SOME EFFECTS OF ABANDONED MANGANESE STRIP MINES
IN SMYTH COUNTY, VIRGINIA
ON STREAM ECOLOGY

by

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INTRODUCTION

Purpose and Scope of Study

Stream pollution has become an ever-increasing problem, especially in recent years, due to the rapid industrial development in today's society. Three major types of stream pollution are recognized. Toxic pollutants do direct harm to a stream by killing all or a portion of the biota. Oxygen-depleting wastes act in a more indirect manner. These organic wastes require so much oxygen for bacterial decomposition that they rob native fauna of this basic necessity. A third, and even more subtle pollutant, is inorganic silt which clogs stream channels, covers spawning beds and creates a shifting and unstable stream bottom.

In southeastern Smyth County and in southwestern Wythe County, Virginia, several streams have been polluted by at least one, and perhaps two of the above classes of pollutants. The sources of this pollution are several abandoned manganese strip mines located in southeastern Smyth County. These mines were abandoned in the mid- to- late 1950's and were left unreclaimed. The United States Forest Service has reclaimed much of those mined areas within the Jefferson National Forest. Other portions are in the process of being reclaimed. Still others have remained untouched since abandonment a decade ago and, on these, ecological succession has made little progress toward revegetating the spoil banks left by the mining operations. Most of these unreclaimed lands lie on private property, the owners of which lack the funds or initiative required to reclaim them.

The mined areas contribute pollution to three large drainage areas, a major portion of which is drained by the headwaters of the south fork of the Holston River. West of the Tennessee Valley Divide the headwaters of Cripple Creek, a large tributary of the New River, has been affected by two extensive mined areas. Reed Creek, another tributary of the New River, has also received a small amount of pollution from one strip mine.

This study was conducted on the Cripple Creek watershed in the spring and summer of 1967. The relative abundance of the various species of fish and macrobenthic organisms in both control and affected streams was measured. Chemical characteristics were also compared, as well as physical characteristics such as bedload, stream bottom composition and intragravel dissolved oxygen levels. Objectives of this study were (1) to obtain an accurate estimate of the extent and nature of pollution due to manganese strip mining in this area and (2) to evaluate the effectiveness of reclamation work which has thus far been completed.

Location

The study area, located in Smyth and Wythe Counties, Virginia, is within a region defined by Miller (1944) as the Glade Mountain manganese district. The district consists of alternating ridges and intermontane valleys, which together form a compact mountainous group which rises 500 to 1,500 feet above the surrounding lowlands. The study area lies on the southeast side of the Appalachian Valley, bordering on the Blue Ridge Province. Fig. 1 shows the location of the study area in Smyth and Wythe Counties.

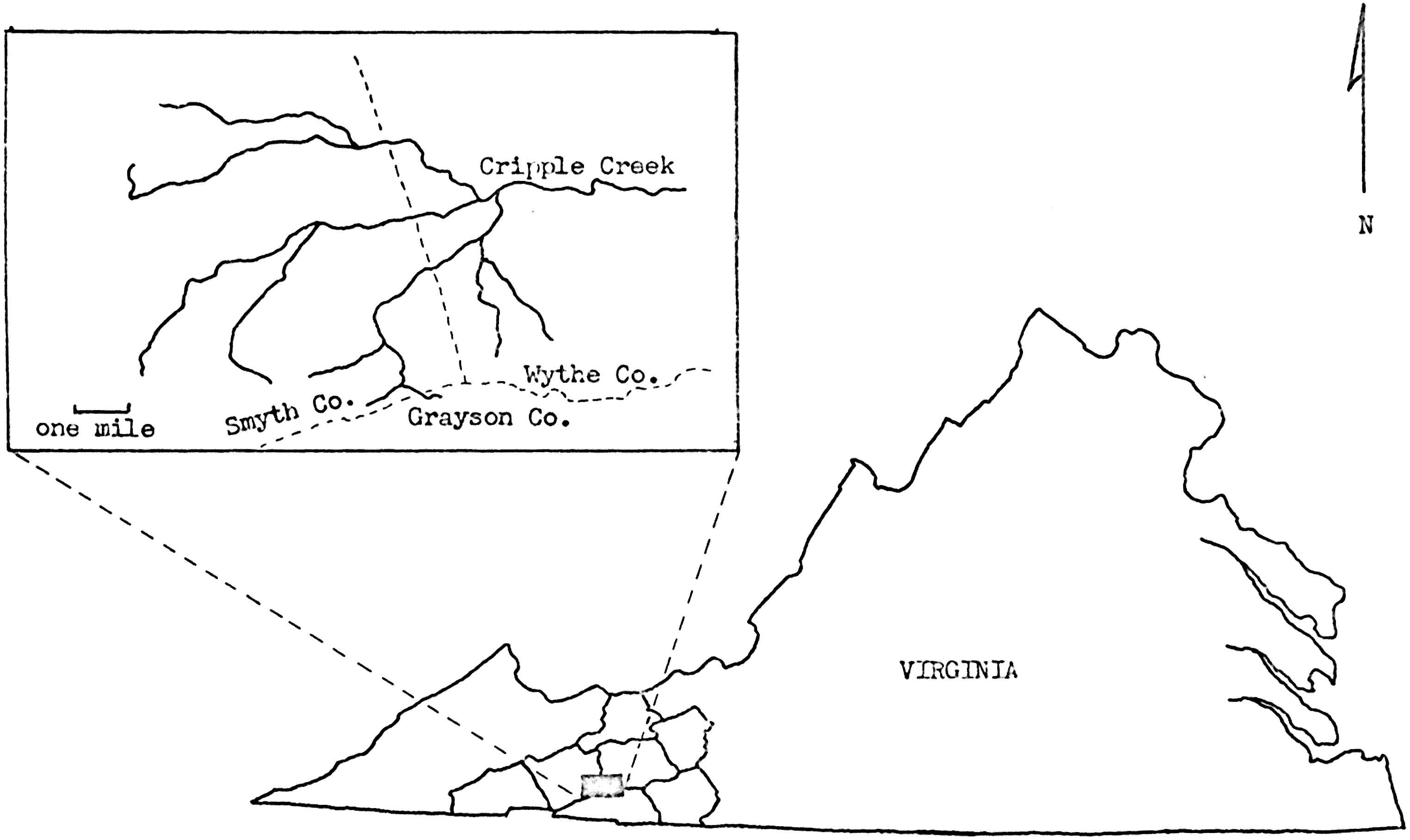

Fig. 1. Location of the study area.

LITERATURE REVIEW

The effects of strip mining on man's environment have caused much controversy in modern times. These effects are probably as varied as the products which are mined in this manner. Two recent publications of the United States Department of the Interior, "Surface Mining and Our Environment" (1967) and "Study of Strip and Surface Mining in Appalachia" (1966), give an excellent introduction to the field of strip mining and resulting problems.

Strip mining affects the aquatic environment in various ways. Siltation and turbid waters may result from almost any form of strip mining. Also, acid or other toxic materials may seep into a stream draining a mine. The type of toxic pollutant depends on the chemical composition of the strata being mined. Siltation results wherever there is overburden subject to erosion, and may be greatly enhanced by the mining process, e.g. hydraulic mining and dredging.

There has been a number of studies concerning the effects of siltation on various aspects of the stream environment (Cordone and Kelley, 1961). Aitken (1936) correlated erosion in Iowa drainage areas with the type of fish present in the stream. He found that a gradual change in the stream environment caused by erosion brought about a corresponding change in the fish fauna. Species of fish which preferred cold clear water were, in many streams replaced by more tolerant forms able to live in warm, turbid and, oftentimes, polluted water. These more tolerant species such as carp, gar and catfish are usually much less desirable than the native trouts, basses and sunfishes which they replace and compete with for food and spawning sites.

Trautman (1933) and Kemp (1949) both reported that silt in suspension may clog the gills of fishes.

Peters (1962) found that intragravel dissolved oxygen decreased downstream as sedimentation increased from irrigation returns. Shelton and Pollock (1966) observed that chinook salmon suffered as much as 85 per cent mortality when 15-30 per cent of the voids in the gravel spawning beds were filled with sediment.

Coble (1961) reported a positive direct correlation between the apparent velocity of water flowing through a streambed and the survival of steelhead trout embryos. He also found a direct correlation between dissolved oxygen concentration of the intragravel water and survival of the trout embryos.

Ellis (1936) concluded that silt from erosion alters aquatic environments chiefly by screening out light, changing heat radiation by blanketing the stream bottom, and by retaining organic material and other substances which create unfavorable conditions on the bottom.

The direct effects of silt from erosion on bottom organisms is well documented. Tarzwell (1938) showed that, on the average, mucky-bottomed pools in a stream not subjected to severe floods yielded four times more aquatic organisms (pound per acre) than similar areas covered with inorganic silt in another stream. Tebo (1955) documented the effects of silt from improper logging on the fauna of stream bottoms.

Ellis (1936) demonstrated the suffocating effect of silt from erosion on fresh water mussels in gravel or sand beds.

Tarzwell (1937) devised a system to rate stream bottom types in terms of productivity. Odum (1959) lists sand or soft silt as the least favorable bottom type with flat or rubble rocks as generally producing the largest variety and density of bottom organisms.

McKee and Wolf (1963) summarized much of the work to date on toxicity of manganese to fish and other aquatic life.

Jones (1939) found 40 ppm. manganese nitrate the lethal limit to stickleback (Gasterosteus aculeatus L.). As the lethal limit, he used the maximum concentration at which the experimental fish would live for 10 days (the average length of life of his control fish).

Clemens and Sneed (1959) reported that 500 ppm. manganese disodium versenate (40 ppm. manganese) was tolerated by fingerling catfish for four days.

Douderoff and Katz (1953) cite the work of Oshima and Iwao of Japan who reported the toxicity of $MnCl_2$ and of $MnSO_4$ relatively slight for fish in fresh water. Their results indicated lethal concentration limits near 4,400 ppm. as manganese (Oshima) and 3,400 ppm. as manganese (Iwao).

On the other hand, Thomas (1915) found 12 ppm. manganese chloride fatal to killifish (Fundulus heteroclitus) in six days in fresh water. He failed to state whether weights of salts included water of hydration. In a later paper (1924) Thomas concluded that manganese apparently has no toxic action in sea water (once again to F. heteroclitus).

The procedures for doing toxicity studies appear to be nearly as numerous as the studies themselves. Many authors fail to report the details of their experimental procedure or their method of calculating concentrations of the toxicant. It is often difficult, therefore, to determine from the literature just how much of a given pollutant may be toxic for the situation at hand.

The American Public Health Association (1965) outlines a standard method for determining acute toxicity of a given toxicant. This method is known as the routine bioassay method for determining the median tolerance limit of a given toxicant. The median tolerance limit, or TL_m, is defined as the concentration of a test material at which point just 50 per cent of the test animals survive for the specified period of exposure (generally 96 hours).

TECHNIQUES AND PROCEDURES

General Sampling Plan

Stream Classes

The study was initially designed so that ecological characteristics of four classes of streams could be compared. These four classes were arbitrarily named according to their association with manganese strip mine activity and to the degree of reclamation which had been done on their watersheds. A reclaimed stream was one on whose watershed was located a strip mined site, revegetated until stable and not subject to more than light to moderate erosion. Partially reclaimed streams drained affected areas on which revegetation efforts had been initiated but which were still subject to heavy erosion. Unreclaimed streams drained raw spoil banks of striped areas on which no artificial revegetation had been attempted and little or no natural ecological succession had occurred. The remaining stream class, or control, contained streams draining areas which had never been disturbed by manganese strip mining.

In the present study it was impossible to include a stream which drained a completely unreclaimed area. Such an area was present, but the small stream draining it was intermittent at best and remained dry during most of the study period.

Classification of streams in the study area (Fig. 2) were as follows. Killinger Creek drained a partially reclaimed area. Blue Spring Creek drained a fully reclaimed area. White Rock Creek and Crigger Creek were control streams. Cripple Creek was the main stream

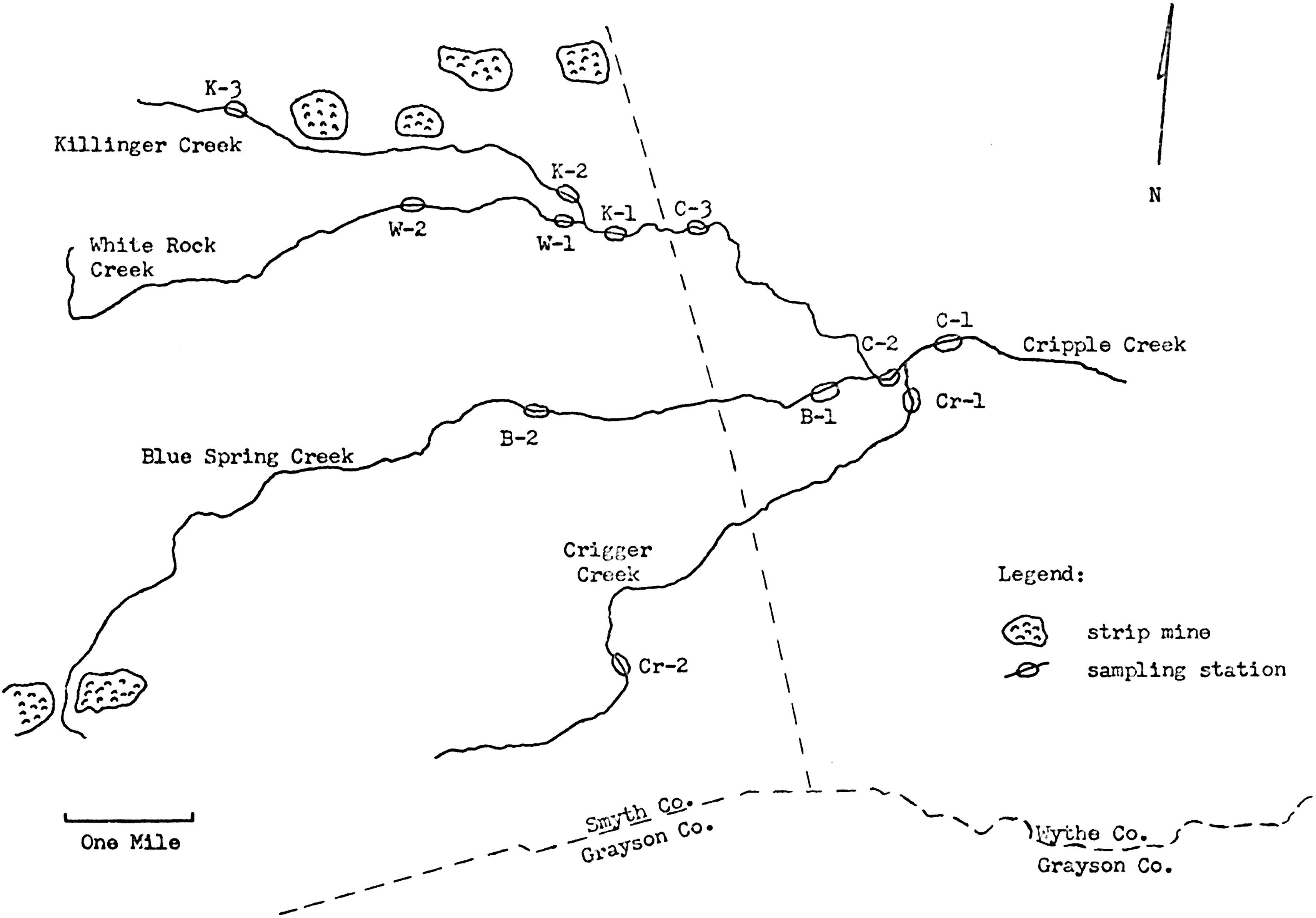

Fig. 2. The study area, showing location of sampling stations.

of the area.

Selection of Sampling Stations

Permanent sampling stations were established on all streams to be studied. On tributaries two stations per stream were established, one near the stream mouth and a second one on the upper portion of the stream. On the main stream stations were selected between tributary mouths. Stations were selected with convenience of access in mind. A topographic map was used to select possible station sites near access roads. These sites were inspected before choosing permanent sampling stations. Fig. 2 shows the location of the permanent sampling stations.

Choice of Sampling Technique

Since the purpose of the study was to detect possible differences in ecological characteristics between affected and control streams, all sampling was carried out on a comparative basis. Thus, an attempt was made to run each determination on all streams during a short interval of time. In this way, any differences existing among streams at a given time could be detected without introducing the error of probable changes in any given stream over a long period of time.

Biological Determinations

Fish Collections

Fish collections were made using two types of shocking apparatus and a twelve foot seine. The shocker used on the larger streams consisted of a 110 volt AC generator driven by a 4-cycle gasoline engine. A 200-foot extension cord connected the generator to the 15-foot electrodes. The electrodes were stretched between two wooden poles and were operated by two men, one at each pole. One or two additional men collected the stunned fish with long-handled dip nets. Rubber gloves and hip boots or waders were worn by the crew.

On smaller streams, the model BP-IC backpack shocker, obtained from Coffelt Electronics Company, Denver, Colorado, was used. A six-foot whip electrode mounted on a single wooden pole was used with this shocker. A switch mounted on the pole controlled the current. The entire apparatus was operated by one man wearing rubber gloves and boots. Another man was needed to start and stop the shocker engine and to collect stunned fish.

All fish were preserved in 10 per cent formalin solution and later transferred to a 40 per cent isopropyl or a 70 per cent ethanol solution as a permanent preservative.

Fish from all stations were identified to species, with one exception. The sculpins were identified to genus; no attempt was made to separate _Cottus bairdi_ from _C. carolinae_. For the purpose of this study, it was not necessary to separate these two almost identical species. Fish were identified with the aid of publications by Eddy (1957), Ross (1959), and the American Fisheries Society (1966).

Macrobenthic Organisms

The unmodified Surber square foot sampler was used to sample available macrobenthic organisms in the study streams. Sampling was carried out during the spring and summer of 1967. Five samples were collected from each station. Collections were sorted in the field using a small pair of forceps to separate the organisms from debris.

All collections were preserved in 70 per cent ethanol and were later identified to family with the aid of a binocular microscope of variable magnification. Pennak (1953) was the reference for family determination and nomenclature. The volume of each sample was determined by displacement in ethanol.

Chemical Determinations

The following chemical determinations were done with the Hach Chemical Company's model AL-59 kit: alkalinity, hardness, free carbon dioxide, and dissolved oxygen. With this kit, determinations were read to one part per million. The low range tests of the kit were used for alkalinity and hardness. The Hach kit greatly simplified water chemistry determinations, allowing the investigator to check all stations in a single day.

Water samples for the determination of iron, manganese, and turbidity were collected at the same time that the above chemistry was done.

Manganese content of the study streams was determined using the procedure outlined by the Hach Chemical Company. Water samples were collected in midstream at each station and acidified in the field. Determinations were made colorimetrically with a Bausch and Lomb Spectronic 20 colorimeter in the evening of the day the samples were collected. An untreated water sample was used as a blank for this determination instead of a distilled water blank to minimize the influence of turbidity on the manganese reading. A standard curve was prepared and manganese concentration, as parts per million, was determined from the curve with per cent absorbance being known.

Total iron was determined by the Hach Company's 1,10 phenanthropline method, using a powder reagent and the Spectronic 20 colorimeter. Samples were acidified in the field and determinations were run in the evening of the same day. Once again, an untreated water sample was used for a blank to eliminate interference due to turbidity. Total iron in parts per million was determined from the table prepared by the Hach Chemical Company. Chemical determinations made with the Spectronic 20 were read to one hundredth of a part per million.

The Hellige glass comparator was used for determining pH values in the field. Brom thymol blue-D and phenol red-D were the indicators used.

Intragravel dissolved oxygen was measured at each station using plastic standpipes (Fig. 3), following the procedure used by McNeil (1962). Standpipes were driven into the streambed at least 24 hours before water samples were collected. The azide modification of the Winkler method was used to analyze samples for dissolved oxygen. Semimicromethods were used, as only a 30 ml sample was collected from each standpipe. A 24 ml aliquant was titrated against .003N sodium thiosulfate delivered from a microburette calibrated at 0.1 ml intervals. With the above concentrations of reagents, parts per million dissolved oxygen could be read directly from the burette. All samples were fixed in the field and titrations were carried out either in the field or at the investigator's apartment within hours after collection.

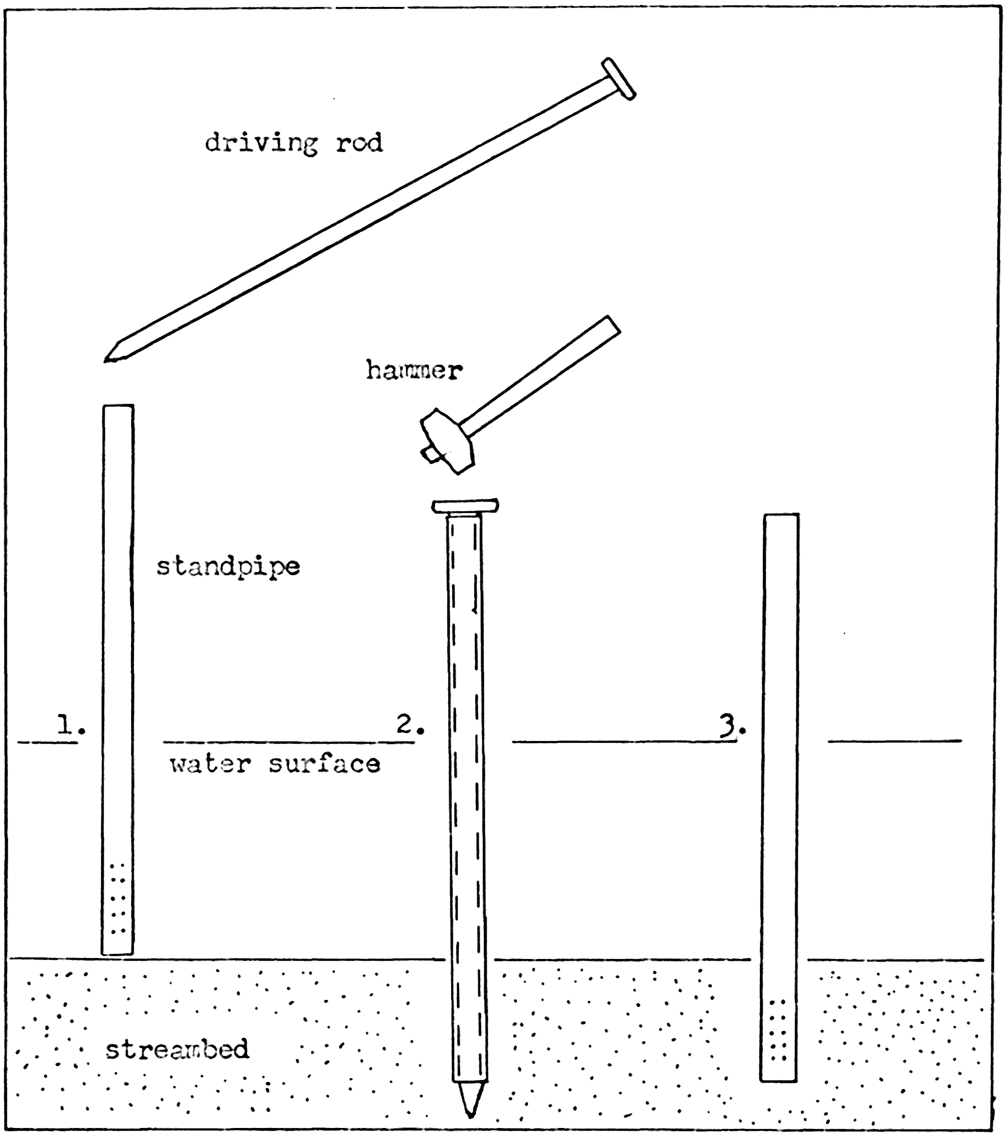

Fig. 3. The plastic standpipe used to measure intragravel dissolved oxygen.

Physical Determinations

Bedload

Hubbell (1964) describes the slot or pit sampler for measuring bedload. This type of sampler consists of a pit of known dimension placed in the streambed so that its top is level with the stream bottom. Bedload discharge is measured by measuring the time required for the pit of known volume to fill.

An inexpensive modification of the pit sampler was used to measure bedload in the study streams. One-pound coffee cans with removable plastic lids were obtained from local dumps. The cans measured approximately 10 cm in diameter and 13.4 cm in height (inside dimensions). The volume was approximately 1000 ml. The cans were filled with water, capped, and buried in the streambed with the top rim of the can level with the streambed surface. The cap was removed and the can left undisturbed for a given length of time. Two or three cans were planted at each station on the same date. All cans were placed at the lower end of a pool, just before it broke into a riffle area (Fig. 4). Cans were checked periodically, capped, and removed when the first can appeared to be nearly full. Large pieces of organic matter were removed and the remaining sediment was put through four U. S. Standard sieves (screen sizes 0.105 mm, 0.210 mm, 0.420 mm, and 0.841 mm). The volume of each particle size class was then measured by displacement in water.

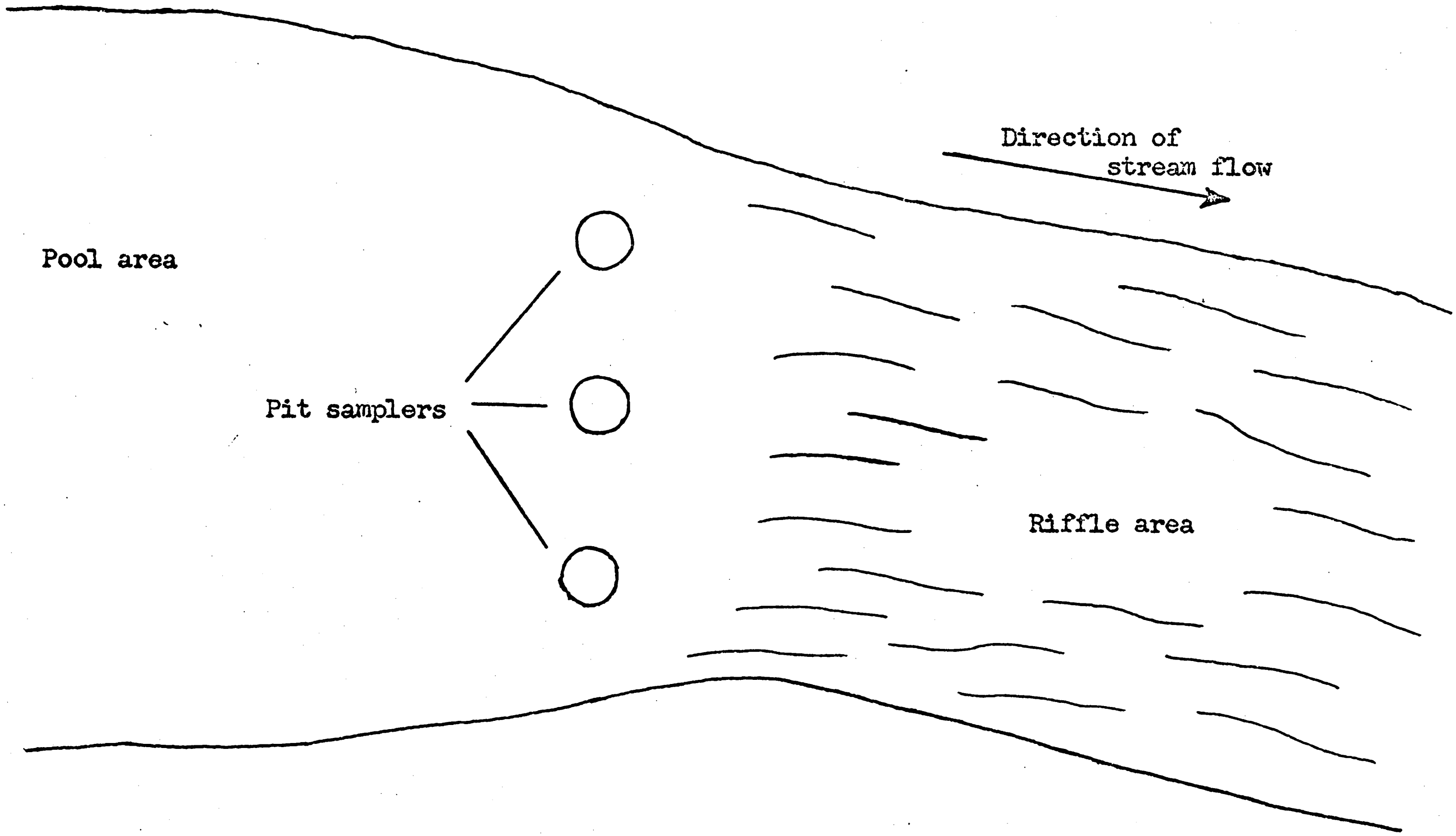

Fig. 4. Diagrammatic stream section, showing placement of bedload samplers.

Streambed Composition

McNeil and Ahnell (1964) describe a sampler which they developed for determining size composition of stream bottom materials. A sampler of this type was tried, but proved unsatisfactory for this study. The majority of the streams studied contained a large proportion of stones of a diameter greater than that of the sampler tube, making it impossible to force the sampler into the streambed.

Since a larger tube diameter would have been impractical for this type sampler, a different technique was developed. A large funnel-shaped apparatus was constructed from sheet metal. The larger opening was twelve inches square. The smaller opening was round (eight inches in diameter), with a metal flange just large enough for a U. S. Standard sieve to fit snugly over it.

In taking the sample, the device was placed in the stream with the square end pointing upstream and three of the finest sieves placed on the lower end (Fig. 5). The sample was taken by digging into the streambed immediately upstream from the funnel with a steel spud-like device which was designed for planting seedlings (Fig. 5). The bottom material thus dislodged was removed by hand and placed in a 12-quart bucket. Sand and silt which washed into the funnel was collected by the sieves, and added to the bucket. Each sample was dug to a depth of about eight inches. Three samples were taken at each station.

Fig. 5. The apparatus used to sample streambed composition.

This technique was found to be faulty in several respects. First, it allowed the finest silt to be washed through the sieves. In addition, due to the constriction of the column of water flowing through the funnel, eddy currents were created around the funnel mouth, which aided in the escape of much of the finer silt.

Streambed samples were separated into nine size classes by shaking and washing them through a series of U. S. Standard sieves of the following mesh sizes (in millimeters): 19, 12.7, 6.35, 3.36, 1.68, .841, .420, and .210 (Fig. 6). A ninth sieve of .105 mm mesh size was used in sampling at a few of the stations, but it was received too late to use at all stations. Silt passing through the finest sieve was collected in a galvanized tub.

The volume of particles retained by each sieve was measured by displacement using a method and apparatus similar to that described by McNeil and Ahnell (1964). Silt which passed through the finest sieve was placed in a large funnel with a 500 ml graduate connected to the bottom, and allowed to settle for 30 minutes (Fig. 7). The volume of settled material was then read directly from the graduate.

Volume of Flow

Stream velocity was measured at each station using a Price no. 1244 current meter. Readings were taken at 50-foot intervals approximately midway between surface and bottom. Readings were not taken in the swiftest current of a given section, but where appeared to be the average current. The average of all readings was taken as the stream velocity at that station.

Fig. 6. Separation of the streambed sample into size classes.

Fig. 7. Apparatus used to measure volume of silt collected in the streambed sample.

Volume of flow in cubic feet per second was determined for each station by the formula r = wdav (Lagler, 1956), where r = volume of flow, w = mean width, d = mean depth, v = velocity, and a = coefficient of roughness (0.8 for rough bottoms and 0.9 for smooth bottoms). Average width was determined from measurements with a 50-foot steel tape at 50-foot intervals. Depth measurements were taken in the center of the stream and halfway between the center and each bank, also at 50-foot intervals. These readings were then averaged to determine mean depth.

Turbidity

The procedure of the Hach Chemical Company was used to determine turbidity in parts per million silicon dioxide. This procedure utilizes the Spectronic 20 colorimeter. Using Hellige turbidity standards, a standard curve was prepared by plotting per cent transmittance against parts per million.

Water samples were taken from the stream surface in rapidly flowing water at each station. Samples were read on the evening of the day collected and were agitated vigorously before determinations were made. The turbidity of each sample in parts per million was read directly from the standard curve, with per cent transmittance determined from the Spectronic 20.

Temperature

Air and water temperatures were taken with a centigrade thermometer at midstream at all stations. Temperatures were taken at the time water chemistry data were collected and when fish and bottom fauna collections were made.

Manganese Toxicity Study

To learn more of the toxicity of manganese to fish, a study was made of acute toxicity of manganese to rainbow trout fingerlings. The experiment was set up at the Wytheville National Fish Hatchery Number 2 at Max Meadows, Virginia. The routine bioassay method presented by the American Public Health Association (1965) for determining median tolerance limit (TL_m) was used. TL_m is defined as the concentration of a test material at which point just half of the test animals are able to survive for the specified period of exposure.

Tests were run in 15 gallon glass aquaria set in fiberglass rearing troughs containing a running water bath for temperature control (Fig. 8). The source of water for the experiment was a large spring which supplies the hatchery. This water was found to be chemically similar to the water in the nearby study streams.

The trout fingerlings used in the experiment were reared at the hatchery and were thus accustomed to the experimental water, making acclimation unnecessary. However, all experimental fish were held for three days to empty their gastrointestinal tracts and accustom them to the aquaria.

The experimental toxicant was manganese (-ous) nitrate ($Mn(NO_3)_2$). Tests were run for 96 hours. Two tests were run; a preliminary test, using three widely varying concentrations of toxicant, established the range of concentrations necessary for the final run. Dilutions were made by adding measured amounts of $Mn(NO_3)_2$ to the

Fig. 8. The set-up for the manganese toxicity study.

aquaria and diluting to 50 liters. Two tanks of each concentration were prepared, and six fish were put in each tank. All concentrations were checked by atomic absorption spectrophotometry to assure accuracy. Temperature, dissolved oxygen, calcium hardness, total alkalinity, free carbon dioxide, and pH were determined daily on each concentration.

Temperature was recorded with a Centigrade thermometer. A portable pH meter was used. Oxygen levels were measured with a model 85 oxygen meter from Delta Scientific Company. The azide modification of the Winkler method was used on the first and last day of the final experiment. The oxygen meter was used on the other days to save time. The meter was accurate to 0.5 ppm.

Free carbon dioxide was determined by standard methods, using phenolphthalein indicator and titrating with 0.01N NaOH.

Total alkalinity was determined by standard methods, using phenolphthalein and brom-cresol green-methyl red indicators.

Standard methods were also employed to determine calcium hardness. Hydroxy naphthol blue was used as the calcium indicator and disodium ethylenediamine tetraacetate (EDTA) was used as the titrant.

Fish were handled with a small soft-mesh dip net. Care was taken to avoid injury during handling and all fish were closely observed after transfer to make sure they received no injuries. Glass covers were used on all aquaria to minimize evaporation and to prevent escape of the test fish.

Observations were made and water chemistry done every 24 hours. All dead fish were removed at the time of observation with a small plastic-framed dip net. The criteria for death was complete lack of movement. To be certain of death the suspected fish was rapped sharply in the caudal region with the frame of the dip net. All fish were frozen, weighed with an analytical balance, and measured with a metric rule.

RESULTS AND DISCUSSION

Geology and Mining History

Geology

According to Butts (1940:5), the Appalachian Valley is only a subdivision of a larger region known as the Appalachian Highlands. This larger region extends from the Gulf Coastal plain to the Central Lowland. The Appalachian Highland is subdivided into four provinces based largely on the type and age of the rocks and on general physiographic differences. Fig. 9 shows the boundaries of these four physiographic provinces in Virginia and the location of the study area in the Appalachian Valley.

The study area is bounded on the south by the Iron Mountains and its northern boundary lies in the heart of the Glade Mountains. According to Miller (1944:6), the Glade Mountains consist of parallel sharp-crested ridges of Erwin Quartzite separated by intermontane valleys of Shady dolomite. The Shady dolomite overlies the Erwin quartzite on one side and is cut off by a fault on the other. Along the south side of the Glade Mountains, parallel belts of Shady dolomite and Rome shale and sandstone combine to form the Rye Valley-Cripple Creek lowland. The Shady dolomite typically consists of light gray, fine to medium-crystalline dolomite in massive beds.
The main part of the Shady is pure dolomite but this grades downward into sandy dolomite and then to dolomitic sandstone at the base of

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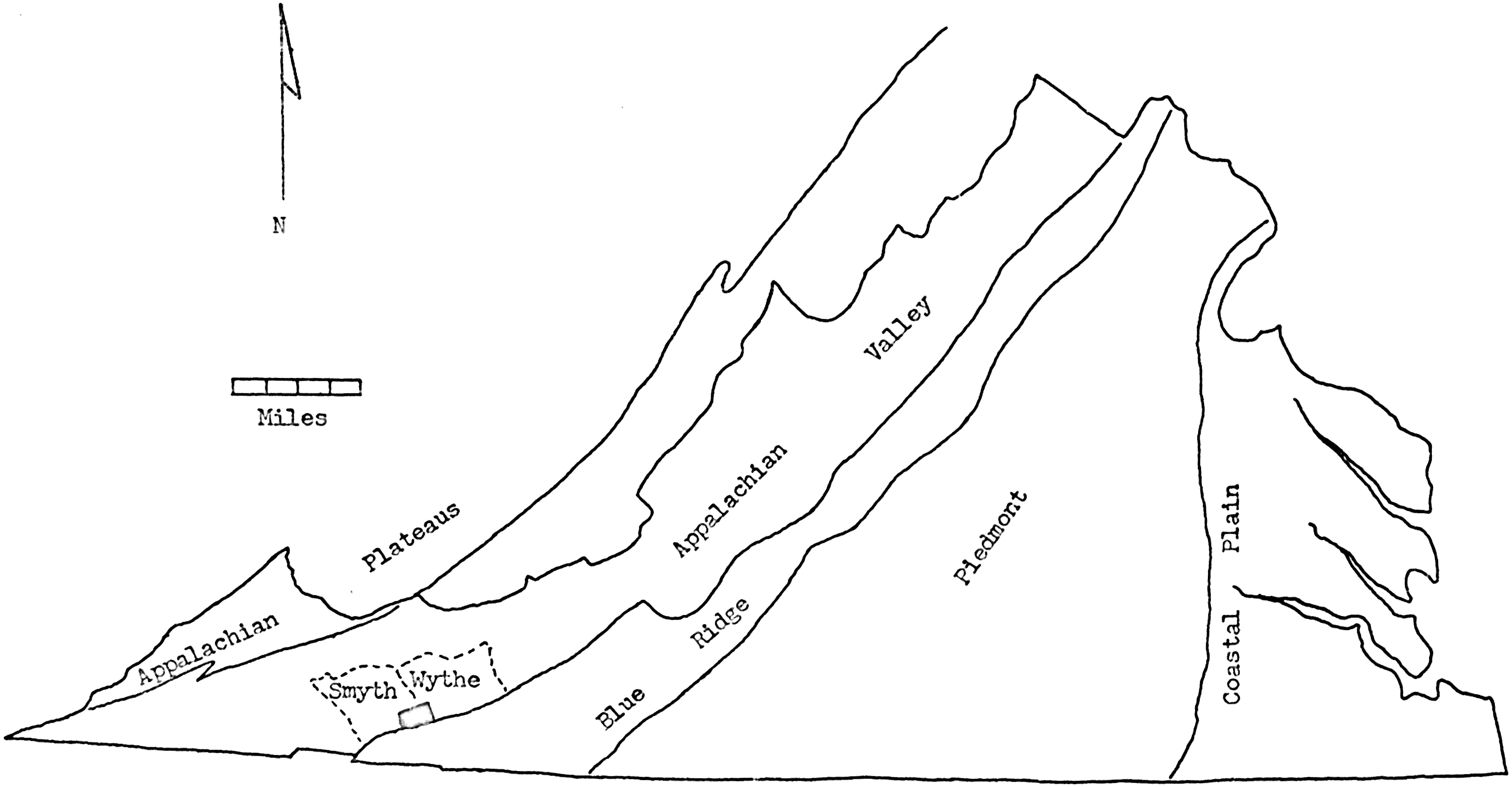

Fig. 9. The physiographic divisions of Virginia, showing the location of the study area in Smyth and Wythe Counties.

the formation. Miller (1944:27) describes the Rome Formation as one of the most distinctive of the Appalachian Valley. It consists of green, red and gray shade and fine-grained sandstone with locally interbedded dolomite and limestone.

Erwin quartzite is composed mainly of platy and shaly fine-grained sandstone, with interbedded quartzite and quartzitic sandstone which are very prominent in outcrops. It is this feature which justifies the name Erwin quartzite. The quartzite is white and yellow, fine- to medium-grained, and occurs largely in beds 1 to 10 feet thick.

Ore Deposition

Miller (1944) describes in detail the manganese deposits occurring in the Glade Mountain district. The predominant ore is cryptomelane, a hard, compact, finely crystalline oxide of manganese. Other manganese ores present include small amounts of psilomelane (a hydrous barium manganate) and pyrolusite, a crystalline black manganous oxide. In addition, hemitite and limonite are commonly found associated with the manganese deposits. Limonite was the important ore of the old iron mines of the region.

In the same work Miller discusses the probable origin of the manganese deposits in the Glade Mountain district. In Tertiary times, deep weathering occurred in the Shady dolomite ($CaMg(CO_3)_3$) in places where the resulting clay was protected from erosion. According to Miller, the manganese ore originally disseminated through the lower part of the Shady dolomite in the form of manganese carbonate, which is relatively soluble in water of high carbon dioxide content. The manganese carbonates were then removed in solution by water seeping downward from the surface, and were drawn off through various channels of circulation such as faults, caverns, joints and porous beds. Ground water moving into one of these conduits from a large area resulted in the pooling of large quantities of manganese-bearing waters in a small area.

Stose (1919:55) proposed that the downward-seeping manganese-saturated waters stopped dissolving and began precipitating due to contact with oxygenated water. In other words, solution took place by downward-seeping vadose water while precipitation of manganese occurred when the saturated vadose water came in contact with the oxygen-bearing water table, allowing the gradual escape of carbon dioxide.

According to Miller (1944:53), Shady dolomite and its residual clay underlie most of the valleys and lower mountain slopes of the Glade Mountain district. However, the majority of the manganese mines occur on the crests of ridge spurs, because it is here that erosion has sufficiently reduced the overlying material to expose the residual clays containing the manganese ores.

Mining History

The following account of the mining history in the study area is compiled from Miller (1944) and conversations with local residents.

Until World War I iron mining in Smyth County was much more important than manganese mining. Most iron ore produced was high in manganese but was processed without regard to this fact. However, the high grade of iron produced by local forges was attributed to this manganese content. Of special note is the high quality of railroad car wheels produced by the Lobdell Car Wheel Company which operated a charcoal furnace near the mouth of White Rock Creek during the latter part of the nineteenth century. Most of the mines contributing ore to this furnace were located in the White Rock Creek valley.

A sharp increase in the value of manganese, brought on by an acute shortage during World War I, resulted in a shift of emphasis from iron to manganese by local operators. This marked the beginning of manganese mining in Smyth County. However, after 1919 prices returned to their pre-war levels and importation of foreign ore made mining of these low-grade ores impractical. There is no record of manganese production in Smyth County from 1919 to 1937.

Mining was resumed during 1937 at Glade Mountain and was continued through World War II, when prices again rose sharply due to a government subsidy on manganese. The Glade Mountain mine became the largest manganese producer in the district.

After the Korean war, removal of the government subsidy again made these ores uneconomical to mine. Thus, mining was discontinued in the 1950's and the stripped areas were abandoned.

Mining Methods

The general mining technique in Smyth County manganese mines used a bulldozer to remove the overburden from the underlying ore. This method was most practical because most of the ore lay relatively near the surface. The ore was loaded into trucks, either by hand or steam shovel, and hauled to the washer where clay and soil were washed away and the remaining rock picked out. The washers were of necessity located near an abundant water source and, after flowing through the washer, water plus its heavy load of silt entered the nearest stream.

In some cases, settling basins were used to minimize siltation, but even then much of the finest silt reached the streams. Thus affected streams remained highly turbid as long as the washers were in operation. After operation of the mines was discontinued, stream siltation continued at intervals due to rapid erosion of the unreclaimed spoil banks. This process has made streams draining mined areas easy to identify by the characteristic red-brown clay silt present in them.

Chemical Analysis

Dissolved oxygen was found in high concentrations at all stations, ranging from 8 to 11 ppm (Table 1). This range is well above the minimum requirements for most fish species (Ellis, 1937:372).

According to Lagler (1956:254), free carbon dioxide concentrations exceeding 20 ppm may be regarded as harmful to fishes. Concentrations in the study streams were well below this, ranging from 5 to 15 ppm.

Alkalinity can be defined as the capacity of water to accept protons (American Public Health Association, 1965:48). It is usually a function of the carbonate, bicarbonate and hydroxide components of the water and depends on the geology of the region drained. Alkalinity values usually range between 45 and 200 ppm in most natural waters (Lagler, 1956:258). Waters with low alkalinity values are generally

Table 1. Summary of water chemistry (expressed as parts per million, except pH) at all stations on the Cripple Creek watershed, summer, 1967. For an explanation of station nomenclature see Fig. 2.

Test	Date	Station-											
		K-1	K-2	K-3	C-1	C-2	C-3	B-1	B-2	W-1	W-2	Cr-1	Cr-2
Oxygen	7/12	9	9	9	9	9	9	9	10	8	10	10	9
	8/29	9	8	10	11	10	9	11	11	10	9	9	10
	Avg.	9	9	10	10	10	9	10	11	9	10	10	10
Carbon dioxide	7/12	5	5	5	10	10	10	10	10	5	5	10	5
	8/29	7	5	8	15	11	6	7	7	7	7	12	3
	Avg.	6	5	7	13	11	8	9	9	6	6	11	4
Alkalinity	7/12	27	9	4	99	99	72	108	109	62	8	107	8
	8/29	6	11	4	83	77	45	87	73	37	6	62	7
	Avg.	17	10	4	91	88	59	98	91	50	7	85	8
Hardness	7/12	27	7	4	102	98	74	105	110	67	5	109	8
	8/29	5	7	4	78	79	46	83	75	38	5	65	7
	Avg.	16	7	4	90	89	60	94	93	53	5	87	8
Iron	7/12	0.09	0.39	0.20	0.08	0.12	0.12	0.03	0.13	0.20	0.20	0.10	0.08
	8/29	0.18	1.18	0.13	0.48	0.85	0.58	0.31	0.19	0.16	0.18	0.24	0.20
	Avg.	0.14	0.79	0.17	0.28	0.49	0.35	0.17	0.16	0.18	0.19	0.17	0.14
Manganese	7/12	0.23	0.48	0.23	0.15	0.19	0.07	0.00	0.32	0.00	0.15	0.07	0.15
	8/29	0.15	0.39	0.35	0.48	0.23	0.48	0.23	0.07	0.39	0.32	0.83	0.15
	Avg.	0.19	0.44	0.29	0.32	0.21	0.28	0.12	0.20	0.20	0.24	0.45	0.15
pH	7/12	7.5	7.2	6.8	8.2	8.0	7.7	8.0	8.2	7.4	6.8	8.2	7.1
	8/29	6.8	7.1	6.8	7.8	8.2	7.6	7.8	7.8	7.3	6.8	7.7	7.1
	Avg.	7.2	7.2	6.8	8.0	8.1	7.7	7.9	8.0	7.4	6.8	8.0	7.1

less productive biologically than those with high values. In the study streams, alkalinity ranged from a low of 4 ppm on the upper station on Killinger Creek to a high of 109 ppm on Blue Spring Creek.

Hardness at all stations closely paralleled the alkalinity and ranged from 4 to 110 ppm. According to the American Public Health Association (1965:146), hardness generally represents the total concentration of calcium and magnesium ions expressed as calcium carbonate. Other hardness-producing metallic ions, such as iron, aluminum, zinc, manganese and strontium, and hydrogen ions are not usually present in significant concentrations in natural waters.

Iron concentrations were low at all stations, ranging from 0.03 to 1.18 ppm. The highest concentration was found at station K-2 on Killinger Creek directly below the mined areas on Glade Mountain. The lowest concentration was found on Blue Spring Creek, which drains a reclaimed area. Iron in natural surface waters is generally oxidized to the ferric condition and forms insoluble hydroxides (McKee and Wolf, 1963:202). Ellis (1935:245) lists 50 ppm iron as the upper limit for fish life. On the other hand, Ebeling (1931:1626), found that 10 ppm iron caused serious injury or death to rainbow trout in five minutes. Concentrations in the study streams were well below either of these lethal levels.

Fig. 10 shows the manganese concentrations found at all stations. Values in the figure represent the average of two samples; one during a period of normal flow, the other during above normal flow. Table 1 lists all concentrations found during both sampling periods. The

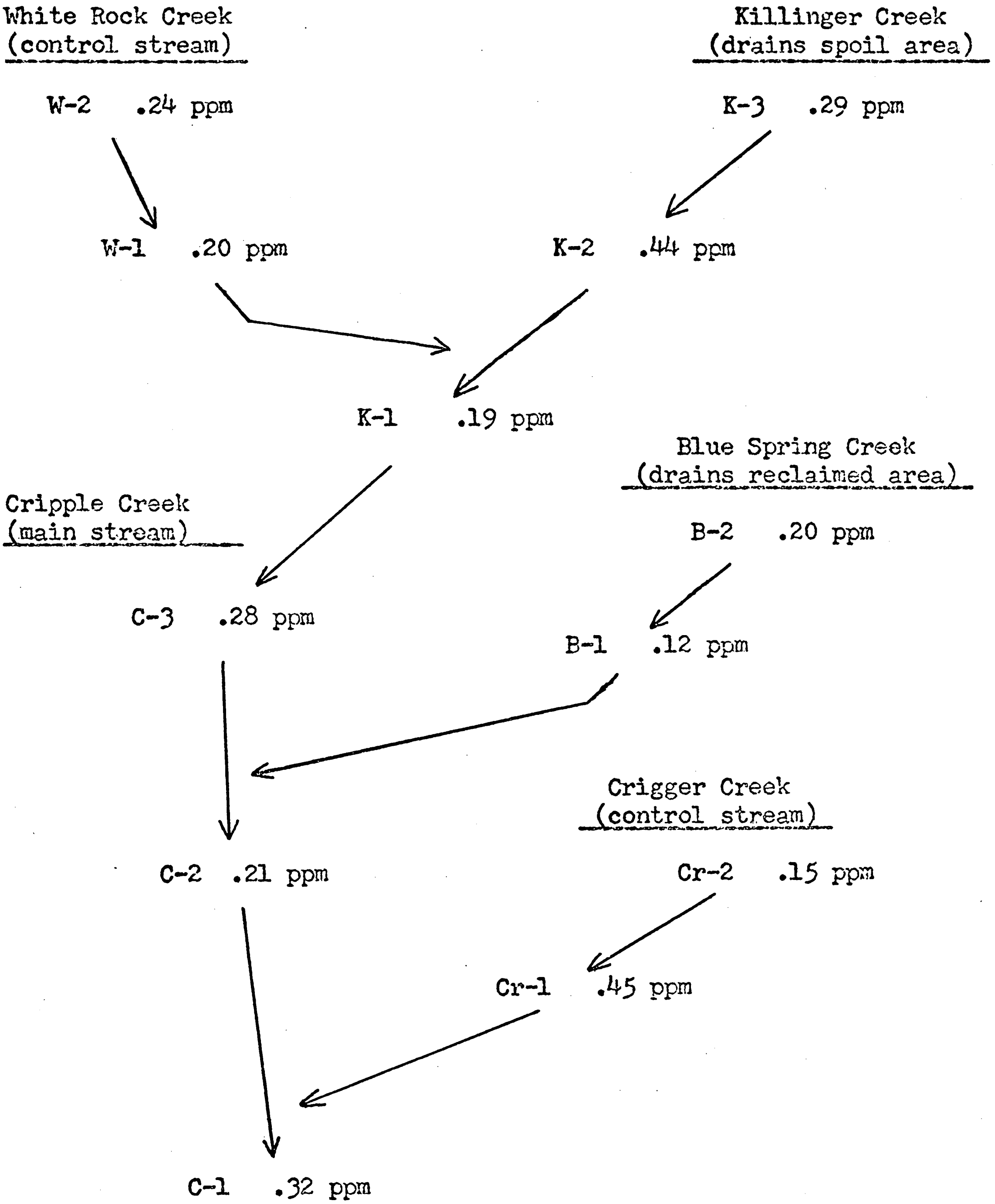

Fig. 10. Average manganese concentrations at stations on Cripple Creek and tributaries, summer, 1967. Arrows indicate direction of flow. Station nomenclature is explained in Fig. 2.

highest concentration of manganese found at any of the stations was 0.83 ppm at station Cr-1 on Crigger Creek. This high reading on a control stream, plus the overall manganese levels observed at other stations, indicates that strip mine activity has not contributed significantly to manganese concentrations in the study streams.

The low concentrations of manganese observed in the study streams should be no great surprise to anyone familiar with the geochemistry of manganese. According to Miller (1944:46-47), the manganese deposits of the Glade Mountain district are comprised mainly of manganese oxide (MnO_2). This oxide of manganese is listed by Goldschmidt (1958:634) as "very insoluble".

McKee and Wolf (1963:214) state that manganic or manganous ions are seldom present in natural surface water in concentrations greater than 1.0 ppm. In ground water, due to reducing conditions, manganese may occur in higher concentrations. According to Goldschmidt (1958: 633) the concentration of manganese in solution is dependent upon the amount of oxygen available. Thus, under aerobic conditions, manganese tends to precipitate from solution, while under anaerobic conditions, it is liable to solution and leaching. Also important, according to Goldschmidt, is the pH of the solution. Thus manganese salts are relatively stable in an acid or neutral solution, but oxidize rapidly under basic conditions.

Considering the above facts about manganese chemistry and the dissolved oxygen levels and pH range observed in the study streams, one would not expect high concentrations of manganese in these streams.

This is in agreement with McKee and Wolf (1963:214), who state that manganese concentrations in natural surface water rarely exceed 1.0 ppm.

McNeil and Ahnell (1964:2) use the term "intragravel water" to describe "water occupying interstitial spaces within the streambed". This intragravel water is of importance to the fisheries biologist because it is within the gravel of the stream substrate that the various salmonid fishes deposit their spawn (Greeley, 1932:240). According to Wickett (1958:1117), survival of chum salmon eggs is dependent, among other things, on the amount of oxygen circulating through the redd. The oxygen content of the intragravel water is directly proportional to the velocity of intragravel currents, which is in turn dependent upon permeability. The test for intragravel oxygen therefore, can be used as a test of permeability of the streambed, which would in turn indicate its usefulness as a spawning site for the salmonid group.

Intragravel oxygen levels observed in the study streams are summarized in Fig. 11. Average intragravel oxygen concentrations were lowest at station C-3 on Cripple Creek. Downstream stations showed a gradual increase in concentrations. Concentrations on Blue Spring Creek averaged about one ppm below those on the control streams. However, high intragravel oxygen levels were found at stations K-1 and K-2 in spite of the fact that these stations lie directly below the mined areas on Glade Mountain, and are heavily silted. It is felt that, because of the difficulty encountered while collecting samples at these stations, these concentrations do not represent the

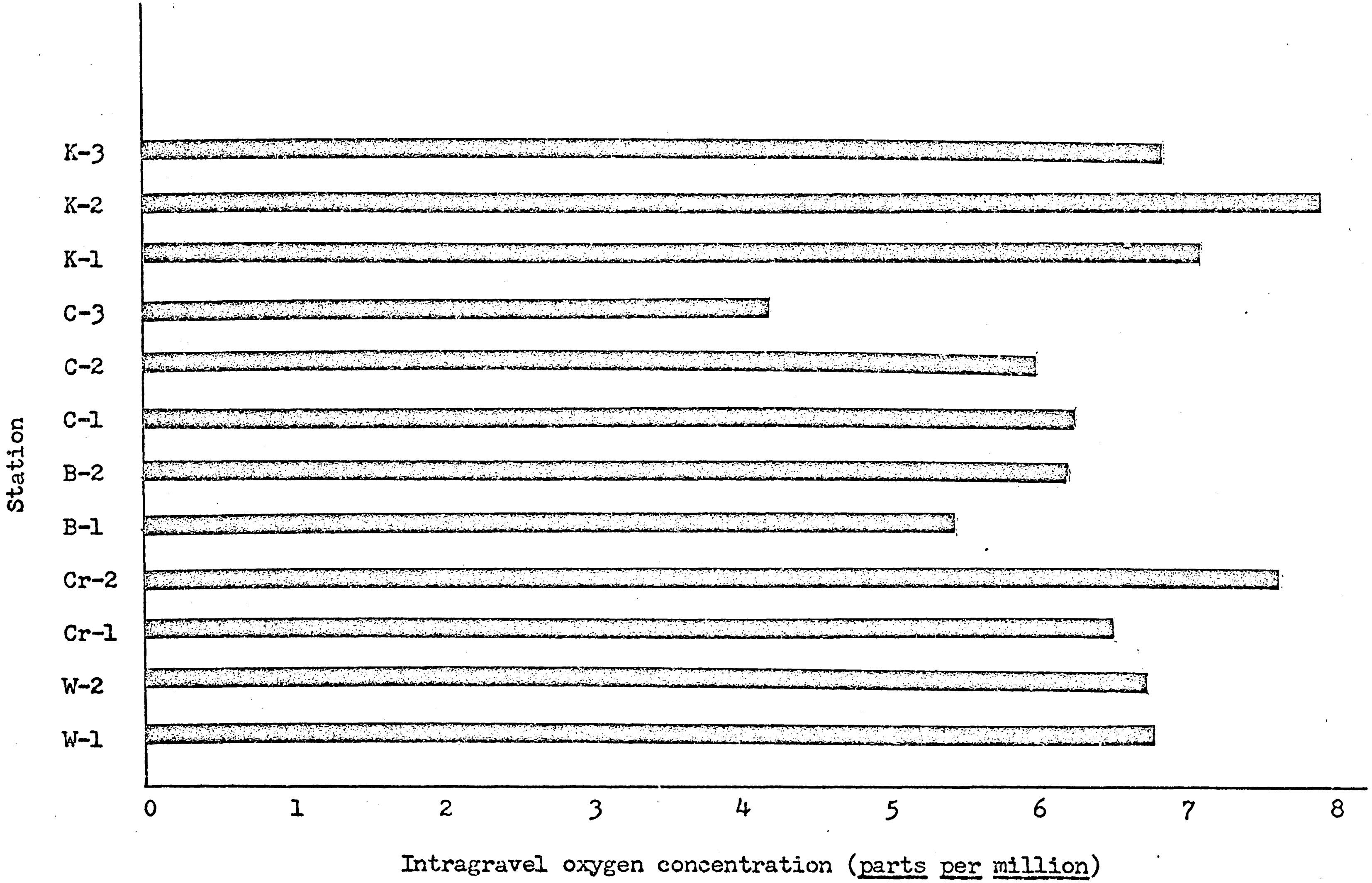

Fig. 11. Average intragravel oxygen concentrations at stations on Cripple Creek and tributaries, summer, 1967. Station nomenclature is explained in Fig. 2.

actual concentrations of intragravel oxygen at these stations. Due to the compaction of the streambeds at these stations, it was very difficult to withdraw enough water from the standpipes for a sample. In many cases, it was known that air was sucked up with the sample, in which case the sample was discarded. However, it was often difficult to tell whether air had been introduced during collection.

Physical Aspects of the Study Streams

Streambed Composition

The importance of streambed composition has already been touched upon. McNeil and Ahnell (1964:6) have demonstrated the relationship between substrate composition and permeability to intragravel water, and that it is possible to compare relative permeability by determining average size composition of the bottom materials. The importance of streambed permeability has already been discussed in terms of intragravel oxygen.

In addition to oxygen needs, as McNeil and Ahnell (1964:1-2) point out, the growth, development and survival of salmon eggs and young are dependent on other chemical and physical properties of the surrounding water. These properties are in turn dependent upon the size composition of the bottom materials, which greatly affect water quality by controlling flow rates and rates of exchange between intragravel and stream water. The presence of fine particles such as silt and sand in spawning beds decreases permeability and has been shown to increase egg and larval mortality of several salmonid species (Shapovalov, 1937: 209; Shaw and Maga, 1943: 40; Cordone and Kelley, 1961:204; Wickett, 1958:1117-1124).

Substrate type is also very significant in determining both type of benthic organisms present and their population densities. Tarzwell (1937:182) rated various bottom types in terms of relative productivity of benthic organisms. Part of this rating system, in which sand is considered least productive and other substrates are assigned numbers relative to sand, follows: sand 1, marl 6, fine gravel 9, sand and silt 10.5, gravel and sand 12, sand, silt and debris 13, gravel and silt 14, rubble 29, coarse gravel 32, mucky areas 35, medium gravel 36, gravel and rubble 53, moss on gravel and rubble 140. Odum (1959:320) lists sand or soft silt as the least favorable bottom type, with flat or rubble rocks as generally producing the largest variety and density of bottom organisms.

McNeil and Ahnell (1964:6) found that permeability was high where bottom material contained less than 5 per cent by volume of sands and silts which pass through a 0.833 millimeter sieve, and that low permeability occurs when more than 15 per cent of the material passes this sieve size. If these results are used as a guide, very few of the study streambeds have more than low permeability (Table 2).

It should be remembered that volumes were measured while the silt and sand was wet; thus, the figures presented in Table 2 may be slightly higher than actual values.

Table 2 shows little variation among samples at most stations. For example, Killinger Creek (below the mined areas) and Cripple Creek shows only slightly greater per cent of particles less than .841 mm diameter. An exception is station B-2 which showed considerable varia-

Table 2. Summary of streambed composition at stations on the Cripple Creek study area, summer, 1967. Figures represent per cent of each particle size class in the samples. Station nomenclature is explained in Fig. 2.

Station	Particle size class (millimeters)-									
	larger than 19	12.7-19	6.35-12.7	3.36-6.35	1.68-3.36	.841-1.68	.420-.841	.210-.420	smaller than .210	smaller than .841
K-3	62.5	5.8	9.7	5.2	3.6	3.0	4.0	2.8	3.5	13.3
K-2	56.2	5.9	8.5	5.7	5.9	7.2	6.5	2.6	1.6	17.9
K-1	64.5	4.8	6.4	4.6	4.9	7.6	4.2	1.2	1.8	14.8
C-3	61.9	5.9	6.1	4.6	5.4	6.4	4.5	2.4	2.7	16.0
C-2	45.7	7.6	10.6	7.7	7.9	10.1	6.4	2.4	1.5	20.4
C-1	53.5	6.7	10.7	5.7	4.5	6.2	7.7	2.4	2.6	18.9
B-2	39.0	7.3	9.4	7.1	8.3	11.2	13.3	2.3	2.2	29.0
B-1	63.3	6.4	7.2	5.4	6.2	7.3	5.2	1.4	2.9	16.8
Cr-2	53.7	5.5	8.7	9.2	9.1	7.0	3.4	1.2	2.2	13.8
Cr-1	43.9	7.2	10.9	10.6	10.5	7.6	3.9	1.7	3.6	16.8
W-2	59.8	5.9	7.5	6.5	5.2	5.6	5.3	2.3	2.0	15.2
W-1	53.9	6.4	11.7	8.4	6.0	5.4	4.0	1.9	2.2	13.5

tion from the rest of the stations. This unusually high per cent of sand and silt was not apparent without sampling. The results at this station appear in contradiction to the large volume of benthic organisms present here. However, it should also be noted that most of that portion of the substrate less than 0.841 mm was actually medium to coarse sand, while in terms of fine sand and silt (less than 0.420 mm), the percentages at station B-2 were on a par with other stations.

To summarize the streambed composition portion of the study, it should be noted that the sampling technique was inadequate to give reliable results. This inadequacy was discussed briefly in the section on Procedures and Techniques. Further, the results do indicate, in spite of their inadequacy, that streambeds at most of the stations are of low permeability, as defined by McNeil and Ahnell (1964:6).

In addition, visual inspection showed that streams draining manganese strip mines contain much more deposited silt of extremely fine size than do control streams. This is not so apparent in rapids areas (where the sampling was attempted), but it can be readily seen in the pools. Deep deposits of brown clay silt were observed in the deeper pools of Killinger, Cripple, and Blue Spring Creeks. The entire substrate of that portion of Killinger Creek below the mined areas had a brown silty appearance. In contrast, very little silt was apparent in the pools of control streams, and most silt there seemed to be of a dark organic nature.

Perhaps much thorough sampling of streambed composition would be required in these streams to determine their relative suitability as spawning sites for trout. The fact that rainbow trout fingerlings were found at both stations on Blue Spring Creek proves that at least some tolerable (if not suitable) sites are available to this species in this stream. No direct correlation was found in the study streams between permeability as expressed by intragravel oxygen concentration and relative streambed composition.

Bedload

According to Gottschalk and Jones (1955:137), sediment is transported in streams in one of two ways: suspended load and bedload. Suspended load is distributed throughout the cross section of the stream channel and moves at the same rate as the stream current. Bedload is carried by sliding or rolling along the bed, and normally moves much slower than the current.

As Cordone and Kelley (1961:191) pointed out, a knowledge of the physical nature of sediment and its movements is of fundamental importance in understanding the modes by which sediment modifies the aquatic environment. With this in mind, bedload was sampled in the study streams to determine the relative stability of the various streambeds.

As shown by Fig. 12, the average bedload of either Killinger, Cripple, or Blue Spring Creeks is much greater than that of either of the control streams. Bedload was practically undetectable at the upper stations on White Rock and Crigger Creeks. It should be noted that

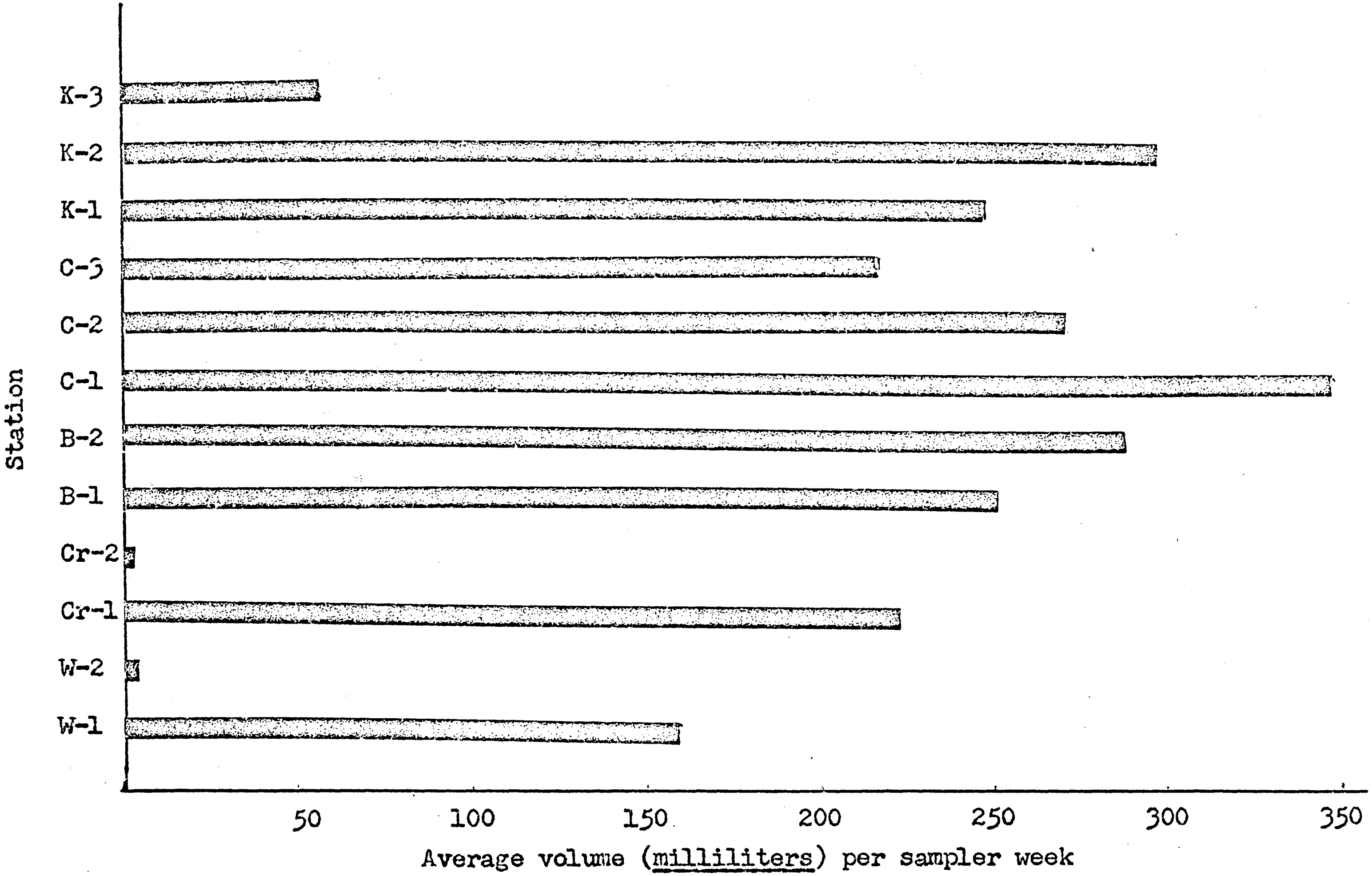

Fig. 12. Bedload at stations on Cripple Creek and tributaries, summer, 1967. Station nomenclature is explained in Fig. 2.

the values given in Fig. 12 are averages of three sampling periods, two during normal flow and one during slightly above normal flow. Most of the bedload at all stations was collected when flow was above normal. However, at station K-2, a much greater portion of the total bedload was collected during normal flow than at other stations.

On Killinger Creek average bedload at station K-2 was about five and one-half times greater than at station K-3, which lies above the mined areas. From station K-2 bedload decreased somewhat at the next two stations downstream, probably due to dilution from White Rock Creek and Cedar Springs, which enters Cripple Creek above station C-3. From station C-3 bedload increased downstream on Cripple Creek as the flow volume increased.

On Blue Spring Creek, bedload was comparable to that of Killinger Creek, but turbidity was not nearly as great as on Killinger. This is probably due to the fact that, since reclamation on the Blue Spring Creek watershed, very little fine silt reaches the stream. Bedload, on the other hand, is still relatively high because of the large amount of silt and sand which has accumulated in the stream channel and which has not yet been flushed out.

In addition, bedload at the lower station on Blue Spring Creek showed a much greater per cent of fine silt (less than .210 mm diameter) than did the upper station (Fig. 13). This seems to indicate further that much of the finest silt has been flushed out of the upper portion of Blue Spring Creek but is still abundant in the lower portion. It appears that since reclamation has stopped the addition of mine silt,

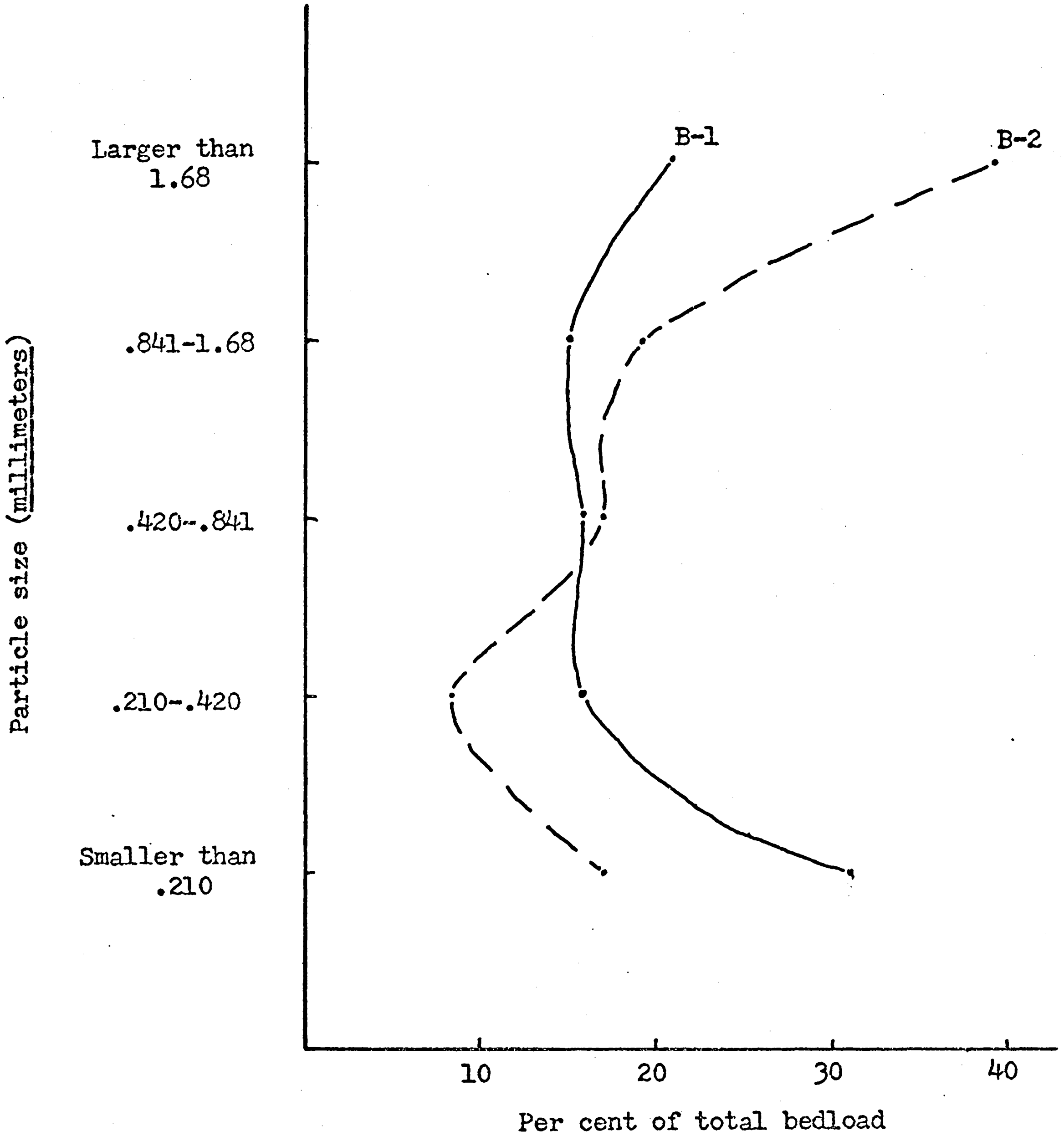

Fig. 13. Size distribution of bedload at stations B-1 and B-2, the lower and upper stations, respectively on Blue Spring Creek, summer, 1967.

the stream will eventually be flushed free of most of the silt which has accumulated from that source.

Turbidity

According to the American Public Health Association (1965:312), turbidity is an expression of the optical property of a sample of water which causes light to be scattered and absorbed instead of transmitted in straight lines through the sample. Turbidity is caused by the presence of suspended matter such as silt, clay, organic matter, plankton and other microscopic organisms.

Of the many causes of turbidity, erosion silt is probably the major one (Ellis, 1931:4). All natural waters are turbid to some degree, with extremes ranging from the purest mountain streams to the muddiest of rivers (Welch, 1935:81). Turbidities as high as 32,000 ppm have been reported on the Missouri River (Wallen, 1951:2).

The effects of turbidity on the aquatic environment are numerous. For example, turbidity may be a limiting factor in the environment of certain aquatic animals which feed by sight (Doan, 1942:452). In addition, photosynthesis of plants may be greatly hampered by turbidity (Cordone and Kelley, 1961:211). Welch (1935:167) gives evidence that turbid waters are warmer than clear waters.

Turbidities observed in the study streams are shown in Fig. 14. Station K-2 was considerably more turbid than any other station at both sampling periods. Cripple Creek also had high turbidities, but Blue Spring Creek was relatively clear, even during the period of above normal flow. The turbidity of affected streams may be due in

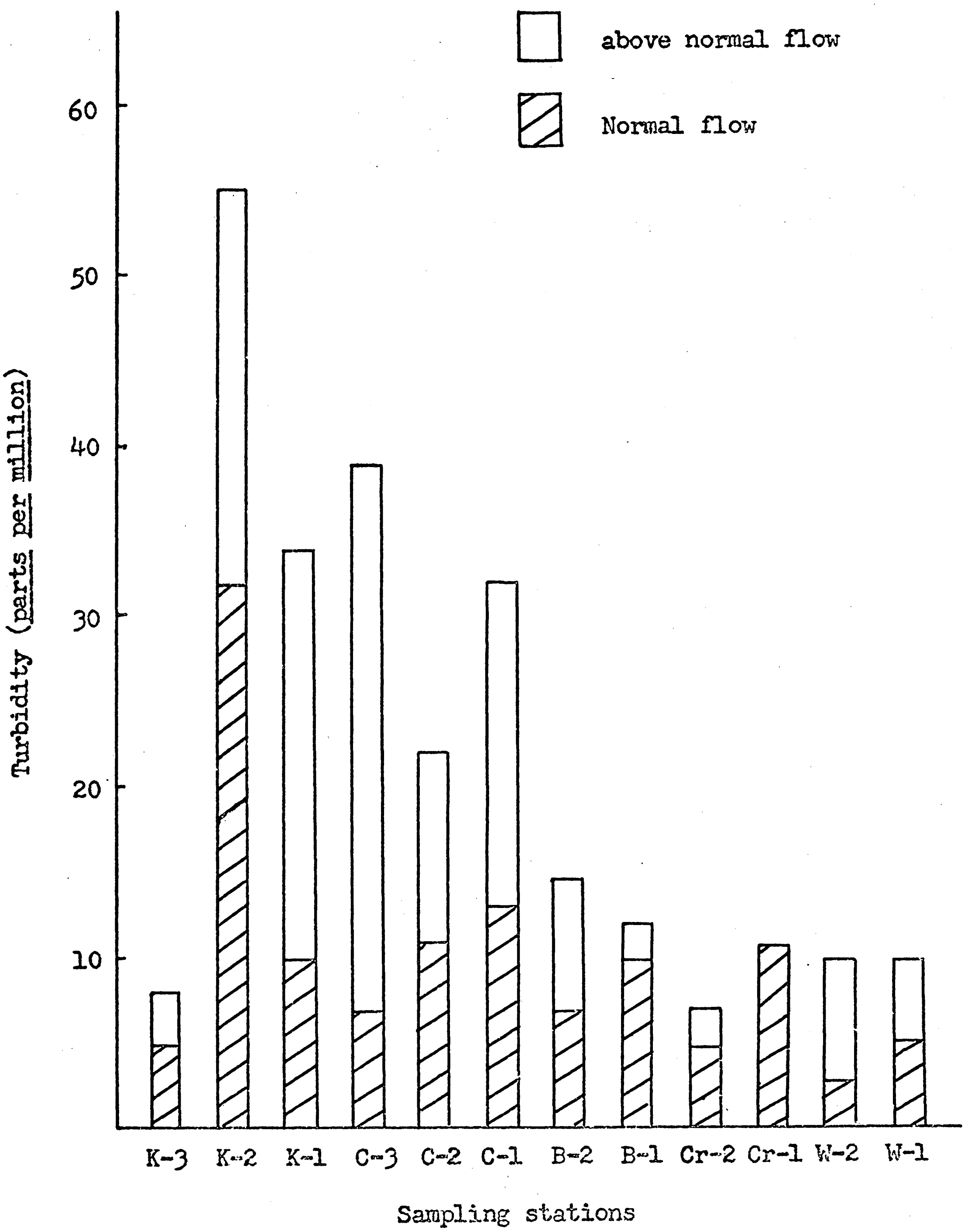

Fig. 14. Turbidities observed at stations on Cripple Creek and tributaries, summer, 1967. Station nomenclature is explained in Fig. 2.

part to colloidal suspensions of iron and manganese compounds (Taylor, 1949:90). Station K-2 on Killinger Creek, especially, was noticably milky even when flow was low. Turbidities in affected streams are doubtless much greater during heavy flow than those observed during the study period. It is probable that turbidities lethal to fish are not present in these streams, since those observed were well below lethal levels listed by Wallen (1951:18-24) for various fish species. Most of Wallen's test fish survived turbidities of 100,000 ppm for one week or more. However, turbidities may be high enough for short periods of time, in Cripple and Killinger Creeks at least, to physically injure fish to some extent (Ellis, 1944:12).

Temperature

Water temperatures recorded during the study period ranged from 7.5°C to 24°C. Table 3 lists average stream temperatures, by station, which were observed during the study period, as well as the standard deviation among samples at each station. The coolest station was K-3 while the warmest one was Cr-1. Station K-1 was also warm, averaging just 0.1°C lower than Cr-1. The warmer temperatures at these stations is most likely due to the shallow depth and lack of shade.

Munns (1948:354) contends that trout may move out of, or die, in streams where temperatures have been elevated due to turbidity. Although trout were less prevalent in turbid streams in the Cripple Creek drainage, this cannot be explained by temperature differences alone. Considering other common factors which affect stream temperatures, such as shade, depth and proximity to springs (Jones, 1964:153),

Table 3. Average water temperatures recorded at stations on Cripple Creek and tributaries, spring and summer, 1967

Station	Avg. Temp. (C)	Standard deviation	Station	Avg. Temp. (C)	Standard deviation
K-3	13.9	1.79	B-2	15.1	2.47
K-2	15.1	2.63	B-1	16.6	1.58
K-1	17.4	4.52	Cr-2	15.9	2.94
C-3	16.6	3.24	Cr-1	17.5	3.59
C-2	16.6	3.29	W-2	14.3	2.98
C-1	16.2	3.03	W-1	14.7	2.51

the variation of temperature in the study streams could be expected on the basis of differences in these factors alone.

Volume of Flow

Table 4 shows the calculated volume of flow at each station. Current meter readings were taken when flow was somewhat below normal. Flow was especially low at station W-2 on White Rock Creek, and was too low to measure at the time meter readings were taken.

Due to the karst nature of the region, many smaller streams are intermittent during dry seasons. Station W-2 is the only study station which is known to go dry. The headwaters of Blue Spring Creek are intermittent, but no stations were established above that portion which flows regularly.

Biological Aspects

Macrobenthic Organisms

Odum (1959:295) defines benthos as "organisms attached or resting on the bottom or living in the bottom sediments". Benthic organisms may be either primary or secondary consumers, and are an important link in the food chain of a stream. According to Behney (1937:77), food organisms available to stream fish come from two sources: organisms living in the stream, and organisms of terrestial origin which accidently fall into the stream. Needham (1928:197-203) demonstrated that 99.3 per cent of all available fish food comes from the stream bottom and that more than 83 per cent of food actually eaten by trout is aquatic in origin.

Table 4. Calculated volume of flow in cubic feet per second (c. f. s.) at stations on Cripple Creek and tributaries, summer, 1967

Station	c. f. s.	Station	c. f. s.
K-3	2.42	B-2	8.11
K-2	3.62	B-1	24.39
K-1	5.88	Cr-2	2.82
C-3	7.65	Cr-1	5.25
C-2	32.89	W-2	----
C-1	42.69	W-1	2.26

The effects of siltation on benthic organisms has been documented frequently. Ellis (1936:44) demonstrated that layers of fine silt produced high mortality to freshwater mussels by suffocation. Hynes (1963:124) maintained that rubble of the stream bottom may be coated with a fine layer of silt at times of slow flow, making the holdfast mechanisms of benthic organisms ineffective.

Probably more important than direct effects, siltation affects benthic organisms indirectly through destruction of the environment. The significance of substrate type to bottom fauna has already been discussed in the section concerning streambed composition.

That substrate type can be drastically altered by sedimentation is a well known fact (Tarzwell, 1938:249; Tebo, 1955:66; Cordone and Kelley, 1961:208). This alteration of substrate type generally involves a change from a stable substrate of gravel and rubble to a shifting sandy one. Bottom insects thus lose their hiding places due to deposition of silt between the stones, and find it difficult to acquire a grip on the substrate (Hynes, 1963:124).

Most of the adverse effects of silt on benthic organisms which have been documented in the literature appear to be at work in Killinger and Cripple Creek. The streambeds of both creeks are heavily silted. Especially at station K-2 and K-1, the crevices between substrate rocks are filled with silt. Also, rubble handled at these stations during benthic sampling was found coated with a slippery layer of fine clay silt. Finally, very little plant life was observed in Killinger Creek, probably due to its removal by the scouring action of the sediment (Jones, 1964:169).

A reduction of about 90 per cent by volume and more than 85 per cent by number of organisms per square foot (Table 5) was noted between station K-3 (above the influence of the mined areas) and station K-2 (below these areas). At station K-1 the quantity of organisms had increased significantly but was still less than half that observed at station Cr-1, a comparable station on a control stream.

Benthic collections on Cripple Creek also showed the effects of siltation. Volume of benthos at station C-3 was only slightly greater than at K-1. Station C-2 (below the mouth of Blue Spring Creek) showed an appreciable reduction from C-3 in number and volume of organisms. This again is evidence that, although Blue Spring Creek drains a reclaimed area and is not receiving much silt from mined areas, it still contributes sediment to the main stream during periods of high flow. Farther downstream on Cripple Creek, at station C-1, numbers of organisms per square foot, and particularly volume, increased sharply, indicating that the stream is recovering downstream from the effects of silt.

As illustrated by Table 5, the quantity of bottom fauna at both stations on Blue Spring Creek was relatively high. This is illustrated from the standpoints of volume, numbers, and number of families per square foot. Quantity of benthos was especially high at station B-2. This station showed much less evidence of fine silt than B-1, which was downstream. It is felt that this lends further evidence that, although reclamation on the watershed of Blue Spring Creek has

Table 5. Summary of benthic collections (average per square foot) taken on Cripple Creek and tributaries, spring and summer, 1967. Station nomenclature is explained in Fig. 2.

Station	Number of organisms	Volume (milliliters)	Number of families
K-3	44	0.50	10
K-2	7	0.03	3
K-1	79	1.15	9
C-3	305	1.92	13
C-2	119	1.21	11
C-1	189	5.52	14
B-2	344	5.04	15
B-1	161	2.80	12
Cr-2	48	2.44	12
Cr-1	176	4.10	15
W-2	17	1.96	6
W-1	79	0.70	11

haltered the entrance of fine silt at the stream's source, sediment has not yet been flushed from the lower portion of the stream.

Table 6 shows the distribution of taxa of benthic organisms at stations in the study streams. The great majority (87.1%) of these organisms belong to one of the five major orders of aquatic insects, that is, Trichoptera, Coleoptera, Plecoptera, Ephemeroptera, and Diptera. These results are in general agreement with other investigations (Pennak and Van Gerpen, 1947:43). Of the five major orders, the Plecoptera and Coleoptera occurred in the smallest numbers. Plecoptera were particularly scarce below the mined areas on Killinger Creek and at both of the upper stations on Cripple Creek. The scarcity of this order, which is most commonly found on rubble (Armitage, 1961: 165), at the above stations is probably directly related to the heavy siltation present there.

The Coleoptera, which also prefer rubble and coarse gravel (Pennak and Van Gerpen, 1947:43), were found to be scarce at stations K-2 and K-1, but were found in larger numbers at all stations on Cripple Creek. It appears that this order has not been affected as greatly by the siltation as has the Plecoptera.

The Diptera, Trichoptera, and especially the Ephemeroptera were found in relatively high numbers (81.8 per cent of all benthic organisms belonged to one of these orders) at all stations. This could be expected, since certain genera of these orders are known to adapt to a wider range of substrate type than are other orders (Pennak and Van Gerpen, 1947:43).

Table 6. Distribution of macrobenthic organisms (five square-foot samples per station) taken on the Cripple Creek watershed, spring and summer, 1967. Station nomenclature is explained in Fig. 2.

ORDER	Station-											
Family	K-3	K-2	K-1	C-3	C-2	C-1	B-2	B-1	Cr-2	Cr-1	W-2	W-1
COLEOPTERA												
Dryopidae	2	0	0	0	0	1	0	0	0	1	0	0
Elimidae	12	3	3	29	13	45	12	40	3	44	0	1
Hydrophilidae	0	0	0	0	0	0	0	0	0	1	0	0
Psephenidae	0	0	0	1	0	1	0	0	0	5	0	1
DECAPODA	2	0	1	2	0	41	0	0	5	5	1	3
AMPHIPODA	0	0	0	0	0	0	1	0	0	0	0	0
COPEPODA	1	0	0	0	0	0	0	0	0	0	0	0
EPHEMEROPTERA												
Baetidae	47	10	31	124	82	180	238	67	28	355	12	105
Ephemeridae	0	0	0	0	0	7	0	3	7	7	0	0
Heptageniidae	70	16	24	15	21	36	11	15	17	91	46	184
DIPTERA												
Tipulidae	3	0	12	50	5	24	43	2	8	13	6	15
Chironomidae	19	2	100	274	55	227	152	42	23	171	3	14
Ceratopogonidae	4	0	0	0	0	3	3	9	11	3	0	2
Simulidae	0	0	51	220	153	51	7	214	0	0	0	6
Empididae	1	0	2	7	0	17	0	4	0	0	0	3
Blepharoceridae	0	0	1	0	56	34	36	53	0	0	0	2
Psychodidae	0	0	0	0	0	0	0	0	0	1	0	0
Rhagionidae	0	0	2	1	0	1	0	0	0	1	0	0
Tanyderidae	0	0	0	0	0	1	0	0	0	0	0	0
Tabanidae	0	0	0	0	0	0	0	0	0	1	0	0

Table 6. Distribution of macrobenthic organisms (five square-foot samples per station) taken on the Cripple Creek watershed, spring and summer, 1967. Station nomenclature is explained in Fig. 2. (continued)

ORDER Family	K-3	K-2	K-1	C-3	Station- C-2	C-1	B-2	B-1	Cr-2	Cr-1	W-2	W-1
GASTROPODA	0	0	0	0	30	19	424	244	0	51	0	0
HEMIPTERA	0	1	0	0	0	0	1	6	0	4	0	0
HYDRACARINA	0	0	0	0	1	0	0	0	0	8	0	0
MEGALOPTERA												
Corydalidae	0	0	0	0	1	0	0	0	0	1	0	0
NEMATODA	0	0	2	1	2	1	0	3	0	2	0	0
ODONATA												
Gomphidae	1	0	0	0	0	0	0	0	2	1	0	0
OLIGOCHAETA	19	0	5	35	0	16	16	6	8	27	3	4
PELECYPODA	0	0	0	0	0	0	2	0	0	0	0	0
PLECOPTERA												
Perlidae	8	0	1	1	0	0	4	0	24	2	0	2
Perlodidae	2	0	0	3	0	0	6	0	5	0	1	7
Nemouridae	1	2	0	6	1	3	6	1	57	17	3	5
Chloroperlidae	3	0	1	0	0	0	1	0	4	3	2	7
Pteronarcidae	0	0	0	0	0	0	0	0	1	0	0	0

Table 6. Distribution of macrobenthic organisms (five square-foot samples per station) taken on the Cripple Creek watershed, spring and summer, 1967. Station nomenclature is explained in Fig. 2. (continued)

ORDER Family	Station- K-3	K-2	K-1	C-3	C-2	C-1	B-2	B-1	Cr-2	Cr-1	W-2	W-1
TRICHOPTERA												
Brachycentridae	0	0	0	0	0	0	7	0	0	0	0	0
Glossosomatidae	6	5	30	202	112	71	47	28	1	30	1	19
Goeridae	1	0	0	0	0	1	6	1	0	0	0	0
Hydropsychidae	8	0	117	544	37	145	108	56	17	17	0	3
Hydroptilidae	0	0	0	1	1	1	0	0	0	0	0	0
Lepidostomatidae	0	0	0	0	0	0	0	0	0	0	1	0
Limnephilidae	2	0	0	1	16	4	5	6	0	14	0	1
Odontoceridae	0	0	0	0	0	0	585	0	0	1	0	0
Philopotamidae	0	0	9	4	0	2	0	2	3	0	1	6
Psychomyiidae	0	0	3	0	1	0	0	0	4	2	1	1
Rhyacophilidae	4	0	2	10	5	4	2	3	1	0	2	3

Of the remaining taxa which were found in the study streams, the Gastropoda show the most striking variation among stations. These were found in great numbers on Blue Spring Creek, which is probably best explained by the fact that this stream drains a limestone valley and is high in dissolved salts, especially calcium carbonate, which is needed for shell construction (Pennak, 1953:680). The high salt content of this water is verified by the high alkalinity and hardness readings on this stream. Numerous gastropods were also found at station Cr-1 and the lower stations on Cripple Creek, stations at which alkalinity and hardness readings were also high.

Fish Distribution

In all, 17 species of fish were collected at the 12 study stations. Table 7 lists these species according to their scientific and common names as given by the American Fisheries Society (1966).

Table 8 shows the distribution of species collected in the Cripple Creek drainage. Clearly, the blacknose dace is the most common species in these streams; it was found at all but one station and in the greatest number of all species. This species was most abundant at station Cr-1, on a control stream, but was also very abundant at stations K-1 and K-2 and at all Cripple Creek stations. This distribution indicates that the blacknose dace can adapt well to turbid water and siltation, even though it may prefer clear streams (Harlan and Speaker, 1956:91; Forbes and Richardson, 1920:163).

Table 7. List of species of fish collected on Cripple Creek and tributaries, 1967. Common and scientific names are from American Fisheries Society (1966).

Common name	Scientific name
Fantail darter	*Etheostoma flabellare* Rafinesque
Blacknose dace	*Rhinichthys atratulus* (Hermann)
Longnose dace	*Rhinichthys cataractae* (Valenciennes)
Rosyside dace	*Clinostomus funduloides* Girard
Mountain redbelly dace	*Chrosomus oreas* Cope
Silver shiner	*Notropis photogenis* (Cope)
Creek chub	*Semotilus atromaculatus* (Mitchill)
White sucker	*Catostomus commersoni* (Lacepede)
Northern hog sucker	*Hypentelium nigricans* (LeSueur)
Green sunfish	*Lepomis cyanellus* Rafinesque
Pumpkinseed	*Lepomis gibbosus* Linnaeus
Bluegill	*Lepomis macrochirus* Rafinesque
Stoneroller	*Campostoma anomalum* (Rafinesque)
Tonguetied minnow	*Parexoglossum laurae* Hubbs
Rainbow trout	*Salmo gairdneri* Richardson
Brook trout	*Salvelinus fontinalis* (Mitchill)
Sculpin	*Cottus* sp.

Table 8. Distribution of fish and total numbers caught in Cripple Creek and tributaries, 1967. Station nomenclature is explained in Fig. 2.

Common name	Station-											
	K-3	K-2	K-1	C-3	C-2	C-1	B-2	B-1	Cr-2	Cr-1	W-2	W-1
Fantail darter	0	0	8	5	20	34	0	1	15	327	0	0
Redbelly dace	0	6	52	2	4	3	0	0	18	5	0	0
Rosyside dace	0	3	59	24	65	28	0	1	13	3	0	0
Longnose dace	0	0	0	0	1	12	0	2	0	0	0	0
Blacknose dace	0	251	533	402	239	271	305	41	268	732	85	139
Silver shiner	0	0	0	0	2	15	0	0	0	20	0	0
Tonguetied minnow	0	0	3	0	0	3	0	1	0	4	0	0
Creek chub	0	6	42	3	0	0	0	0	0	2	4	5
Stoneroller	0	1	0	0	2	14	0	0	0	34	0	0
Sculpin	0	0	0	61	79	77	161	73	1	119	0	0
White sucker	0	2	50	27	28	27	1	10	0	6	0	0
Hog sucker	0	0	0	0	1	6	0	0	0	0	0	0
Rainbow trout	0	0	0	1	0	1	8	1	1	0	0	0
Brook trout	14	0	0	0	0	2	1	0	0	0	8	0
Pumpkinseed	0	0	0	2	0	0	0	0	0	0	0	0
Green sunfish	0	0	0	4	0	0	0	0	0	0	0	0
Bluegill	0	0	0	1	0	0	0	0	0	0	0	0

Other fishes which seem to do well in silted study streams are the rosyside dace and the redbelly dace; the former was found in greatest number at station K-1. The creek chub and the white sucker were also found in greatest number at station K-1.

Although certain members of the minnow family and the white sucker appear in greatest numbers in the silted streams, no game fish (except the sucker) were taken on Killinger Creek below the mined areas. On Cripple Creek, the only game fish were an occasional stocked trout and three species of Centrarchidae at station C-3, which undoubtedly were escapees from several pay-fishing ponds located beside this station.

In contrast to the types of fish found in the silted streams, native brook trout were found at two stations; K-3, above the mined areas on Killinger Creek, and W-2 on a control stream. In addition to native trout, rainbow trout fingerlings were found at both stations on Blue Spring Creek, indicating that spawning is taking place on this reclaimed stream.

Overall, sampling in the study streams revealed that cyprinid fishes far outnumber all other types. According to Everhart (1958: 66) this can be expected because of the wide variety of habitats and food types utilized by this family. Minnows occupy an important role in the food chain of a stream, providing forage for more desirable game fish. However, the presence of large numbers of minnows may make a stream less desirable to competing game fish such as the brook trout which seems to thrive best in waters which no other fish inhabit (Everhart, 1958:47).

The distribution of the fantail darter in the study streams indicates that this species may be intolerant of silty conditions. Darters are known to prefer swift, shallow riffles (Thompson and Hunt, 1930:59), but although these conditions existed at practically all stations, the fantail darter was found in large numbers only on Crigger Creek, a control stream which is free of the fine clay silt typical of streams draining mined areas.

The small numbers of species of fish observed in White Rock Creek (a control stream) needs clarifying. Much of the lower portion of this stream is known to dry up during exceptionally dry seasons. Therefore, the abundance of fish in this section of the stream at any given time would depend on the time since the section last went dry and on the rate of re-invasion by new individuals. Larimore, et. al. (1959:282) list several factors which govern the rate of re-invasion of a stream habitat. The most limiting factor on White Rock Creek is probably a barrier. A corrugated metal culvert, installed at the mouth of this stream where it flows under route 715, forms a small fall, at the base of which is a broad, smooth slab of concrete. The lack of a plunge pool probably makes it difficult for fish to attain sufficient speed to hurdle this small fall, restricting re-invasion of this stream from below.

Of the documented influences of siltation on fish fauna, those at work in the study streams appear to be largely indirect, through destruction of food organisms, spawning sites, and cover. Silt in suspension is probably the only direct effect at work in these streams, and this apparently occurs only occasionally and for comparatively short periods of time. Perhaps the best way to sum up the effects of silt on the fish populations of the Cripple Creek drainage is to quote from Aitken (1936:1059), who writes of stream conditions in Iowa. "The gradual change in the stream environment caused by erosion has brought about a corresponding change in the fish fauna. Where once abounded those types of fish that preferred cold, clear waters, today are found forms that are able to live in warm, turbid, and oftentimes polluted streams."

Manganese Toxicity Experiment

The hypothesis that manganese may be present in toxic concentrations in those streams in the study area which drain manganese strip mines grew largely from the fact that many of the heavy metals (which include manganese) are known to be toxic to many fish species. According to Jones (1939:437), the heavy metals precipitate the gill secretions and cause death to fish by asphyxiation. Jones (1939:436) lists manganese as the least toxic of the heavy metals due to its high solution pressure, making it slow to combine with other ions or compounds (in this case, the proteins of the gill secretions).

A literature search concerning the toxicity of manganese to fish resulted in conflicting information. No information was found concerning the toxicity of manganese to any of the fish species present in the study streams. Therefore, a controlled experiment with rainbow trout fingerlings was considered important to the overall study.

The findings of the toxicity study are presented in Fig. 15. The results of the final experiment indicate that the median tolerance limit (TL_m) for rainbow trout fingerlings is about 16 ppm manganese. Results of the preliminary experiment, which established the range of the concentrations to be used for the final experiment, support the above findings. During the preliminary study, fish were subjected to concentrations of 1.6, 16, and 160 parts per million manganese. At the end of the 96-hour period, 7 out of 12 or 58 per cent of the test fish were dead. If the results of both experiments are combined, the 96-hour TL_m is found to be slightly less than 16 ppm (Fig. 16).

The 96-hour TL_m is only a useful measure of acute toxicity under certain experimental conditions and does not represent concentrations which may be considered safe in natural stream habitats subject to continuous exposure (American Public Health Association, 1965:559). In addition, under natural stream conditions, the toxicity of a given pollutant may be only a fraction of the established 96-hour TL_m. Finally, the TL_m determined by the above experiment is most useful only when viewed in the light of the results of the on-the-site sampling in the study streams. The conditions of the above experiment are summarized in Table 9.

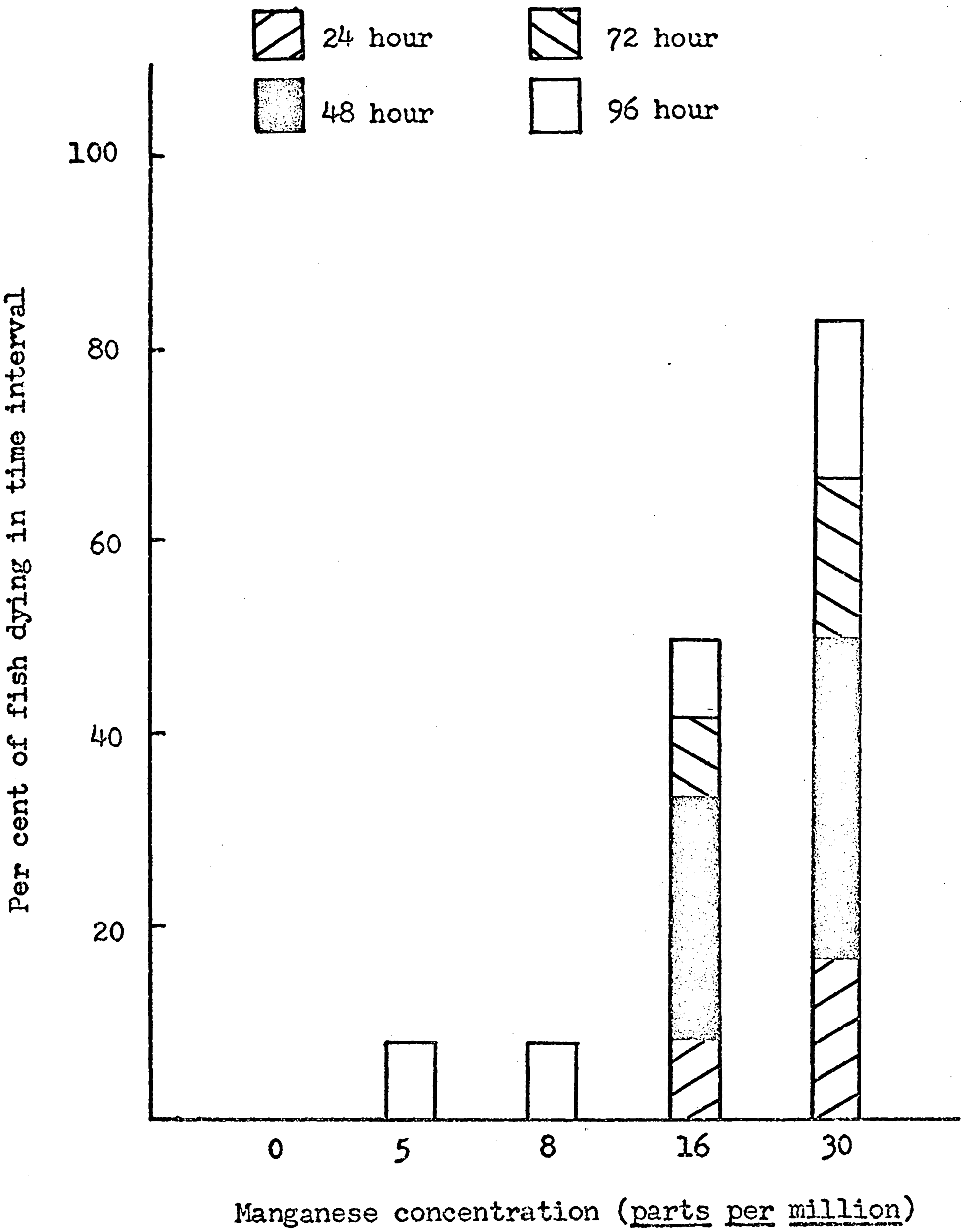

Fig. 15. Results of the manganese toxicity experiment (final run), Wytheville National Fish Hatchery, December, 1967.

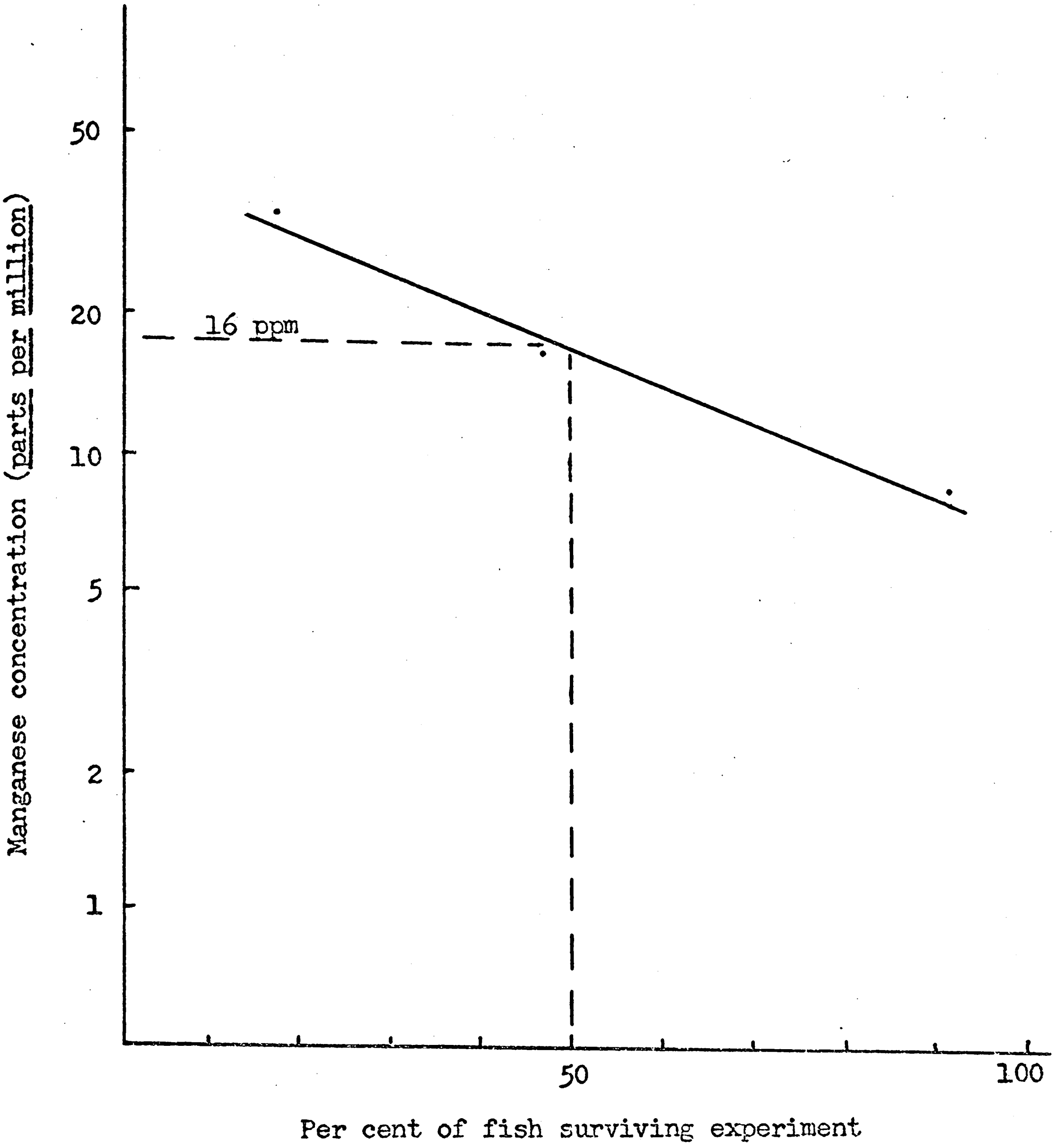

Fig. 16. Results of manganese toxicity study (preliminary and final runs combined), showing the 96-hour TL_m about 16 ppm.

Table 9. Average conditions of the manganese toxicity study for each concentration used, December, 1967

	Manganese concentration (ppm)	Oxygen (ppm)	Carbon dioxide (ppm)	Alkalinity (ppm)	Calcium hardness (ppm)	Temperature (C)	pH	Fish length (centimeters)	Fish weight (grams)
P	1.6	8.3	6.1	84	58	12.6	7.9	5.05	2.20
	16.0	8.5	6.1	83	59	12.6	7.8	5.23	2.59
	160.0	9.2	6.0	84	60	12.6	7.9	5.23	2.55
	0.0	8.2	6.4	83	59	12.6	7.9	5.29	2.63
F	5.0	8.4	5.5	87	59	12.6	7.6	5.53	2.93
	8.0	8.4	6.0	90	59	12.6	7.6	5.78	3.21
	16.0	8.5	6.1	88	58	12.6	7.6	5.46	2.93
	30.0	8.9	6.1	87	62	12.6	7.6	5.32	2.91
	0.0	8.5	5.9	89	65	12.6	7.6	5.47	2.75

P-- preliminary experiment

F-- final experiment

RECOMMENDATIONS

Following are suggestions for related research which the author feels would be especially beneficial.

1. Controlled experiments with different manganese salts to establish chronic toxicity limits for various species of fish, and possibly benthic organisms and algae. These chronic limits would more closely correspond to actual stream conditions and would be very helpful in determining whether manganese is toxic in a given situation.
2. Further work on the ecology of benthic organisms, preferably at the species level, to determine which organisms can be most reliably used as indicators of silt pollution.
3. More research on sediment transport and deposition in stream channels and its effects on the physical aspects of the substratum.

SUMMARY AND CONCLUSIONS

The results of this study may be summarized as follows:

1. Pollution from abandoned manganese strip mines has caused severe damage to certain streams in Smyth and Wythe Counties, Virginia.
2. The nature of the pollution appears to be inorganic silt.
3. No definite evidence was found that manganese ions in solution occur in toxic concentrations in the streams studied.
4. A controlled experiment with manganese nitrate indicated that the 96-hour TL_m for rainbow trout fingerlings is around 16 parts per million manganese, which further indicates that manganese is not toxic in these streams.
5. Results of physical and biological sampling indicate that reclamation has been effective on the Blue Spring Creek watershed. Turbidity on Blue Spring Creek was comparable to control streams, and bedload data indicated that the stream is gradually being cleared of the fine silt deposits which resulted from mining activity. The high production of macrobenthic organisms found on Blue Spring Creek and the fact that rainbow trout are spawning lends further evidence that reclamation has been very effective.
6. The effects of silt pollution were evident at all stations on the main stream, but they were markedly less noticable at the lower station on Cripple Creek.

7. The effects of siltation were most evident on Killinger Creek, which drains a strip-mined area that is only partially reclaimed. This stream showed approximately a 90 per cent by volume and more than 85 per cent by number reduction of benthic organisms from station K-3, above the mined areas, to station K-2, below them. Native trout were found only above the mined areas on this stream.
8. Fish of the non-game type are dominant in the study streams, with the highest percentage of game fish occuring at stations unpolluted by mine silt.

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SOME EFFECTS OF MANGANESE STRIP-MINING IN SMYTH COUNTY ON STREAM ECOLOGY

by

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ABSTRACT

Abandoned manganese strip mines in Smyth County, Virginia have for many years contributed pollution to the streams draining them. Streams in the Cripple Creek drainage area were sampled during the summer of 1967 to determine the nature and extent of pollution in them, and to evaluate the reclamation work being done by the United States Forest Service. Affected streams were compared with control streams on the basis of physical, chemical and biological properties.

Manganese levels in all streams sampled were found to be below one part per million. A controlled experiment with $Mn(NO_3)_2$ showed that the median tolerance limit for rainbow trout fingerlings is about 16 ppm Mn which, together with stream sampling data, indicates that manganese is not present in toxic concentrations in the study streams.

Killinger Creek, which drains a partially reclaimed area, was found to support fewer species of fish and benthic fauna than Crigger Creek, a comparable control stream. Siltation is probably the main contributing factor. Bedload was much greater in affected streams than in control streams. Although volume of bedload was high in Blue Spring Creek, which drains a reclaimed area, particle size distribution of the bedload indicates that much of the finest silt has been flushed

from the upper portion of this stream. Blue Spring Creek supports an abundant population of aquatic insects and fish fauna, indicating that reclamation has been effective on this watershed. It was also found that rainbow trout are spawning successfully in this stream.