ | 3.07 | 2.31 | 2.34 | 1.24 | 2.10 | 2.33 |
| $\bar{d}$ redundancy | .43 | .51 | .51 | .55 | .57 | .55 |
| H | 3.02 | 2.25 | 2.29 | 1.17 | 2.05 | 2.17 |
| H redundancy | .43 | .52 | .52 | .58 | .58 | 59 |
| Density Organism/ft$^2$ | 236 | — | — | — | — | 4 |

## Table 38
(Continued)

|  | Station Number |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | 5 | 6 | 7 | 8a | 9 | 10 |
| Number of Organisms | 116 | 1310 | 792 | 297 | 882 | 1008 |
| Number of Taxa | 15 | 31 | 30 | 22 | 34 | 31 |
| $\bar{d}$ | 2.50 | 2.81 | 2.26 | 2.90 | 3.65 | 3.06 |
| $\bar{d}$ redundancy | 39 | .44 | 56 | .36 | 2.8 | 39 |
| H | 2.26 | .275 | 2.18 | 2.73 | 3.55 | 2.99 |
| H redundancy | .47 | .45 | .58 | .41 | .30 | .40 |
| Density Organisms/ft$^2$ | 9 | — | 72 | — | — | 175 |

## Table 39

### Correlation Matrix of Stations Collected October 1970

### Indian Creek, Pennsylvania

| Station Number | Station Number | | | |
|---|---|---|---|---|
| | 2a | 3 | 4 | 5 |
| 3 | -.00 | – | – | – |
| 4 | .84 | .13 | – | – |
| 5 | .81 | .14 | .98 | – |
| 10 | .93 | .14 | .85 | .83 |

## Table 40

Correlation Matrix — May 1971

| Station Number | Station Number<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 2 | .82 | — | — | — | — | — | — | — | — |
| 3 | .22 | .22 | — | — | — | — | — | — | — |
| 4 | .77 | .96 | .23 | — | — | — | — | — | — |
| 5 | .59 | .82 | .41 | .79 | — | — | — | — | — |
| 6 | .46 | .46 | .09 | .37 | .31 | — | — | — | — |
| 7 | .88 | .76 | .21 | .70 | .50 | .66 | — | — | — |
| 8 | .27 | .37 | .27 | .23 | .67 | .27 | .26 | — | — |
| 9 | .49 | .62 | .12 | .57 | .53 | .89 | .66 | .41 | — |
| 10 | .62 | .65 | .23 | .48 | .72 | .53 | .67 | .85 | .62 |

## Table 41

### Correlation Matrix — June 1971

| Station Number | Station Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 3 | 4 | 5 | 6 | 7 | 8 | 8a | 9 |
| 3 | .16 | — | — | — | — | — | — | — | — |
| 4 | .38 | .02 | — | — | — | — | — | — | — |
| 5 | .85 | .06 | .43 | — | — | — | — | — | — |
| 6 | .61 | -.03 | .41 | .55 | — | — | — | — | — |
| 7 | .67 | .05 | .34 | .73 | .54 | — | — | — | — |
| 8 | .59 | .09 | .39 | .61 | .55 | .87 | — | — | — |
| 8a | .20 | -.01 | .31 | .27 | .16 | .05 | .23 | — | — |
| 9 | .66 | .08 | .29 | .55 | .68 | .87 | .85 | .11 | — |
| 10 | .51 | -.03 | .46 | .58 | .48 | .45 | .60 | .83 | .50 |

## Table 42

Correlation Matrix -- July 1971

| Station Number | Station Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 8b | 9 | 10 |
| 2 | .92 | — | — | — | — | — | — | — | — | — | — | — |
| 2a | .82 | .82 | — | — | — | — | — | — | — | — | — | — |
| 3 | .68 | .74 | .39 | — | — | — | — | — | — | — | — | — |
| 4 | .63 | .66 | .53 | .61 | — | — | — | — | — | — | — | — |
| 5 | .75 | .79 | .50 | .87 | .66 | — | — | — | — | — | — | — |
| 6 | .43 | .41 | .52 | .16 | .42 | .24 | — | — | — | — | — | — |
| 7 | .75 | .87 | .66 | .77 | .72 | .82 | .55 | — | — | — | — | — |
| 8 | .71 | .79 | .50 | .88 | .66 | .88 | .31 | .86 | — | — | — | — |
| 8a | .34 | .42 | .51 | .03 | .37 | .22 | .47 | .52 | .27 | — | — | — |
| 9 | .62 | .66 | .67 | .39 | .65 | .50 | .90 | .80 | .57 | .64 | — | — |
| 10 | .44 | .55 | .60 | .16 | .43 | .30 | .55 | .68 | .40 | .90 | .76 | — |
| 11 | .51 | .53 | .59 | .03 | .35 | .21 | .47 | .48 | .26 | .80 | .65 | .88 |

## Table 43

### Correlation Matrix – August 1971

| Station Number | Station Number | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 4 | 5 | 6 | 7 | 8 | 8a | 9 | 10 |
| 2 | .87 | – | – | – | – | – | – | – | – | – | – | – |
| 2a | .85 | .89 | – | – | – | – | – | – | – | – | – | – |
| 3 | .34 | .27 | .28 | – | – | – | – | – | – | – | – | – |
| 4 | .47 | .30 | .32 | .41 | – | – | – | – | – | – | – | – |
| 5 | .48 | .30 | .32 | .41 | .99 | – | – | – | – | – | – | – |
| 6 | .65 | .55 | .58 | .28 | .53 | .54 | – | – | – | – | – | – |
| 7 | .87 | .76 | .81 | .43 | .76 | .76 | .64 | – | – | – | – | – |
| 8 | .42 | .31 | .31 | .31 | .72 | .72 | .48 | .61 | – | – | – | – |
| 8a | .53 | .31 | .23 | .39 | .82 | .85 | .65 | .63 | .64 | – | – | – |
| 9 | .81 | .68 | .70 | .41 | .81 | .81 | .82 | .92 | .65 | .76 | – | – |
| 10 | .90 | .84 | .85 | .39 | .63 | .64 | .61 | .96 | .53 | .57 | .88 | – |
| 11 | .48 | .49 | .30 | .26 | .69 | .69 | .48 | .55 | .54 | .64 | .62 | .48 |

## Table 44

Correlation Matrix — September 1971

| Station Number | Station Number | | |
|---|---|---|---|
| | 2a | 3 | 8 |
| 3 | .72 | — | — |
| 8 | .89 | .88 | — |
| 10 | .79 | .89 | .81 |

## Table 45

### Correlation Matrix — October 1971

| Station Number | Station Number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4 | 5 | 6 | 7 | 8 | 8a | 9 | 10 |
| 2 | .53 | — | — | — | — | — | — | — | — | — | — | — | — |
| 2a | .94 | .63 | — | — | — | — | — | — | — | — | — | — | — |
| 3 | .55 | .15 | .52 | — | — | — | — | — | — | — | — | — | — |
| 3a | .71 | .71 | .59 | .30 | — | — | — | — | — | — | — | — | — |
| 4 | .53 | .63 | .44 | .18 | .71 | — | — | — | — | — | — | — | — |
| 5 | .84 | .33 | .71 | .52 | .70 | .52 | — | — | — | — | — | — | — |
| 6 | .91 | .47 | .86 | .51 | .65 | .49 | .81 | — | — | — | — | — | — |
| 7 | .74 | .53 | .58 | .35 | .87 | .70 | .83 | .73 | — | — | — | — | — |
| 8 | .76 | .48 | .61 | .38 | .80 | .73 | .86 | .72 | .93 | — | — | — | — |
| 8a | .49 | .22 | .39 | .26 | .53 | .24 | .39 | .51 | .37 | .26 | — | — | — |
| 9 | .67 | .37 | .57 | .35 | .65 | .49 | .64 | .78 | .66 | .63 | .52 | — | — |
| 10 | .82 | .58 | .70 | .42 | .85 | .72 | .85 | .78 | .91 | .94 | .38 | .67 | — |
| 11 | .59 | .42 | .38 | .27 | .85 | .70 | .76 | .56 | .90 | .90 | .38 | .61 | .86 |

## Table 46

### Correlation Matrix – December 1971

| Station Number | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 3 | 4 | 7 | 8b |
| 3 | .50 | – | – | – | – |
| 4 | .14 | .23 | – | – | – |
| 7 | .11 | .18 | .04 | – | – |
| 8b | .44 | .12 | .10 | .29 | – |
| 10 | .43 | .72 | .21 | .23 | .37 |

## Table 47

Correlation Matrix – March 1972

| Station Number | Station Number |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | 1 | 3 | 3a | 4 | 5 | 6 | 7 | 9 |
| 3 | .38 | – | – | – | – | – | – | – |
| 3a | .68 | .89 | – | – | – | – | – | – |
| 4 | .76 | .19 | .46 | – | – | – | – | – |
| 5 | .63 | -.01 | .28 | .92 | – | – | – | – |
| 6 | .61 | .64 | .62 | .50 | .32 | – | – | – |
| 7 | .46 | .01 | .15 | .48 | .41 | .74 | – | – |
| 9 | .42 | .22 | .26 | .35 | .21 | .82 | .90 | – |
| 10 | .84 | .26 | .54 | .87 | .82 | .68 | .62 | .56 |

## Table 48

### Correlation Matrix — May 1972

| Station Number | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 5 | 6 | 7 |
| 2 | .95 | — | — | — | — | — | — | — |
| 2a | .92 | .97 | — | — | — | — | — | — |
| 3 | .19 | .03 | .02 | — | — | — | — | — |
| 3a | .26 | .04 | .02 | .55 | — | — | — | — |
| 5 | .69 | .70 | .69 | .11 | .29 | — | — | — |
| 6 | .88 | .90 | .92 | .21 | .12 | .68 | — | — |
| 7 | .44 | .30 | .32 | .44 | .86 | .52 | .43 | — |
| 10 | .75 | .72 | .71 | .38 | .17 | .52 | .88 | .38 |

## Table 49

Correlation Matrix — June 1972

| Station Number | 1 | 2 | 2a | 3 | 3a | 4 | 5 | 6 | 7 | 8 | 8a | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | .64 | — | — | — | — | — | — | — | — | — | — | — |
| 2a | .80 | .88 | — | — | — | — | — | — | — | — | — | — |
| 3 | .75 | .15 | .27 | — | — | — | — | — | — | — — | — | |
| 3a | .08 | .00 | .02 | .02 | — | — | — | — | — | — — | — | |
| 4 | .72 | .88 | .98 | .15 | .03 | — | — | — | — | — — | — | |
| 5 | .19 | .12 | .11 | .08 | .05 | .16 | — | — | — | — — | — | |
| 6 | .87 | .52 | .66 | .73 | .47 | .58 | .15 | — | — | — — | — | |
| 7 | .86 | .27 | .42 | .96 | .02 | .30 | .13 | .77 | — | — — | — | |
| 8 | .80 | .20 | .33 | .96 | .02 | .22 | .15 | .74 | .97 | — — | — | |
| 8a | .01 | .00 | .00 | -.02 | .00 | .02 | .16 | -.00 | .01 | -0.1 | — | — |
| 9 | .33 | .31 | .32 | .38 | .40 | .29 | .13 | .64 | .27 | .30 | .00 | — |
| 10 | .21 | .18 | .16 | .40 | .03 | .13 | .20 | .48 | .25 | .32 | .05 | .87 |

## Table 50

Correlation Matrix — July 1972

| Station Number | Station Number<br>1 | <br>2a | <br>3 | <br>3a | <br>4 | <br>5 | <br>6 | <br>7 | <br>9 |
|---|---|---|---|---|---|---|---|---|---|
| 2a | .80 | — | — | — | — | — | — | — | — |
| 3 | .28 | .37 | — | — | — | — | — | — | — |
| 3a | .30 | .39 | .22 | — | — | — | — | — | — |
| 4 | .60 | .73 | .63 | .46 | — | — | — | — | — |
| 5 | .52 | .64 | .20 | .23 | .41 | — | — | — | — |
| 6 | .33 | .36 | .42 | .45 | .63 | .22 | — | — | — |
| 7 | .18 | .16 | .26 | .29 | .52 | .29 | .47 | — | — |
| 9 | .29 | .31 | .27 | .21 | .46 | .17 | .58 | .43 | — |
| 10 | .28 | .30 | .04 | .03 | .06 | .30 | .26 | .16 | .69 |

## Table 51

### Correlation Matrix — October 1972

| Station Number | Station Number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 3a | 4 | 5 | 6 | 7 | 8a | 9 |
| 2 | .92 | — | — | — | — | — | — | — | — | — | — |
| 2a | .94 | .99 | — | — | — | — | — | — | — | — | — |
| 3 | .00 | .00 | .00 | — | — | — | — | — | — | — | — |
| 3a | .79 | .69 | .72 | .00 | — | — | — | — | — | — | — |
| 4 | .59 | .70 | .70 | .15 | .74 | — | — | — | — | — | — |
| 5 | .48 | .56 | .57 | .17 | .74 | .96 | — | — | — | — | — |
| 6 | .55 | .63 | .63 | .06 | .74 | .89 | .93 | — | — | — | — |
| 7 | .61 | .63 | .65 | .06 | .89 | .94 | .95 | .90 | — | — | — |
| 8a | .64 | .54 | .57 | .04 | .90 | .64 | .72 | .81 | .81 | — | — |
| 9 | .35 | .43 | .43 | .10 | .57 | .76 | .82 | .90 | .76 | .69 | — |
| 10 | .05 | .03 | .03 | .57 | .06 | .14 | .22 | .14 | .09 | .18 | .20 |

Figure 1

Dendrogram of Stations Collected in October 1970

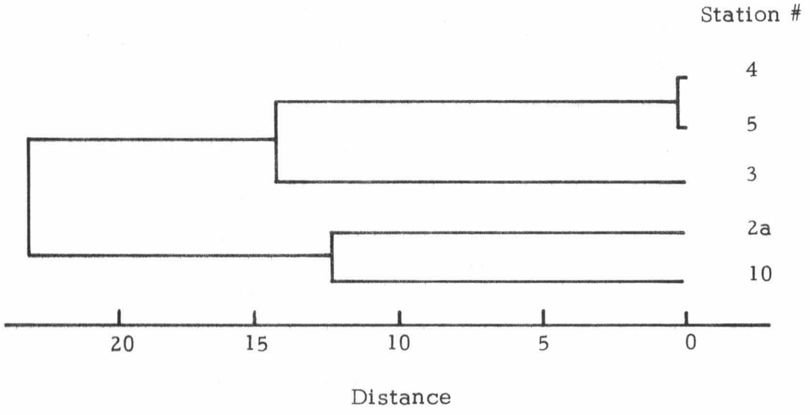


Figure 2

Dendrogram of Stations Collected in May 1971

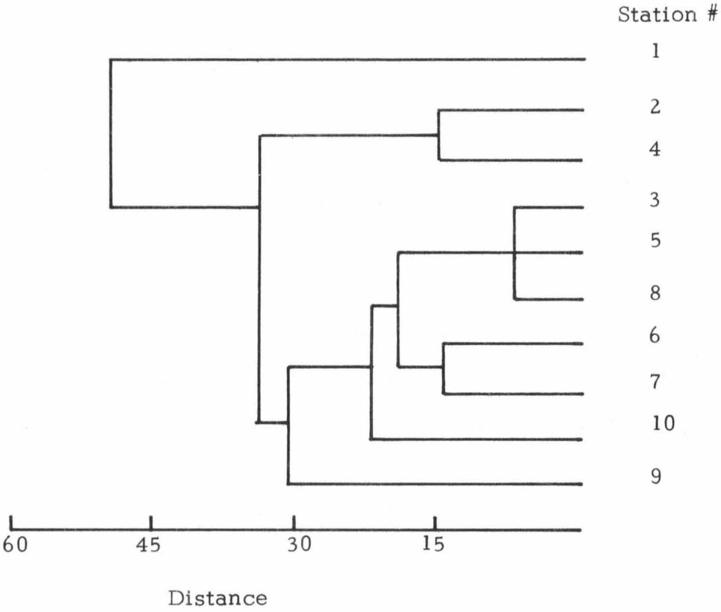
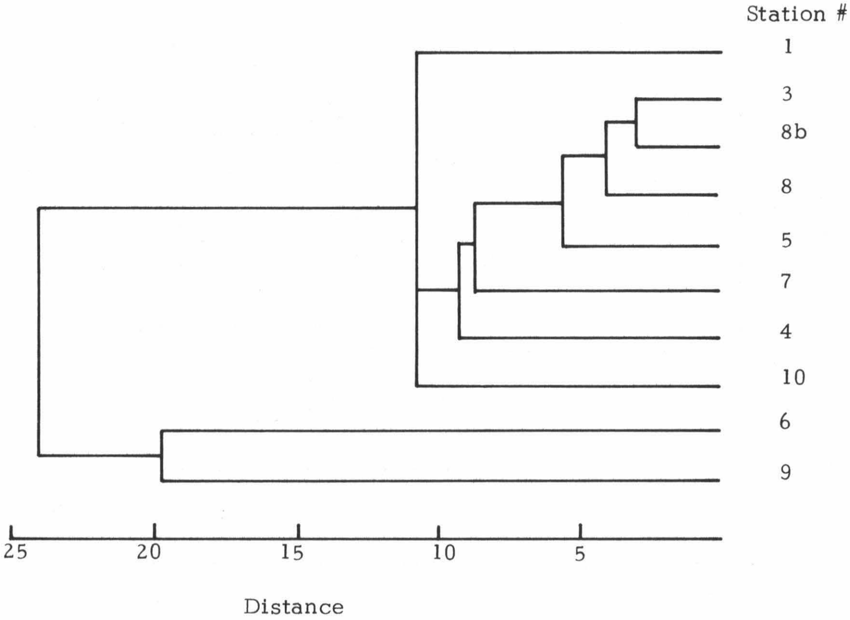


Figure 3

Dendrogram of Stations Collected in June 1971



## Figure 4

Dendrogram of Stations Collected in July 1971

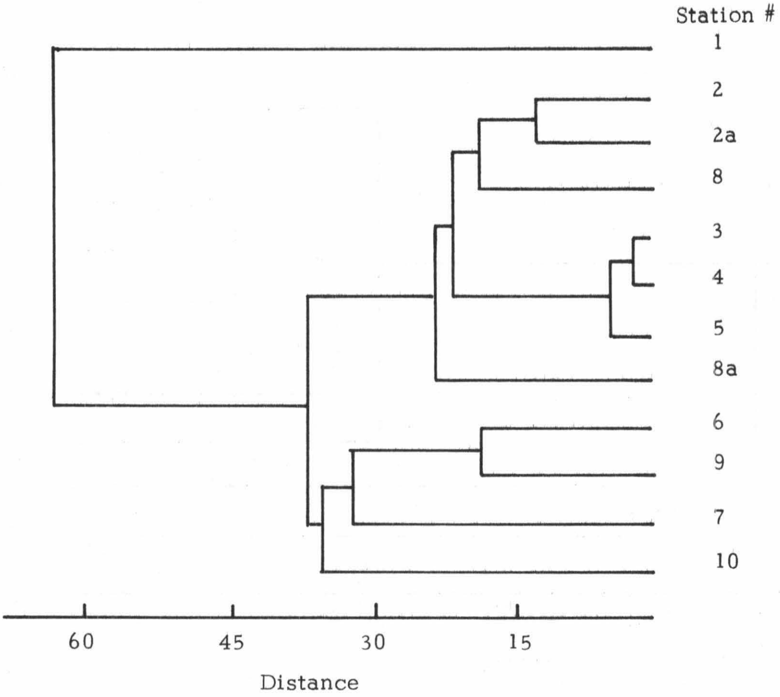
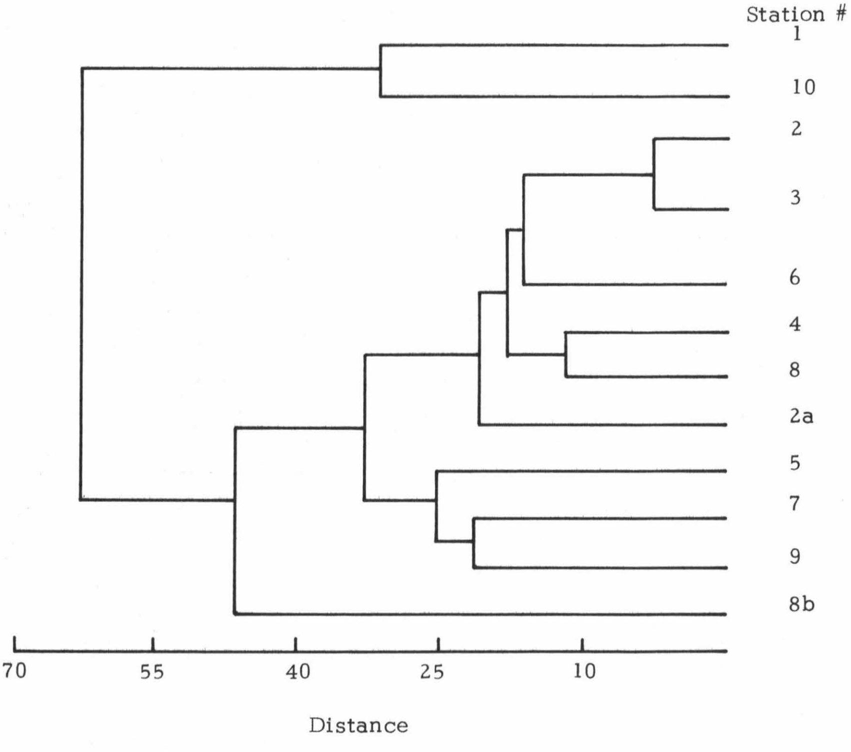


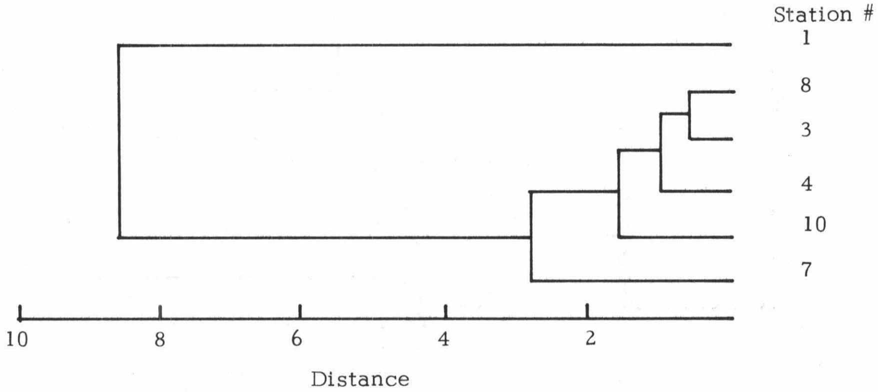
Figure 5

Dendrogram of Stations Collected in August 1971



## Figure 6

Dendrogram of Stations Collected in December 1971



## Figure 7

Dendrogram of Stations Collected in March 1972

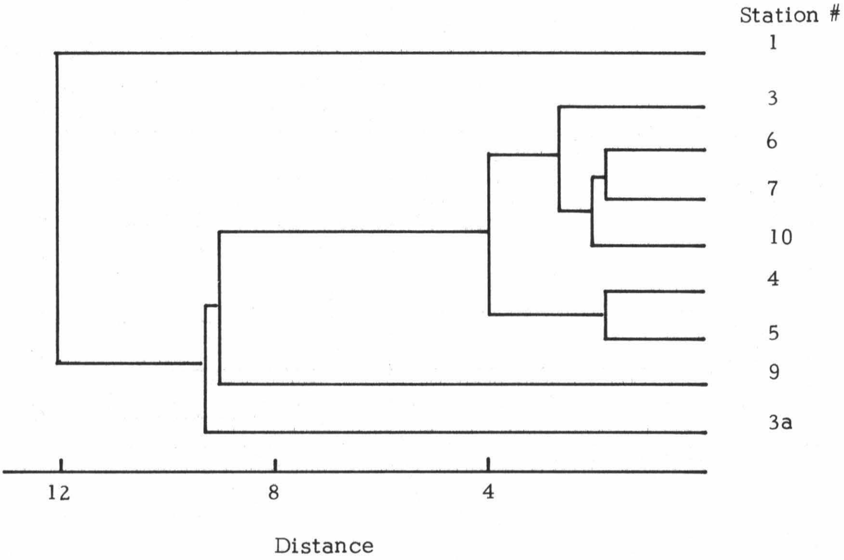


Figure 8

Dendrogram of Stations Collected in May 1972

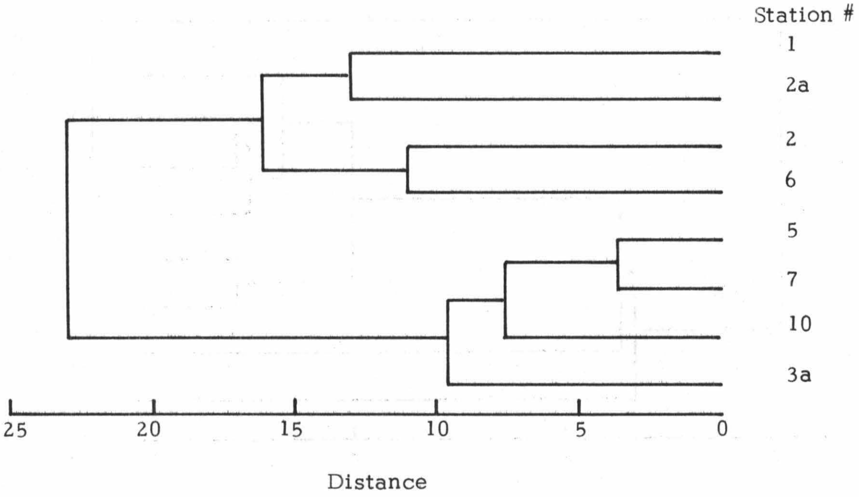


Figure 9

Dendrogram of Stations Collected in June 1972

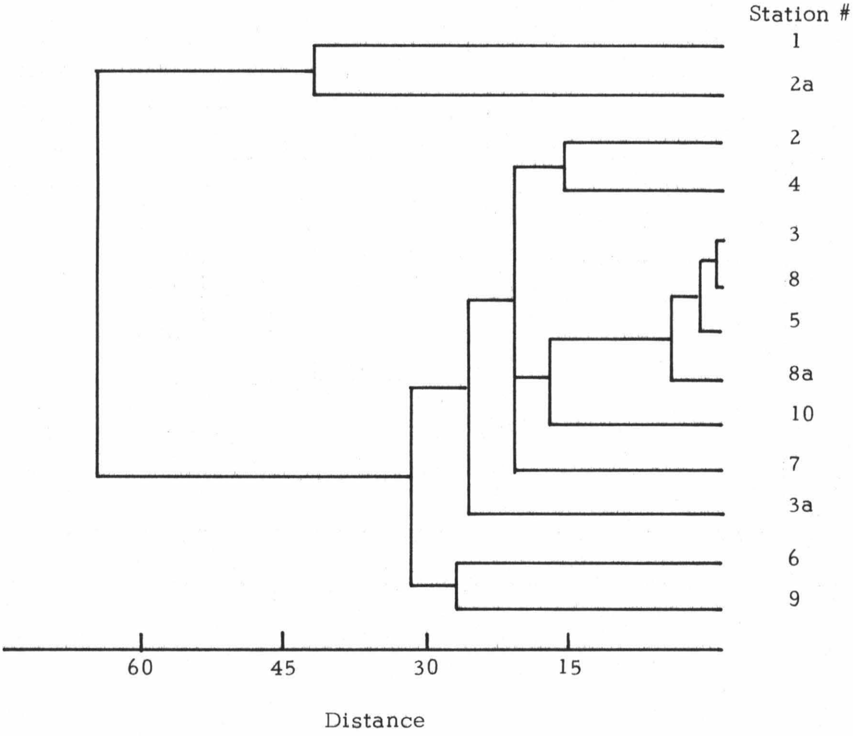
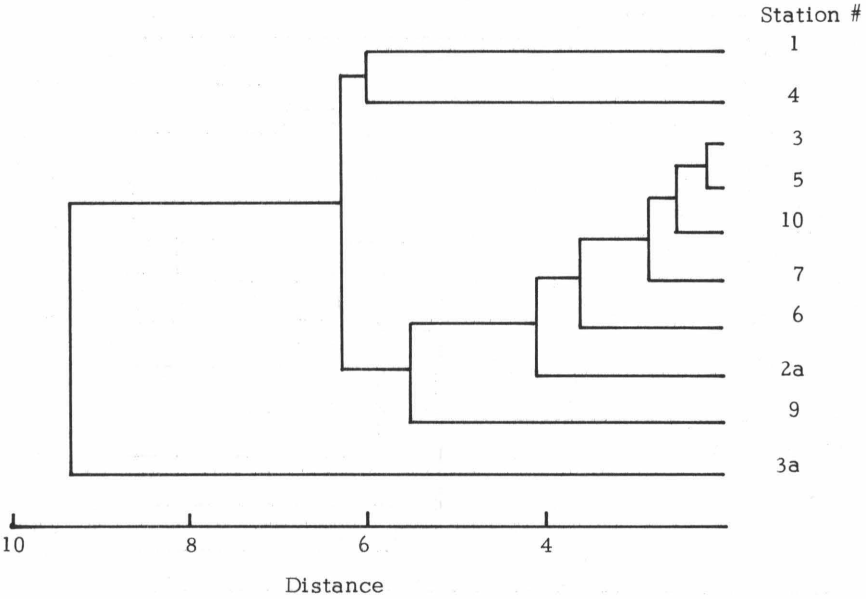


Figure 10

Dendrogram of Stations Collected in July 1972



# APPENDIX II-B

## Mill Creek Data

## Table 1

### Biological Data, Mill Creek Acid Stress Study

| | Before Acid | After Acid | Experimental Station 2 | 6 | 13 | 19 | 28 | 34 | 49 | 64 | 93 | 147 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Organisms | 372 | 215 | 217 | 267 | 419 | 616 | 843 | 667 | 625 | 822 | 541 | 578 |
| Number of Taxa | 43 | 30 | 27 | 32 | 39 | 34 | 36 | 31 | 30 | 35 | 26 | 23 |
| $\bar{d}$ | 3.91 | 4.24 | 2.79 | 3.73 | 4.04 | 3.63 | 3.08 | 3.30 | 3.02 | 3.26 | 2.87 | 3.06 |
| $\bar{d}$ Redundancy | 0.28 | 0.08 | 0.46 | 0.25 | 0.22 | 0.29 | 0.40 | 0.34 | 0.39 | 0.37 | 0.40 | 0.32 |
| Density | 74 | 43 | 43 | 53 | 83 | 103 | 168 | 133 | 125 | 164 | 108 | 115 |

# Table 2

Biological Data, Mill Creek Acid Stress Study

| | Before Acid | After Acid | Reference Station | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 6 | 13 | 19 | 28 | 34 | 49 | 64 | 93 | 147 |
| Number of Organisms | 384 | 241 | 1027 | 577 | 628 | 998 | 971 | 830 | 477 | 572 | 973 | 1243 |
| Number of Taxa | 37 | 31 | 38 | 37 | 34 | 36 | 36 | 35 | 25 | 27 | 25 | 30 |
| $\bar{d}$ | 3.82 | 3.78 | 4.08 | 3.87 | 4.27 | 3.87 | 3.26 | 3.52 | 2.69 | 2.70 | 3.17 | 3.28 |
| $\bar{d}$ Redundancy | 0.26 | 0.22 | 0.21 | 0.25 | 0.14 | 0.24 | 0.37 | 0.31 | 0.44 | 0.45 | 0.32 | 0.32 |
| Density | 76 | 48 | 205 | 115 | 105 | 199 | 194 | 166 | 95 | 114 | 194 | 258 |

## Table 3

Dominant Orders and Dominant Taxa — Mill Creek Acid Stress Study

| | | 8/20 | 8/20 | 8/22 | 8/26 | 9/3 | 9/9 | 9/18 | 9/24 | 10/9 | 11/6 | 12/4 | 1/23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Experimental Section | Order | C(62*) | C(34) | C(43) | C(35) | C(25) | C(35) | T(40) | E(32) | E(43) | C(34) | C(40) | T(41) |
| | | D(13) | E(32) | P(21) | D(19) | E(19) | E(22) | E(24) | E(31) | C(32) | T(31) | E(32) | C(26) |
| | | E(12) | T(15) | T(18) | E(19) | D(16) | T(15) | T(22) | C(28) | T(19) | C(24) | T(21) | E(18) |
| | Taxa | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 4 | 4 | 2 | 3 |
| Reference Section | Order | C(41) | C(41) | E(48) | E(40) | E(36) | E(39) | E(33) | E(46) | C(41) | C(50) | E(37) | T(44) |
| | | E(26) | E(23) | T(19) | C(30) | C(23) | C(27) | C(31) | C(24) | E(28) | E(23) | C(27) | E(22) |
| | | D(12) | T(13) | P(10) | T(15) | T(19) | T(17) | T(28) | T(20) | T(25) | T(21) | T(27) | C(21) |
| | Taxa | 2 | 2 | 5 | 5 | 5 | 4 | 4 | 4 | 2 | 2 | 4–5 | 6 |

*% of total collection

C — Coleoptera
D — Diptera
E — Ephemeroptera
P — Plecoptera
T — Trichoptera

1. *Rhizelmis sp*
2. *Cleptelmis sp*
3. *Hydropsyche sp*
4. *Ephemerella sp*
5. *Benetis sp*
6. *Glossosoma sp*

## Table 4

### Density and Diversity Values for Drift Study

| | Day | $\bar{d}$ | Density (organisms/ft$^2$) |
|---|---|---|---|
| Experimental | 4 | 2.52 | 110 |
| Section | 21 | 2.76 | 262 |
| Control | 4 | 2.92 | 159 |
| Section | 21 | 3.18 | 210 |

# APPENDIX II-C

## Little Scrubgrass Creek Data

Table 1

Little Scrubgrass Creek Water Chemistry – March 1949*

| | | Sampling Location Station Number | | | | | |
|---|---|---|---|---|---|---|---|
| | Mine Drainage | 1 | 3 | 6 | 8 | 9 | 10 |
| pH | 3.2 | 4.6 | 5.4 | 5.9 | 6.7 | 7.0 | 6.9 |
| Total Acidity (ppm) | 130 | NR | 15 | NR | 2 | 2 | 1 |
| Total Alkalinity (ppm) | 0 | NR | NR | NR | 14 | NR | 12 |

*Pennsylvania Fish Commission

## Table 2

Little Scrubgrass Creek — Water Chemistry*

| | Date | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5-18-67 | 6-13-67 | 7-13-67 | 8-2-67 | 9-5-67 | 10-11-67 | 11-14-67 |
| Station 1 | | | | | | | |
| pH | 4.2 | 4.2 | 4.0 | 4.1 | 4.4 | 4.2 | 4.5 |
| Alkalinity | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fe | 0.4 | 0.4 | 0.4 | 0.4 | 0.0 | 0.4 | 0.0 |
| Al | 14.6 | 1.8 | 8.6 | 7.9 | 2.8 | 10.4 | 6.8 |
| $SO_4$ | 268 | 400 | 418 | 385 | 430 | 357 | 245 |
| Station 2 | | | | | | | |
| pH | 7.9 | 9.9 | 10.7 | 11.7 | 9.5 | 8.3 | 9.5 |
| Alkalinity | 8 | 30 | 38 | 166 | 10 | 12 | 4 |
| Fe | 0.4 | — | 1.0 | 2.0 | — | — | — |
| Al | 5.0 | 2.07 | 9.64 | 1.5 | 2.43 | 4.75 | 11.4 |
| $SO_4$ | 279 | 450 | 425 | 475 | 415 | 395 | 235 |

## Table 2
(Continued)

| | Date | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5-18-67 | 6-13-67 | 7-13-67 | 8-2-67 | 9-5-67 | 10-11-67 | 11-14-67 |
| Station 3 | | | | | | | |
| pH | 7.0 | 8.5 | 10.0 | 8.4 | 7.1 | 7.3 | 7.4 |
| Alkalinity | 10 | 32 | 14 | 24 | 4 | 10 | 10 |
| Fe | 0.4 | 0.4 | 2.0 | 1.2 | 0.8 | 1.2 | 0.0 |
| Al | 5.0 | 1.1 | 7.68 | 1.8 | 1.11 | 1.21 | 2.14 |
| $SO_4$ | 179 | 266 | 224 | 247 | 262 | 248 | 167 |
| Near Station 4 | | | | | | | |
| pH | 6.8 | 8.0 | 7.6 | 7.9 | 7.4 | 7.4 | 7.2 |
| Alkalinity | 4 | 20 | 18 | 28 | 14 | 16 | 8 |
| Fe | 0.8 | 0.4 | 1.2 | 1.2 | 0.8 | 1.2 | 1.2 |
| Al | 0.24 | 0 | 0.28 | 0.07 | 0 | 0 | 1.04 |
| $SO_4$ | 127 | 207 | 210 | 190 | 225 | 181 | 135 |

Moneval (1968)

## Table 3

### Little Scrubgrass Creek — Water Chemistry*

| | Station Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 6 | Near 8 | 9 | 10 |
| July 1967 | | | | | | | |
| pH | 3.8 | 11.5 | 7.5 | 7.8 | 8.5 | 6.5 | 6.8 |
| Total Alkalinity | – | 620 | 27 | 48 | 48 | 22 | 12 |
| Total Acidity | 150 | 0 | 26 | 20 | 7 | 23 | 21 |
| $SO_4$ | 505 | 505 | 330 | 220 | 225 | 260 | 245 |
| Fe | 0.4 | .28 | .331 | .41 | .1 | .14 | .44 |
| January 1968 | | | | | | | |
| pH | 4.8 | 8.0 | 8.3 | 8.0 | 7.2 | 6.7 | 7.2 |
| Total Alkalinity | 0 | 60 | 75 | 59 | NR | 41 | NR |
| Total Acidity | 228 | 12 | 30 | 0 | 0 | 0 | 4 |
| $SO_4$ | 480 | 480 | 425 | 210 | 166 | 92 | 65 |
| Fe | 0.25 | 0.25 | 0.6 | 0.6 | 1.0 | 0.2 | 10.1 |

## Table 3
(Continued)

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 6 | 8 | 9 | 10 |
| September 1968 |  |  |  |  |  |  |  |
| pH | 4.8 | 10.2 | 7.6 | 7.5 | 7.5 | – | – |
| Total Alkalinity | – | 78 | 84 | 38 | 42 | – | – |
| $SO_4$ | 362 | 430 | 230 | 161 | 28 | – | – |
| Fe | 6.0 | 0.4 | 1.2 | 0.6 | 0.8 | – | – |

*Source: Pennsylvania Fish Commission (1967, 1968)

Table 4

Little Scrubgrass Creek Water Chemistry — October 1970*

| | Station Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| MP-Alkalinity | 2 | 42 | 34 | 38 | 50 | 34 | 34 | 36 |
| Total Acidity | | | | | | | | |
| (Cold) | 14 | 0 | 2 | 4 | 4 | 2 | 2.5 | 4 |
| (Hot) | 26 | 0 | 4 | 4 | 4 | 2 | 2.5 | 4 |
| Total Hardness | 17.4 | 19.82 | 15.39 | 12.94 | 6.64 | 9.67 | 9.56 | 9.21 |
| Calcium | 10.14 | 15.27 | 12.47 | 10.14 | 5.13 | 6.99 | 7.22 | 6.76 |
| Fe | 0 | 0 | 0 | 0 | 0 | 0 | .3 | 0 |
| pH | 4.5 | 7.1 | 8.5 | 7.5 | 8.1 | 7.0 | 6.9 | 6.9 |
| $SO_4$ | 270 | 243 | 207 | 179 | 50 | 112 | 120 | 98 |

## Table 5

Little Scrubgrass Creek Water Chemistry – May 1971

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| MP Alkalinity | 4 | 4 | 34 | 28 | 54 |
| Total Acidity | | | | | |
| (Cold) | 20 | 8 | 2 | 2 | 2 |
| (Hot) | 24 | 32 | 4 | 0 | 0 |
| Total Hardness | NR | NR | NR | 24.9 | 5.7 |
| Calcium | NR | NR | NR | 5.4 | 4.4 |
| Fe | 0 | 0 | 0 | 0 | 0 |
| pH | 4.5 | 5.0 | 7.0 | 7.0 | 7.5 |
| $SO_4$ | 250 | 125 | 150 | 140 | 48 |

## Table 5
(Continued)

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 |
| MP Alkalinity | 34 | 46 | 42 | 48 | 38 |
| Total Acidity | | | | | |
| (Cold) | 2 | 2 | 2 | 2 | 2 |
| (Hot) | 0 | 0 | 0 | 0 | 0 |
| Total Hardness | 11.5 | 10.2 | 8.3 | 6.5 | 8.7 |
| Calcium | 4.8 | 7.6 | 5.9 | 5.4 | 6.1 |
| Fe | 0 | 0 | 0 | 0 | 0 |
| pH | 6.5 | 7.5 | 7.5 | 7.5 | 7.0 |
| $SO_4$ | 121 | 109 | 58 | 24 | 28 |

## Table 6

Little Scrubgrass Creek Water Chemistry — July 13, 1972

| | Station Number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 2a | 3 | 5 | 6 | 8 | 8a | 9 | 10 | 10a |
| MP Alkalinity | 0 | 18 | — | 28 | 62 | 32 | 32 | — | — | — | — |
| Total Acidity | | | | | | | | | | | |
| (Cold) | 62 | 0 | — | 2 | 4 | 4 | 4 | — | — | — | — |
| (Hot) | 80 | 6 | — | 8 | 6 | 6 | 6 | — | — | — | — |
| Total Hardness | 27.96 | 46+ | — | 20.98 | 6.87 | 11.42 | 11.3 | — | — | — | — |
| Calcium | 8.93 | 12+ | — | 11.07 | 5.48 | 7.34 | 7.34 | — | — | — | — |
| Fe | .15 | 0 | — | 0 | 0 | 0 | 0 | — | — | — | — |
| $SO_4$ | 304.7 | 316.6 | — | 249.8 | 64.2 | — | 142.6 | — | — | — | — |
| pH | 4.7 | 8.4 | — | 7.7 | 7.75 | 7.6 | 7.4 | — | — | — | — |

## Table 7

Little Scrubgrass Creek Water Chemistry — November 1972

| | Station Number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8a | 9 | 10 |
| Total Alkalinity (ppm) | 0 | 24 | 14 | — | 42 | 12 | — | 26 | 28 | — | — |
| Total Acidity | | | | | | | | | | | |
| (Cold) | 44 | 0 | 4 | — | 2 | 6 | — | 2 | 4 | — | — |
| (Hot) | NR | NR | NR | — | NR | NR | — | NR | NR | — | — |
| Fe | NR | NR | NR | — | NR | NR | — | NR | NR | — | — |
| $SO_4$ | 250.4 | 245.1 | 192.5 | — | 60.45 | 112.25 | — | 113.86 | 45.18 | — | — |
| pH | 4.5 | 8.7 | 7.6 | — | 7.3 | 6.65 | — | 7.1 | 7.0 | — | — |

## Table 8

Little Scrubgrass Creek Biological Data Summary — October 1970

| | Station Number | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Number of Organisms | 115 | 8 | 108 | 347 |
| Number of Taxa | 9 | 5 | 14 | 12 |
| $\bar{d}$ | 1.93 | 2.16 | 3.13 | 2.72 |
| $\bar{d}$ redundancy | .41 | – | .13 | .23 |
| H | 1.79 | 1.46 | 2.86 | 2.63 |
| H redundancy | .46 | – | .23 | .26 |
| Density Organisms/ft$^2$ | – | – | 13 | 22 |

## Table 8
(Continued)

| | Station Number | | | |
|---|---|---|---|---|
| | 5 | 6 | 7 | 8 |
| Number of Organisms | 971 | 536 | 295 | 170 |
| Number of Taxa | 23 | 25 | 14 | 11 |
| $\bar{d}$ | 3.02 | 3.03 | 2.58 | 2.72 |
| $\bar{d}$ redundancy | .33 | .35 | .32 | .19 |
| H | 2.95 | 2.93 | 2.47 | 2.57 |
| H redundancy | .35 | .38 | .36 | .24 |
| Density Organisms/ft$^2$ | 133 | 50 | 9 | 12 |

## Table 9

### Little Scrubgrass Creek Biological Data Summary — July 1971

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Number of Organisms | 57 | 2 | 23 | 94 | 873 |
| Number of Taxa | 5 | 2 | 5 | 13 | 33 |
| $\bar{d}$ | 1.48 | 1.00 | 1.61 | 2.54 | 3.67 |
| $\bar{d}$ redundancy | .37 | – | .28 | .32 | .27 |
| $\bar{H}$ | 1.33 | .05 | 1.31 | 2.28 | 3.57 |
| H redundancy | .45 | – | .53 | .42 | .29 |
| Density Organisms $^2$ | – | – | – | 7 | 102 |

Table 9
(Continued)

| | Station Number | | | | |
|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 |
| Number of Organisms | 389 | 76 | 414 | 87 | 215 |
| Number of Taxa | 24 | 18 | 19 | 14 | 21 |
| $\bar{d}$ | 2.24 | 3.47 | 2.47 | 3.00 | 2.84 |
| $\bar{d}$ redundancy | .55 | .08 | .43 | .38 | .37 |
| H | 2.11 | 3.03 | 2.36 | 2.69 | 2.64 |
| H redundancy | .58 | .27 | .46 | .48 | .43 |
| Density Organisms/ft$^2$ | 54 | 4 | 23 | 15 | 13 |

## Table 10

Little Scrubgrass Creek Biological Data Summary — July 1972

| | Station Number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 6 | 8 |
| Number of Organisms | 69 | 39 | 12 | 206 | 46 | 67 |
| Number of Taxa | 6 | 8 | 7 | 23 | 11 | 9 |
| $\bar{d}$ | 1.51 | 2.38 | 2.58 | 3.65 | 2.49 | 2.04 |
| $\bar{d}$ redundancy | .44 | .12 | -1.1 | .16 | .26 | .38 |
| H | 1.36 | 2.03 | 1.85 | 3.41 | 2.10 | 1.81 |
| H redundancy | .52 | .33 | .46 | .23 | .48 | .48 |

## Table 11

Little Scrubgrass Creek Biological Data Summary — November 1972

|  | Station Number |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 5 | 6 | 8 | 8a |
| Number of Organisms | NR | 4 | 73 | 893 | 109 | 246 | 550 |
| Number of Taxa | NR | 4 | 10 | 28 | 15 | 14 | 26 |
| $\bar{d}$ | NR | 2.00 | 2.33 | 3.59 | 2.97 | 2.67 | 3.42 |
| $\bar{d}$ redundancy | NR | — | .29 | .25 | .22 | .29 | .26 |
| H | NR | 1.15 | 2.08 | 3.50 | 2.70 | 2.54 | 3.30 |
| H redundancy | NR | — | .40 | .27 | .32 | .33 | .29 |

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