# EFFECTS OF ACID-MINE WASTES ON AQUATIC ECOSYSTEMS*

JOHN DAVID PARSONS, Department of Botany, Southern Illinois University at Carbondale, Carbondale, Illinois 62901.

## ABSTRACT

The Cedar Creek Basin (39th N parallel 92nd W meridian) was studied for the period June 1952 through August 1954 to observe the effects of both continuous and periodic acid effluent flows on aquatic communities. The acid strip-mine effluent contained ferric and ferrous iron, copper, lead, zinc, aluminum, magnesium, titratable acid, and elevated hydrogen ion concentration, and was toxic to many of the aquatic organisms. In the areas of Cedar Creek, subjected to continuous acid flow, planktonic and benthic species had become adapted to the severe conditions and varied in abundance and diversity. No fishes were observed in the area with continuous acid effluents. Downstream, where periodic mineral acid conditions changed drastically during an excessive effluent flow, planktonic and benthic communities had high diversity but low density. The populations of fishes were variable in this stream reach. The chemical basis of water quality variability was shown to be time related, and statistically related to the aquatic communities.

Physical, chemical and biological conditions of acid lakes formed by surface mining were reviewed. In addition to apparent physical and chemical differences in lakes, due in part to variable solar absorbance due to suspended oxides of iron, chemical variability related to organic composition was reviewed. It is quite probable that degradation of such lakes can be reversed.

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## INTRODUCTION

Acid precipitation, its chemistry and its effects, is not a new problem nor is it a problem restricted to a specific geographical area. Highly polluted precipitation has fallen over Scandinavia since the late 1800's, in the Sudbury Basin of Canada since the mid-1920's, and in the eastern United States since the late 1940's and early 1950's.

Acid precipitation contains large amounts of hydrogen ion, sulfate, and nitrate, with a variety of heavy metals, e.g., copper, lead and zinc, that have been produced mainly from manufacturing activities using highly sulfated fossil fuels. The result has been a wide range of deleterious effects on the environment.

The decline in the quality of aquatic ecosystems in Norway, first reported in the 1920's, has become a national disaster with the loss of much of the sport fisheries and the commercial salmon fisheries. Similar decline in the quality of aquatic habitat due to acid precipitation is now affecting other waters with the subsequent loss of fish populations. Notably, the 'smelter belt' region of Canada and the Adirondack Mountain region of the northeastern United States have recently been affected.

An older body of information, which lends itself to the prediction of the outcome of acidification of aquatic ecosystems by the sulfate ion and its myriad possible cations is, at least in part, available in the numerous studies concerning acid-mine wastes and the environment.

The literature* on coal strip-mine effluents is now voluminous, treating both the effects on natural waters and the chemical and biological succession in man-made acid sulfate waters. While a thorough literature search was conducted this paper does not incorporate a comprehensive literature review. With an understanding of the stream ecosystem in normal flux, its response to acid-mine wastes, and the recovery of man-made acid lakes, the general effects of acid precipitation on aquatic ecosystems should be predictable, though not necessarily completely abatable at this time.

The stream ecosystem from origin to confluences has been characterized in numerous ways: by a current in one direction, by an increase in volume, by changes in substrate structure, by the longitudinal change in the two major habitats, i.e., riffle to riffle-pool to pool communities, and by an increase both in temperature and in the dissolved oxygen supply.

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*Mine Drainage Abstracts, A Bibliography. 1964. With Supplements 1965 through 1974. Bituminous Coal Research, Inc. Pittsburgh, Pennsylvania.

These physiographic changes are accompanied by longitudinal biotic colonization, through specialized structures, physiological response, and by simply taking advantage of the physical environment afforded. This colonization results in a myriad of longitudinal communities of aufwuchs, plankton, benthos, and fishes. The populations within each group increase in diversity with the continual development of the ecosystem.

The open stream ecosystem is dependent upon the watershed -- terrestrial, as well as ponds, lakes and backwaters -- for its basic energy supply, and upon drift as the major mechanism in the distribution of that energy supply.

## THE STREAM ECOSYSTEM IN NATURAL FLUX

During the annual seasonal cycle, animal populations will vary in numbers naturally. Zooplankton, though seldom reaching the predominance of benthos or fishes, fluctuates widely in numbers, primarily as a function of stream volume and flow. Warm spring rains bring on the first of the plankton which by June reach a relatively stable population. The small amount of rain during the 'dog days' of August heralds the onset of low volume and low flow with a marked increase in the number of individuals per taxon. Continued low volume and flow, plus the major introductions of allochthonous materials, contributed during September and October in northern temperate forested regions, bring about a series of nearly separate leaf-choked temporary ponds. These factors contribute to the drastic change in the species composition and the size of populations which takes place. With November rains and full stream volume and flow, a small population pulse occurs in December, only to be followed by the disappearance of zooplankton from January through March until the spring rains.

The more stable benthic populations give way to emerging, maturing, breeding adults, which repopulate the stream during the short period of time in June and July. The first sampling of new larvae begins in August. The apparent increase in numbers, the innate lag time, variables in reproduction, the dispersal and hatching of eggs, and the growth of larvae which occur through September, October, and November are all factors in determining population size. During the period of limited rainfall, low stream flow severely hampers the complete colonization of the riffle areas. As the various species grow to catchable size and continue to mature through the winter months, the size of the populations remains rather constant. The biomass, however, increases markedly through March, April, and May, reaching a maximum again at the time of emergence.

As the dominant life form, the fishes are also the most restricted in distribution. The high waters in the spring bring about feverish upstream migration of many species. The low stream flow of late summer forces the riffle species to seek the nearest pool. The populations are under the great stress of near oxygen depletion. Fall rains bring an increased inflow and usually a redistribution of the fishes. The fish populations then remain stable until the spring rains bring about an increase in the volume of flow and the upstream migration of the fishes.

## THE STREAM ECOSYSTEM AND ACID WASTES

When strip-mining* activities are in the upper reaches of a stream, two aquatic ecosystems become directly associated with acid wastes: 1) the natural stream or stream drainage system and 2) a variety of man-made lakes. The watershed associated with the lakes 1) has a greatly increased surface area, 2) is an exposed source of toxic materials, and 3) is the source of acid waste run-off for both lake and stream.

The chemical breakdown of iron sulfide, the sulfuritic material associated with strip-mine areas, is due to both chemical and biological oxidation (Parsons, 1957). The oxidation products of this material are primarily sulfuric acid and iron sulfate (Parsons, 1957; Stumm and Morgan, 1970). The occurrence of various other sulfate salts depends upon the nature of the mineral content of the associated strata.

Apparently, oxidation of iron sulfide is nearly complete before the products enter the lake. Therefore, the strip-mine lakes serve as holding areas and have little to do with the formation of mine effluents. The major role of the lake is the hydrolysis of ferric sulfate (Parsons, 1955, 1957, 1964). Though this reaction produces another molecule of sulfuric acid, it also forms basic ferric sulfate, which is readily oxidized.

Acid-mine wastes consist chiefly of the sulfates of ferrous iron, ferric iron, aluminum, calcium, and magnesium, together with traces of a wide variety of other ions including at times several heavy metals (Braley, 1951; Parsons, 1955).

The effects of acid wastes on a stream are often modified by natural events, such as the emergence or migration or both of animal populations and the amount and distribution of rainfall. The latter affects stream flow and thus, the dilution factor. Further, a flow of acid wastes disrupts the abiotic environment, i.e., 1) the increase in the number of toxic ions and their concentrations, 2) the precipitation of the normal silt load, 3) the dissipation of the bicarbonate buffer system, and 4) destruction of dissolved oxygen, with the ultimate

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*The mining of coal at the surface. "Open-cast-mining" is the term familiar to international readers.

destruction of the biotic populations of the ecosystem.

As an example of the effects of acidification, the studies on Cedar Creek and the ecological ramifications of sulfate and related cations (Parsons, 1955, 1956, 1968) will be used as a basis for the discussion of acid precipitation. Researches on the effects of acid-mine wastes on aquatic ecosystems show a number of reactions which are quite similar to the effects of acid precipitation. These acid-mine waste effects are often more abrupt, but not necessarily more calamitous. A second aquatic ecosystem, ponds or lakes, created by the extraction of coal, their chemical characteristics, a chemical aging to normalcy (Parsons, 1955, 1964; Campbell et al. 1965a, 1965b; Campbell and Lind, 1969), and the reverse process of the effects of acid precipitation on fresh waters, will be the basis for additional elaboration.

The Cedar Creek Study was neither the first nor will it be the last study on the effects of acid effluents on the ecology of streams. The study was, however, definitive in covering the acid chemistry and the plankton, benthic, and fishes populations. In an earlier singular study of the hydrogen ion, Trax (1910) lamented that the Youghiogheny River was more acid than the Allegheny River. In a more recent comprehensive work, Cairns et al. (1971) found, in six case histories, that stream communities exhibited various degrees of recovery after reclamation. Recovery was found to be ". . .a function of physical, chemical, and biological characteristics of the receiving stream, the severity and duration of the stress, and the availability of undamaged areas to serve as sources for recolonizing organisms" (Cairns et al. 1971).

## DESCRIPTION OF STUDY AREA

The Cedar Creek Basin (Figure 1) is located in Boone and Callaway counties (39th N parallel 92nd W meridian) in central Missouri north of the Missouri River, on the southern edge of the easternmost projection of the Western Interior Coal Province (Campbell, 1922; Parsons, 1955).

Cedar Creek is 44.4 miles (71.5 kilometers) long, flowing north-south with a gradient of 6.7 feet per mile (1.3 meters per kilometer), a mean velocity of one-third foot (0.1 meter) per second, and a traversal time of approximately eight days. Cedar creek drains a narrow valley of approximately $1.28 \times 10^5$ acres ($5.18 \times 10^4$ hectares), an average of $2.9 \times 10^3$ acres of watershed for each linear mile of stream ($7.2 \times 10^3$ hectares per kilometer). The general appearance of the strip-mine areas of this study is shown in Figure 2. The physical relationship of the disturbed areas to Cedar Creek and its tributaries is shown in Figure 3, with source areas of acid waters designated numerically.

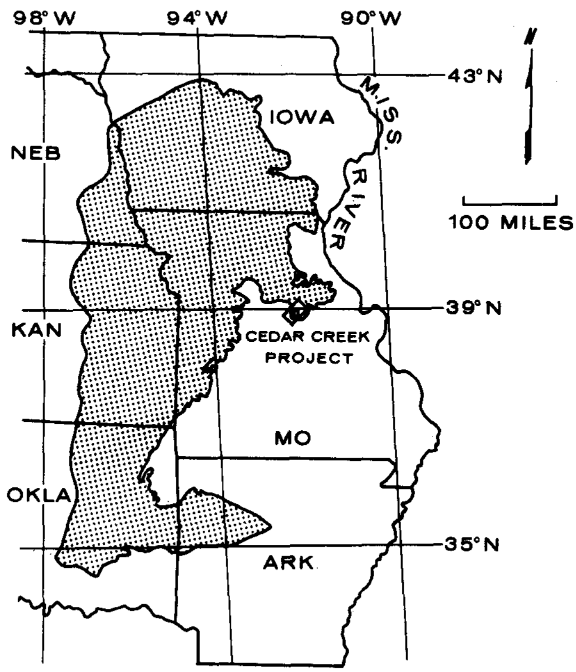


Figure 1. Location of the Cedar Creek Studies - Missouri, U.S.A.

The upstream area of the watershed was disturbed by surface mining operations. A total of 33% of the headwater region consisted of overburden materials with numerous strip pits. The assay of these materials has been reported to be 78% toxic, i.e., areas with more than 75% of the surface material having a pH of 4.4 or less (Rogers, 1951). This area also contained several lakes formed by mining operations. Watershed physiographic conditions varied significantly from highly disturbed areas with toxic overburden to narrow valley with rock outcrops and high bluffs. Stations 1-5 were representative of the upper watershed conditions, Stations 6-9 of the middle watershed, and Stations 10 and 11 of the lower watershed (Figure 4).

## METHODS AND MATERIALS

Studies on Cedar Creek were begun June 1952 and continued through August 1954. Monthly samples were supplemented with intensive sampling to describe major events on the watershed.

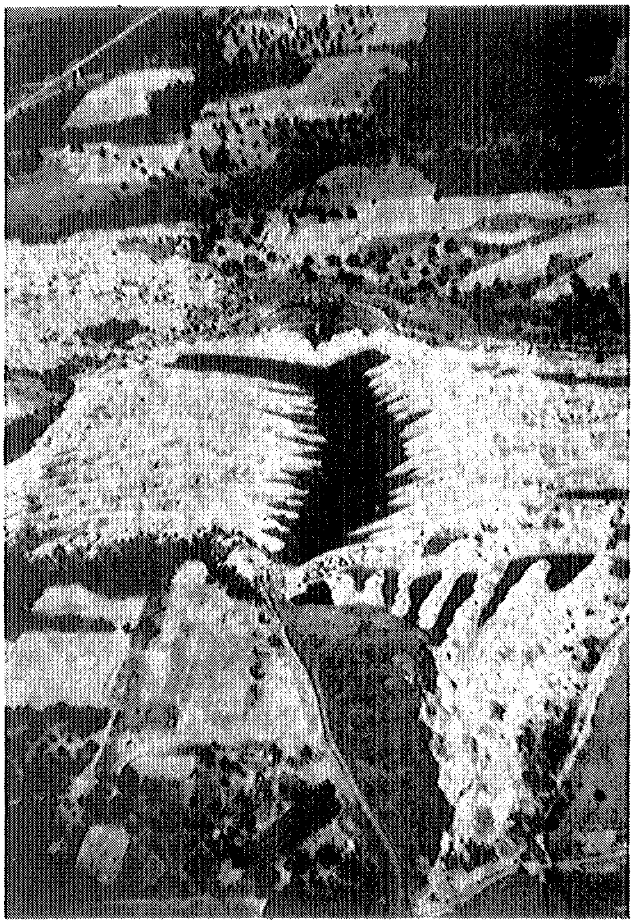

Figure 2. General strip-mine area
with typical chevron basin
red lake.

## Chemical

Standard methods (APHA, 1947) of chemical analysis were used to determine oxygen (sample-blank modification of the Winkler method), alkalinity, acidity, and pH (glass electrode) of water samples (Ellis et al. 1946). The titrametric benzidine method was used to determine the sulfate content of the samples following the procedure of Ellis et al. (1946). This method was modified due to the interference of ferric iron in accordance with Theroux et al. (1943). To determine the amount of the remaining sulfur(ous) compounds, the above procedure was used for the assay of sulfides, sulfites, and other non-sulfate sulfur(ous) forms following an oxidative procedure.

The remainder of the ions were assayed by colorimetric methods designed for trace analysis, using a Hellige-Diller photoelectric colorimeter, Model 400. The procedures as given by Ellis et al. (1946) were used to determine the concentration of both ferric iron (thiocyanate

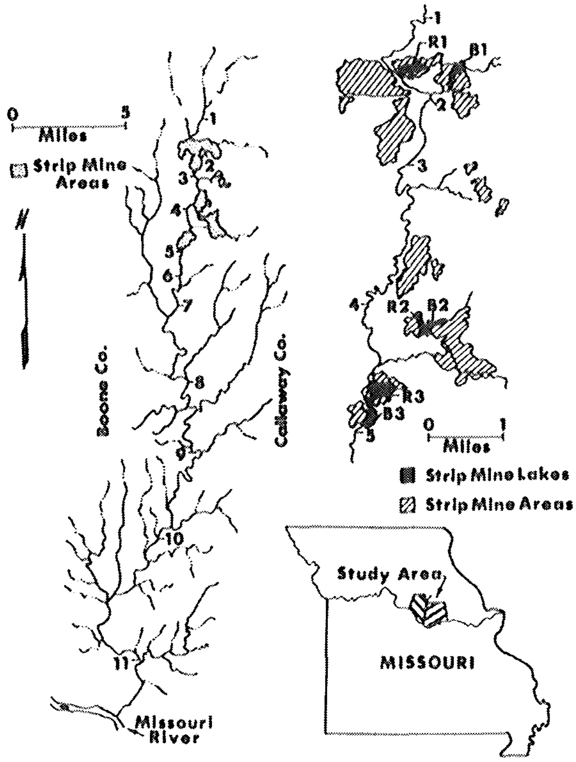


Figure 3. Cedar Creek with permament sampling stations and related lakes with color notation.

method) and copper (sodium diethyldithiocarbamate method). Ferrous iron (2,2' dipyridyl method), zinc and lead (diphenylthiocarbazone mixed-color method), aluminum (aurintricarboxylate method), and calcium (oleate method), were assayed following the procedures of Sandell (1950). Magnesium was determined by thiazole yellow method, a procedure adapted from Graham (1950).

## Biological

Standard methods (Parsons, 1955, 1968) were used in collecting, preserving and counting both planktonic and benthic samples.

During the study of the populations of fishes, samples were taken once a month with an electric seine. The seine was modeled after Funk (1947), modified by Larimore et al. (1950), and further modified by Parsons (1955).

Figure 4. Station 10, typical of the mid and lower stream.

### Physical

Physical measurements were taken employing the Secchi disc and platinum wire techniques for turbidity, a Foxboro thermophone for water temperatures at one-foot (0.3 meter) intervals in depth of both types of acid lakes, and a Taylor pocket thermometer for stream temperatures.

### Data Processing

Statistical analyses, modeling, and the prediction of the best line of fit are the result of multiple linear regressional analysis -- Program Linear (McNeil et al. 1973). Discriminatory program BMDO5M and parameter 'accountability program BMDO3M were used for further data analyses.

## RESULTS

### Acid Waste Delivery

There were two different aspects of acid-mine pollution in Cedar Creek. The upstream area, Stations 2 through 7, was continuously polluted by acid-mine effluents originating in the strip-mine areas above Station 5 (Figure 3). The downstream area, Stations 8 through 11 was considered unpolluted (Figure 3). However, during excessive flows of acid-mine effluents, part or all of the downstream area was polluted.

The initiation of an excessive acid flow occurs in the Cedar Creek Valley immediately above Station 5. A sizable portion of this area drains, in terms of strip-mine run-off, directly into Cedar Creek. Here, as on the other strip-mine lands of this general area, salts produced by the breakdown of iron sulfide are concentrated by evaporation at the surface of the spill piles. Large amounts of the various sulfate salts accumulate during the warmer months of the year under the high temperatures and prolonged dry periods. It appears that rainfall initiates excessive acid flows by dissolving the various sulfate salts from the spill piles and carrying the resultant effluent ions into the stream (Parsons, 1956).

The maintenance of an excessive acid flow, to the extent that the downstream unpolluted area is affected, depends primarily upon the addition of effluent ions from the overflow of strip-mine lakes. Thus, the level of the strip-mine lakes is important, for if maintained at a high level the effluent overflow during a rain increases the distance which the acid flow will travel.

## The Natural Ecosystem

The usual distinct longitudinal succession associated with a stream of this type has been modified to a more or less recognizable degree (Parsons, 1968). The modified biotic succession has been in response to the continuous atypical aquatic phase of the environment. The greatest deviation from the expected pattern was found in the most susceptible group, the fishes, and the least in the benthos with its great dependency upon the character of the abiotic substrate phase of the environment, with an intermediate response in the zooplankton with both inhabitable volume as well as quality of the water phase being a factor.

### Abiotic

The visual indicators of an acid flow entering the unpolluted area of the stream were the formation of a milky suspension, followed by suds formation at the surface from the "saponification" of the natural occurring suspended solids (Figure 5), and the precipitation of these solids as a white flock (Figure 6). The reaction with the most dramatic results is shown in Figure 7, as the pH drops abruptly during an acid flow, with the loss of bicarbonate ion and thus the loss of the buffer capacity of the stream. Of near equal importance was the oxygen-ferrous iron relationship. As noted in Figure 8, the oxygen concentration also drops abruptly and as much as 2 mg/liter, but does not become a critical factor in the survival of stream communities.

Within 2 months, the effects of the mineral acid have all but dissipated. The hydrogen ion concentration reached a peak in 48 hours with a gradual dissipation after the first week (Figure 9). Bicarbonate ion, on the other hand, did not recover until about 3 1/2 months

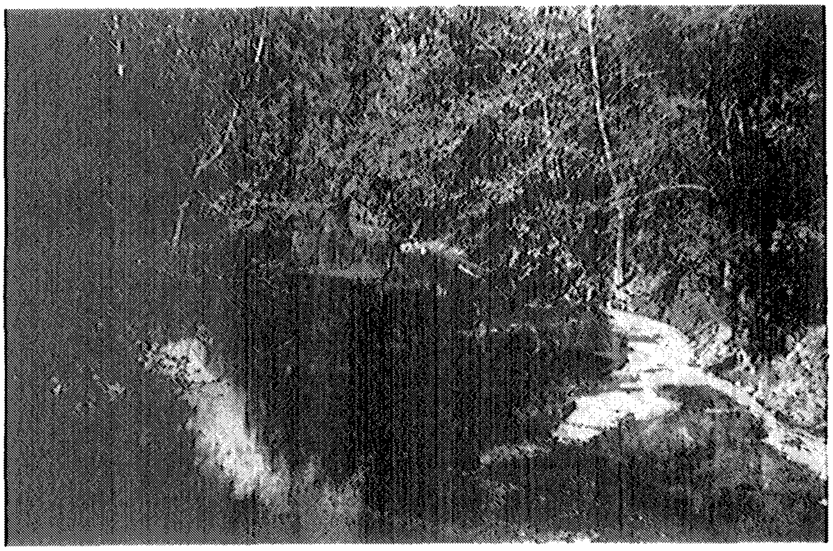

Figure 5. Sudsing action during an acid effluent flow.

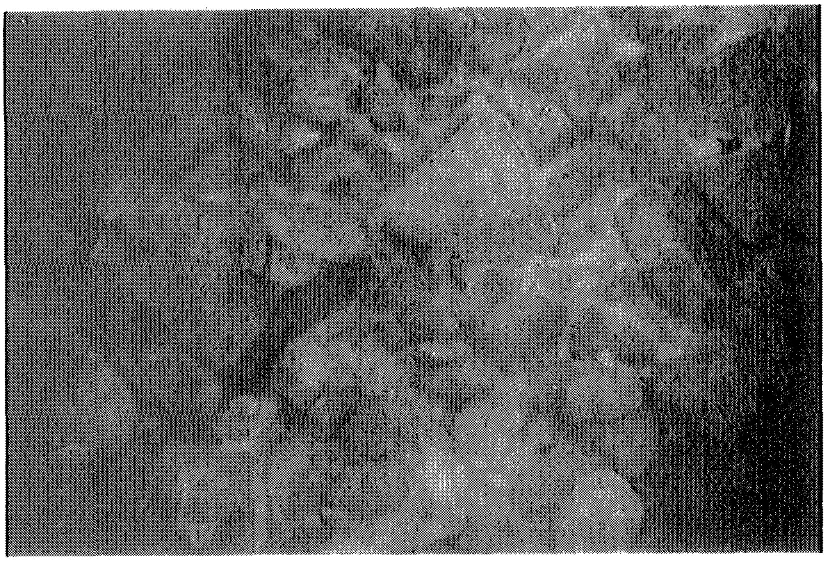

Figure 6. Precipitated flock - the end-product of acid water reaction with normal turbidity.

following the onset of an acid flow, due to the lack of runoff from the watershed. Concentrations of dissolved oxygen fell to their lowest in 48 hours and gradually increased to near normal readings in 2 months (Figure 10). Neither ferric nor ferrous iron concentrations were such as to affect the normal biotic communities.

Titratable acid reached its highest concentration in 48 hours and though it dropped rapidly (Figure 11), the concentration was sufficient

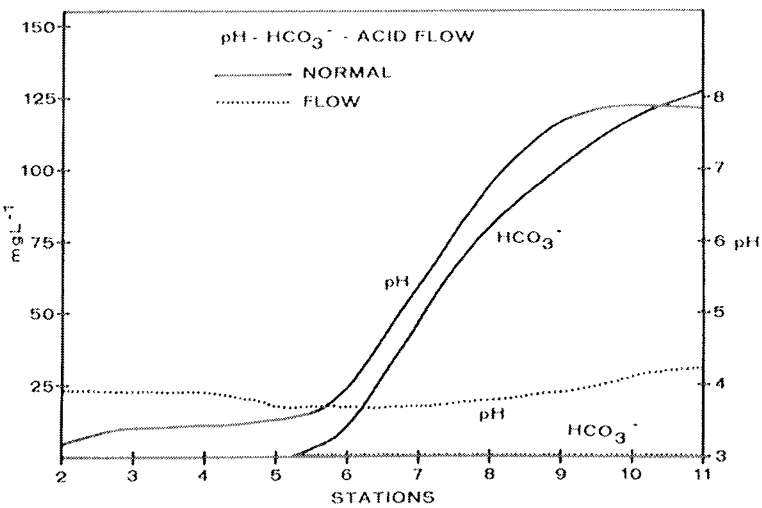


Figure 7. Linear reaction of pH and bicarbonate ion - onset of flow.

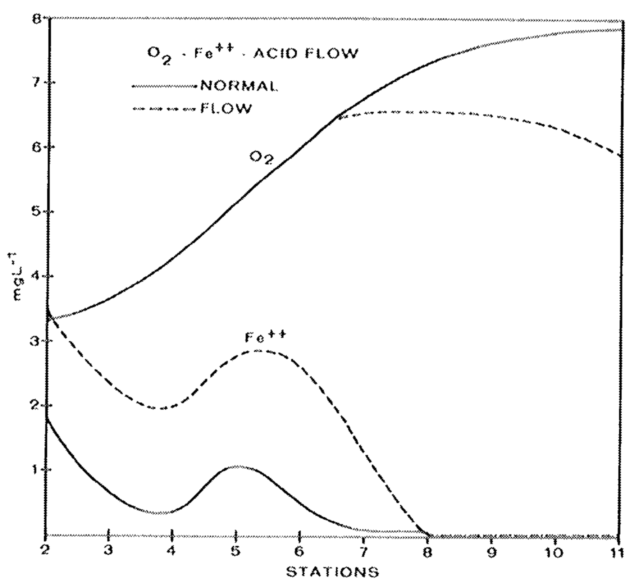


Figure 8. Linear reaction of oxygen and ferrous iron - onset of flow.

at 30 mg/liter mineral acid to completely control the recovery of the buffer system.

The calcium-magnesium ratio for flowing waters of the area was approximately 20:1 mg/liter and in the acid-mine affected streams about 1:2 mg/liter. Concentrations of both remained high until mid-winter (Figure 12).

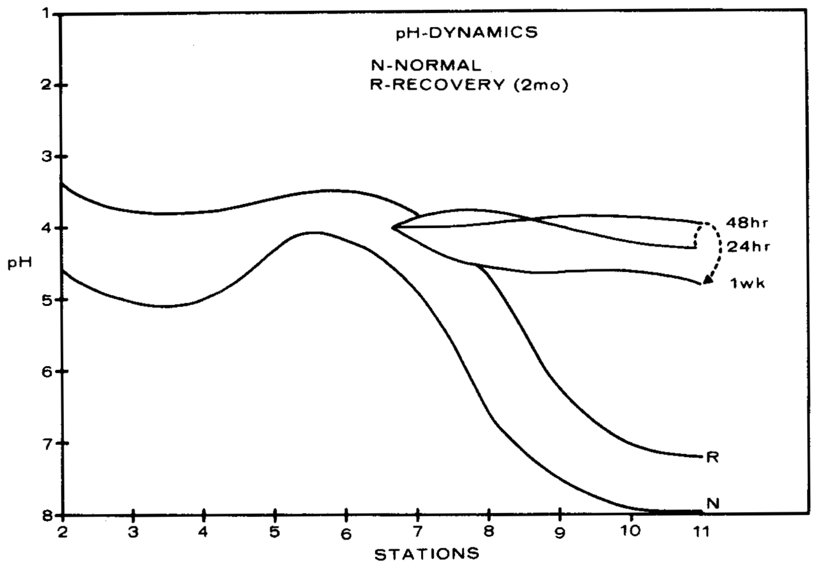


Figure 9. Time and linear reaction - pH with acid flow.

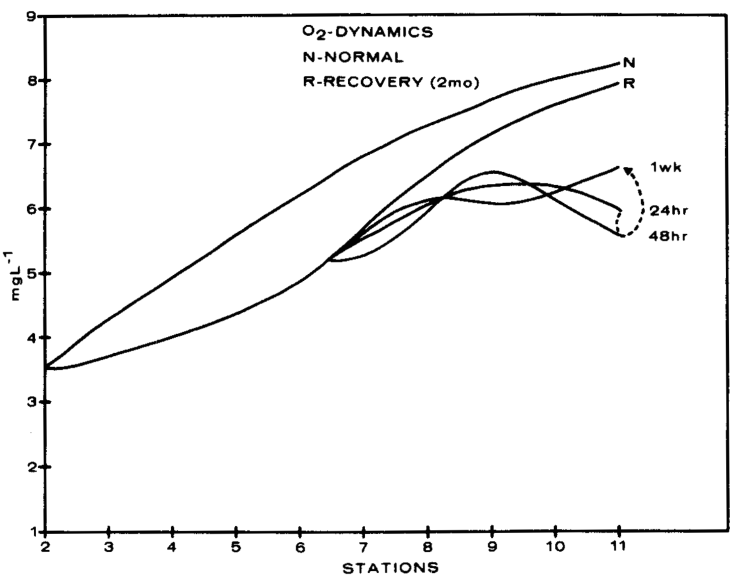


Figure 10. Time and linear reaction - oxygen with acid flow.

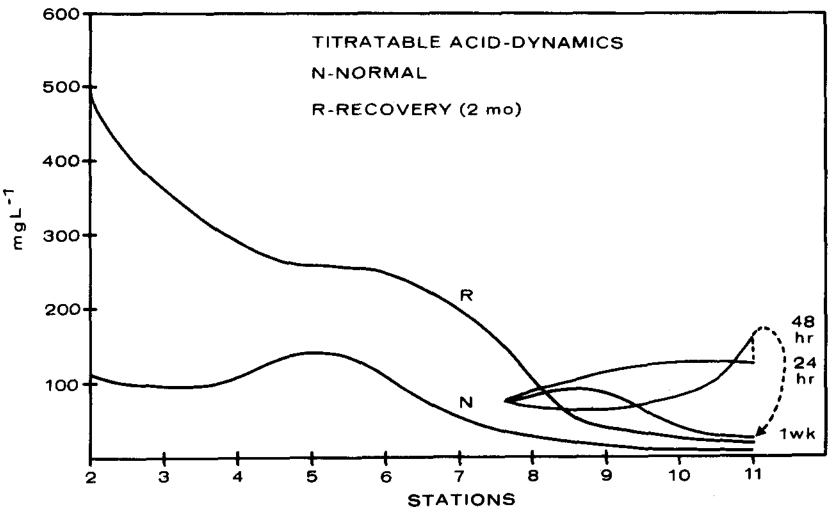


Figure 11. Time and linear reaction - titratable acid with acid flow.

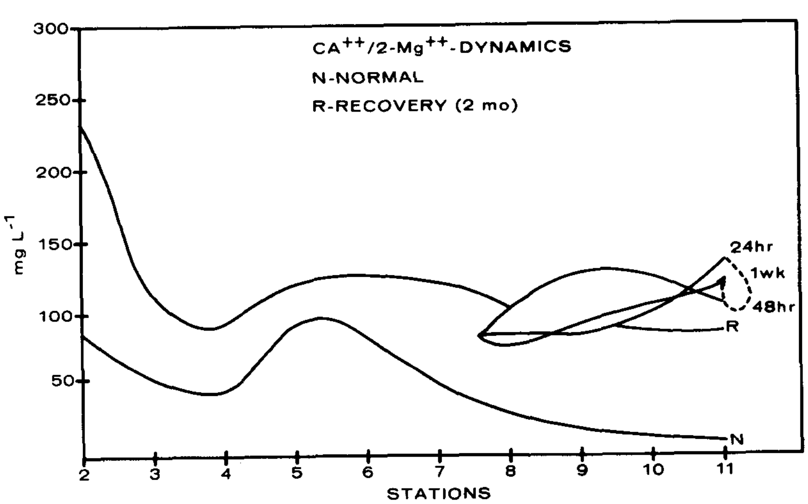


Figure 12. Time and linear reaction - calcium, magnesium with acid flow.

Sulfate as the predominant anion was always present in normal waters from the continuous seepage flow from the upstream mine areas. Although sulfate, aluminum, and zinc were found in a 30:6:1.5 relationship, the ions responded similarly during an acid flow (Figure 13). The concentrations of aluminum and zinc dropped to zero by mid-winter.

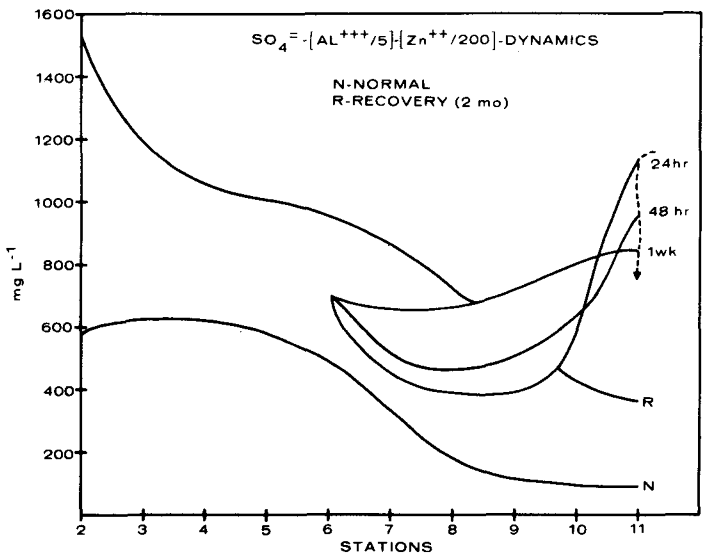


Figure 13. Time and linear reaction - sulfate, aluminum, zinc with acid

Neither lead nor copper concentrations were high enough to play a significant role in water quality of the ecosystem during an acid flow.

## Biotic

To illustrate quantitatively the effects of acid-mine effluents upon stable stream populations, the total number of individuals are plotted against decreasing acid toxicity under stable water flow conditions. These 'normal' populations are compared with 'flow' populations and referenced to the previous year's populations for both the planktonic and benthic communities (Figures 14, 15).

The large increase in zooplankton individuals was typical of acid flows. Qualitatively, the upstream populations were comprised of four to six species of test rotifers which were the residents of the polluted region. Downstream, the original populations were destroyed. Drift rotifer populations made up the plankton communities. Zooplankton populations were for the most part non-existent during the winter months. Once these populations were destroyed, full recovery was not complete until the following spring. Fluctuations in these populations

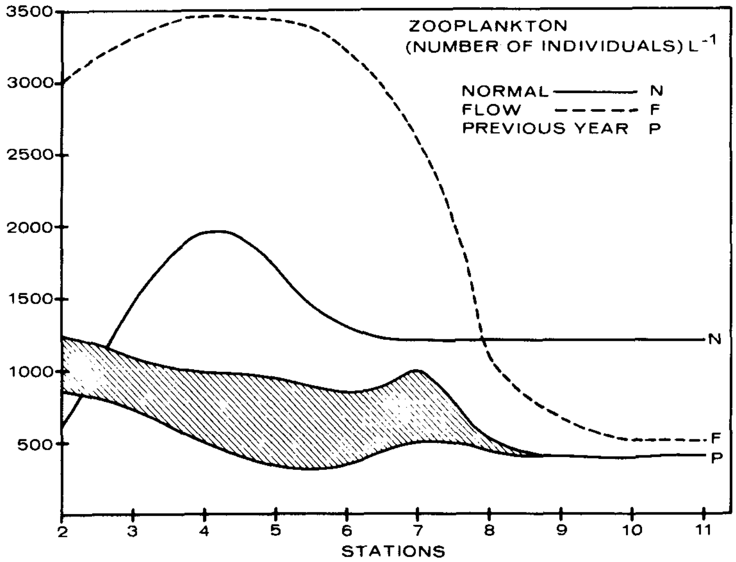


Figure 14. Zooplankton response to acid effluent stress.

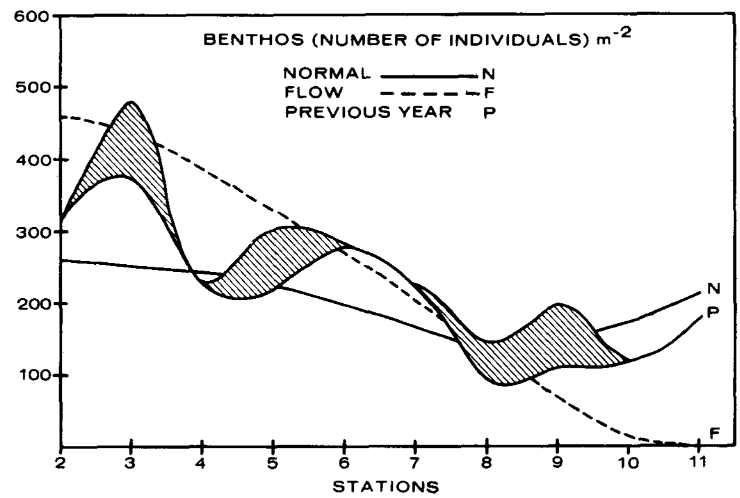


Figure 15. Benthos response to acid effluent stress.

during the previous years were very likely due to fluctuations in volume of flow rather than water quality.

The increase in benthic populations during and following an acid flow were due to the development of a second generation by several species, especially Procladius spp. (Figure 16). The effects of acid water on the populations in the transition zone (Stations 7 through 9)

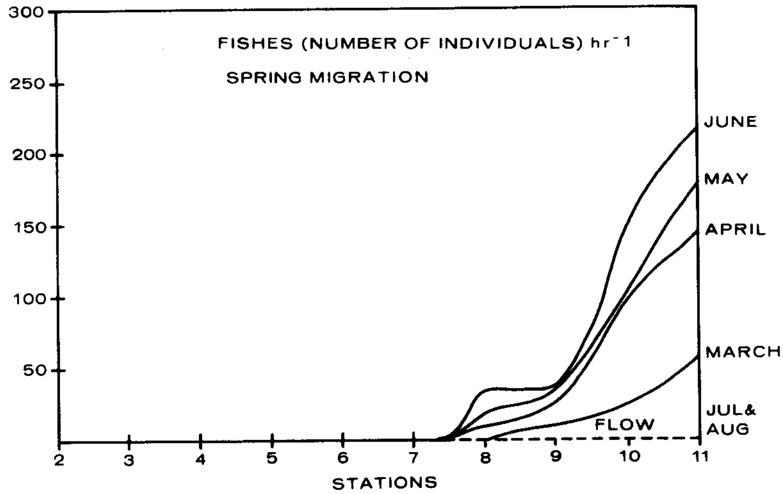


Figure 16. Fishes response to acid effluent stress.

range from moderate to heavy. The benthic communities at Stations 10 and 11 were all but destroyed. The fluctuations during the previous year were due, again, to second generation populations. Repopulation by benthic species proceeded in a normal manner by adults from the polluted region and tributaries of Cedar Creek.

The periodic migration of fishes up a tributary stream is initiated with increased spring flow (Figure 16). Populations of fishes were observed above the permanent sampling Station 8, and the populations appeared to stabilize in Stations 8 through 11 by mid-June. The effects of a late acid flow in June are shown in Figure 16. Recovery of the populations was not complete until the following spring. Observations of the previous year indicated that rather low populations were carried over the winter season. It appears that fish population dynamics were approximately the same from year to year, i.e., high spring populations with migration from the Missouri River, followed by a low or wanting winter population, depending upon normally low fall flow or summer acid flow, respectively.

## Analyses

Utilizing Program Linear and the community approach to analyze the effects of acid-mine effluents on the ecology of a stream (Parsons, 1968), the following results were obtained: 1) the $R^2$ for zooplankton populations (criterion) and the abiotic and biotic environment as predictors was 0.9987 and highly significant; 2) the $R^2$ for benthic populations (criterion) and the abiotic and biotic environment as predictors was 0.9991 and highly significant; and 3) the $R^2$ for fishes (criterion) and the abiotic and biotic environment as predictors was 0.9964 and, again, highly significant.

Analysis of the stream data by station in both time and the linear dimension revealed that $R^2$'s were seldom above 0.50. Thus there was as much or more variance within each station's measured parameters as there was among the stations' environments. This statement holds true regardless of the choice of criterion or the numerous restrictive codings placed on the acid effluent parameters as predictors.

The use of the discriminatory program BMDO5M was quite useful, for its use 1) confirmed the validity of the community approach above and 2) showed a definite transitional zone alluded to by Parsons (1955). Program BMDO3M was used to determine the parameters factored out and accountable for the variance. Parameter accountability, in order, within each stream area, was as follows: 1) titratable acid, sulfate, calcium and magnesium ions (polluted zone), 2) titratable acid, calcium, magnesium and aluminum ions (transitional zone), and 3) bicarbonate ion, temperature, calcium and magnesium ions (normal zone).

## The Man-Made Ecosystem

One of 25 hectares in the United States is covered with water and one in 50 of these may some day become useful as water supplies for domestic, industrial and recreational activities. There are, to date, any number of impressive sites of reclaimed lands and lakes; however, these are woefully small in number compared to the hundreds of thousands of hectares now in need of reclamation.

Two types of lake basins were formed during surface mining of the Cedar Creek Area. In the chevron basin 90-95% of the resultant water mass was in contact with the surrounding spoil banks, whereas the parallel lake basin, when filled, was 50% or less continuous with the disturbed watershed. The chevron lakes had the potential of becoming a holding basin for near 100% of the acid run-off from the immediate spoils without additional earth moving. Parallel basins could receive and hold less than 1% of the potential acid water from adjacent strip lands.

In this study, of the three red lakes, two were chevron and one parallel; of the three blue lakes, two were modified chevron (chevron diggings off a parallel high wall) and one parallel. The physical and chemical characteristics of both red and blue lakes have been presented in some detail by Parsons (1955, 1964).

### Physical

Turbidity caused by the reddish-black oxides of ferric iron in the red lakes played a major role in thermal stratification during the summer months and contributed to a heat budget which was 65% less per unit volume than that of blue lakes. This held true regardless of any of the above morphometric characteristics. Conversely, the blue lakes, of approximately the same water quality, minus the iron oxides, were homothermous throughout the year.

### Chemical

The chemical breakdown of the sulfuritic materials occurred on the strip-mine spoil banks and was complete or nearly so before the run-off entered the lakes. This was based on the fact that no forms of sulfur other than sulfate were found in lake waters. A vast variety of cations may be associated as sulfates and are a function in both quality and quantity of the strata adjacent to the coal seam, above and below.

In the case of the Cedar Creek Studies, strip-mine lakes were in part responsible for the duration of toxic flows. The water quality of the six study lakes was assayed and the following chemicals were found to be present in varying quantities: ferric iron, ferrous iron, aluminum, copper, lead, zinc, calcium, magnesium, sulfates, hydrogen ion, and titratable acidity.

Other measures of the chemical and physical qualities of strip-mine lakes have been reported by early works of Crawford (1942) and Heaton (1951) and more recently the excellent works of Campbell et al. (1965a, 1965b) and Campbell and Lind (1969).

## DISCUSSION

Researchers studying acid precipitation will continue to be faced with events similar to those presented above, as some aquatic ecosystems become slightly polluted with acids and heavy metals, while others are subjected to heavy effluent concentration triggered by sporadic rains, rapid thaw, and the like.

Various types of acid flows were described by Parsons (1955, 1956) indicating the complexity of factors which were responsible for the initiation and maintenance of a toxic flow. The biotic communities which were continually polluted, with their adaptive populations, were not adversely affected by the additional acid present during a toxic flow. The subtle adaptive responses of taxa to the continuous stress of acid-mine effluents were reported by Parsons (1968) and Dambach and Olive (1969).

Acid flows into relatively undisturbed areas are an entirely different matter. Large fish kills are, by far, the most visually dramatic result and receive the most attention in the news media. In the more severe cases, nearly all of the animal populations are decimated. Recovery of these populations, as in the case of the initiation and maintenance of acid flows, hinges on a number of interdependent factors.

Typically, recovering plankton populations will be pioneered by euglenoid forms within a few weeks, benthic populations may arise from acid-resistant eggs and invaders from the adaptive populations, and the fishes may repopulate the upstream communities at the next high water nontoxic flow. (Parsons, 1955, 1968)

The obvious effect of acid-mine effluent upon the biota of a stream, especially the fishes, following the destruction of the bicarbonate buffering system, is very likely acidaemia in fishes (Powers, 1922; Lloyd and Jordan, 1964; Reppert, 1964), and this appears to be true in the invertebrates (Parsons, 1955, 1968; Warner, 1971).

From a quantitative measure of both plankton and benthic populations, it would be difficult to assess the effect of the change in water quality during an acid flow. A qualitative assessment of the community structure and species diversity (Parsons, 1955, 1968) was necessary to complete the analysis of acid-mine effluents on a stream ecosystem. Stream communities subjected to acid-mine effluents declined in species diversity (Parsons, 1968; Dambach and Olive, 1969). The presence of metal ions appeared to accentuate this effect in some areas (Dills and Rogers, 1972).

With the recovery of the buffer system, the fishes repopulated Cedar Creek. However, the recovery of the original invertebrates depends upon the complete restriction of acid flow and its metals into the stream from the mine area. The restriction of run-off of acid water into streams coupled with natural stream characteristics has been shown to be closely related to the successful recolonization of animal communities (Cairns et al. 1971; Dieffenbach, 1974).

The mechanism in the streams would be similar to that in lakes in that the successful colonization of bottom habitat does not necessarily mean the re-establishment of the original species in complete life cycle (Harp and Campbell, 1967). Now three major parameters may be useful in establishing the influence of acid water, regardless of its origin, on aquatic ecosystems: 1) quantitative analysis of populations, 2) community structure, and 3) the establishment of a complete life cycle.

Cedar Creek Area strip-mine lakes of the study have not been researched in detail since the original work. However, 10 years later, a cursory series of aerial and ground observations were made.* Of particular note was the fact that chevron red lakes were still reddish-black and acid, while the single parallel lake was natural in appearance and supported submergent vegetation.

Early attempts to classify strip-mine lakes by previously established systems of lake classification have been reported by Crawford (1942) and Heaton (1951). However, it remained for Parsons (1955, 1964),

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*Parsons, J. D. 1965. Unpublished data.

using both chemical and physical parameters, to establish a means of physiocochemical aging as the foundation of acid lake classification.

That chemical recovery and biological colonization of lakes occur naturally in time has been shown by early works of Crawford (1942) and Heaton (1951), and the more recent works of Riley (1960), Campbell et al. (1965a, 1965b), Harp and Campbell (1967), Campbell and Lind (1969), Smith and Frey (1971), and Stickney and Campbell (1972). The mechanism of chemical recovery in such lakes, experimental evidence on accelerated recovery, and the use of organic waste matter as a precursor to such recovery have been well-researched by Decker (1971), Ogg (1972), Simmler (1973), King and Simmler (1973), and King et al. (1974). These works might well be used by acid precipitation researchers in an attempt to recover already acidified waters, in view of the 170 billion metric tons net primary production (dry weight) produced by the biosphere (Whittaker and Likens 1975) and the disproportionate distribution by man's activities.

In comparing strip-mine lakes to natural lakes, Campbell and Lind (1969) mentioned "the initial successional stage is acid rather than classically oligotrophic, . . .". Oligotrophication as a self-accelerating phenomenon in natural lakes subjected to an excessive supply of acid materials (Grahn et al. 1974) is now recognized in both Norway and Sweden as a feedback mechanism to further accelerate the process of acidification.

Must the recovery of the ecosystem, through the recovery of its various populations, emulate those of the original communities in terms of the number of individuals, represented by the same species and carrying on a complete life cycle, or should we be satisfied with some usable measure of biomass per unit of time or space? It has already been shown that in spite of 1) the wide variety of taxa present from lake to lake (Lind and Campbell, 1970) and 2) the remarkably distinctive limnochemistry from lake to lake (Campbell et al. 1965a, 1965b; Campbell and Lind, 1969), the rates of community metabolism in strip-mine lakes were surprisingly similar.

It would appear that we should now relate levels of community metabolism to levels of quality and quantity of the causative biomass in order to establish an acceptable set of standards by which to assess the success of rehabilitation programs used in the reclamation of acid ecosystems.

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