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STREAM DAMAGE FROM MANGANESE STRIP-MINING

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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.

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INTRODUCTION

Stream pollution from strip and surface mining is widespread in many areas of the United States. This type of pollution takes various forms, and depends largely on the nature of the substance being mined and on the methods used. In southwestern Virginia several streams have been affected by manganese strip-mining which occurred in that area at various intervals during the early part of the 20th century. While much of the disturbed land has been reclaimed, there is still some work to do to complete the restoration. The majority of recent studies of strip mine pollution of streams have dealt with the problems of toxic wastes. Some of the studies pertinent to the Appalachian region include Musser (1963), Turner (1958), Warner (1965), Lloyd and Jordan (1964). The problems of stream siltation have been documented in less detail. Ellis (1936), Sido and Mackenthun (1963), and Peters (1962) studied the effect of stream silt from various sources. There seems to be no documentation of pollution from manganese strip mining. Further, very little information is available relating degree of reclamation with stream recovery.

In the Spring of 1967 a study was begun to document damage to streams draining abandoned spoil banks. The objectives of this study were (1) to determine the extent of mine-caused damage to the Cripple Creek watershed, (2) to describe the effects of the strip-mine effluents on the aquatic community, and (3) to determine whether measurable recovery was occurring in a stream draining a reclaimed area.

PROCEDURES

Five streams on the headwaters of Cripple Creek in southwestern Wythe Co. and southeastern Smyth Co., Virginia were studied (Fig. 1). Killinger Creek drained an area on Glade Mountain which had been extensively disturbed and on which very little reclamation had been

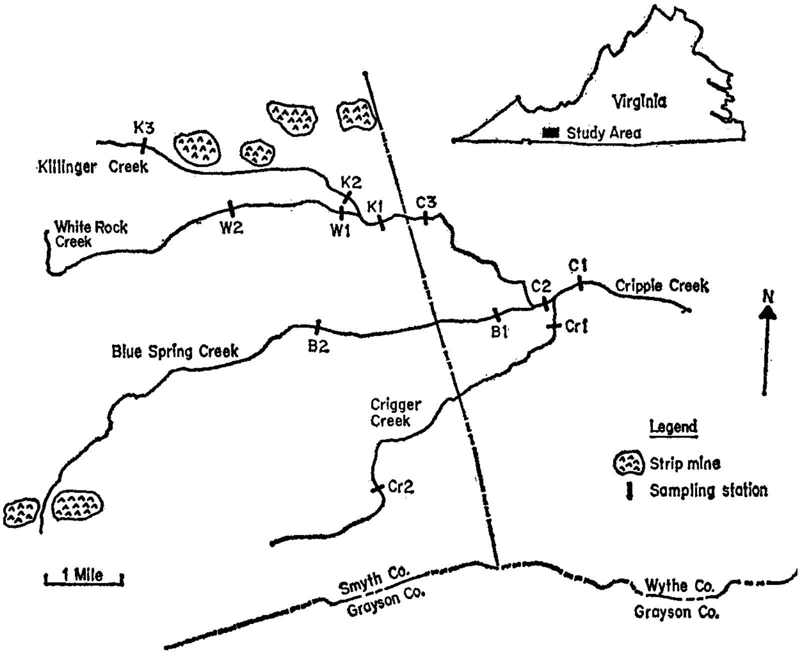

FIG. 1. Cripple Creek study area with location of manganese strip mines and sampling stations.

completed. Blue Spring Creek drained a reclaimed area on Iron Mountain. White Rock Creek and Crigger Creek were control streams, unaffected by strip-mining. Cripple Creek, the main stream, was sampled between the mouths of the above tributaries.

Fish collections were made by shocking and/or seining. A record was kept of the number of each species collected at each station. All collections were preserved and later identified to species.

Macrobenthic organisms were collected using the unmodified Surber square foot sampler. Five samples were collected from each station and then preserved and later identified to family. Total volume of each sample was determined by displacement in ethanol.

Bedload was measured in the study streams using a modification of the pit sampler described by Hubbell (1964). One-pound coffee cans with removable plastic lids 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 several days. 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. Cans were checked periodically, and removed when the first one appeared nearly full (usually after about one week). 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.

Streambed composition was measured by digging 8 inches into the streambed with a steel spud-like device designed for planting seedlings. The substrate was removed by hand and placed into a 12-quart bucket. A large funnel-shaped device, constructed of sheet metal and U. S. Standard sieves, was positioned directly downstream from the sample site to catch sand and silt displaced by the current (Fig. 2). Three samples were taken at each station.

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, 0.841, 0.420, 0.210. The volume of particles retained by each sieve was measured by displacement using a method described by McNeil and Ahnell (1964). Silt which passed through the finest sieve was collected in a tub, then placed in a large funnel with a 500 ml graduate connected to the bottom, and allowed to settle for 30 minutes. The volume of silt was then read directly from the graduate.

Turbidity, expressed as parts per million silicon dioxide, was determined using a Bausch and Lomb Spectronic 20 colorimeter. Water samples for turbidity were taken from the stream surface in rapidly flowing water.

The following chemical determinations were made with the Hach Chemical Company's model AL-59 kit: alkalinity, hardness, free carbon dioxide, and dissolved oxygen. The Hellige glass comparator was used to determine pH. Water chemistry was done at all stations on the same day.

The Hach Chemical Company's method was used for manganese determinations. Water samples were collected at midstream and acidified immediately. Determinations were made with a 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; manganese concentration, as parts per million, was determined from the curve with percent absorbance being known.

A routine bioassay study was made of the acute toxicity of manganese to rainbow trout fingerlings at the Wytheville National Fish Hatchery Number 2 at Max Meadows, Virginia. Tests were run in 15-gallon glass aquaria set in fiberglass rearing troughs containing a running water bath for temperature control. The source of water for the experiment

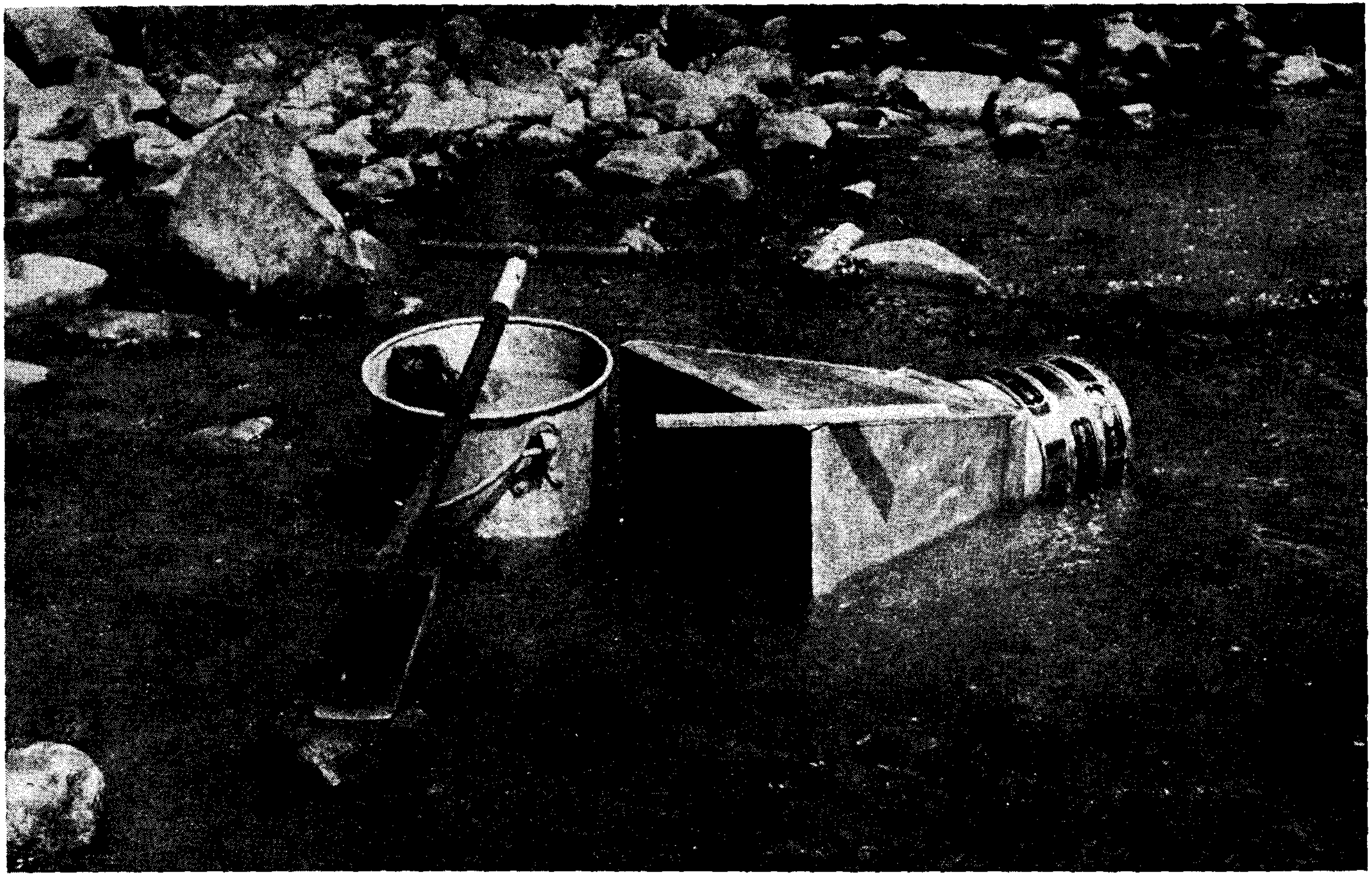

FIG. 2. Equipment used in measuring stream bed composition.

was a large spring which supplies the hatchery. This water was found to be chemically similar to the water in the nearby study streams. Two tests were run using manganese (-ous) nitrate ($Mn(NO_3)_2$) for 96 hours. The criteria for death was complete lack of movement.

RESULTS AND DISCUSSION

According to Miller (1944), Shady dolomite and its residual clay underlie most of the valleys and lower mountain slopes of the Glade Mountain district. Erosion of the overlying material at the crests of ridge spurs has exposed the clay, along with its deposits of iron and low-grade manganese ores.

Prior to World War I iron was mined in this area on a limited scale. Then, an acute shortage of manganese during the war caused a shift of emphasis from iron to manganese mining. Prices dropped after the war, and mining was discontinued, but shortages during World War II and the Korean War brought renewed mining activities. Finally, in the 1950's mining stopped and the stripped areas were abandoned (Fig. 3). Natural revegetation did not occur and erosion proceeded at a rapid rate.

In 1961 the United States Forest Service began reclaiming stripped areas on Iron Mountain by grading the spoil banks and seeding them with pine and locust and various grasses (Fig. 4). Settling ponds were built to check the movement of silt; gabions and culverts were installed for drainage channels. By 1965 all stripped areas on Iron Mountain had been revegetated—a total of about 115 acres.

On Glade Mountain reclamation began in 1965. Progress was rapid at first and by the end of 1966 more than half of the 227 disturbed acres had been graded and seeded. Then, reclamation funds decreased, and work slowed down. When this study was completed early in 1968, 84 acres on Glade Mountain were still subject to heavy erosion. Forty-five acres still lay bare by 1971, with no projected date for complete reclamation.

CHEMICAL ANALYSIS

The results of water chemical investigations at all stations is presented in Table 1. Water chemistry is about what one would expect for headwater streams such as those studied, and certainly well within tolerable limits of most fish species (Lagler, 1956; Ellis, 1937).

Manganese concentrations were found to be low at all stations. These results are in agreement with McKee and Wolf (1963) who give 1.0 ppm as the upper limit for manganese concentration in most surface waters. The slightly higher manganese reading at station K2, which lies just below the unreclaimed area on Killinger Creek suggests that the spoil banks are contributing somewhat to the manganese concentration in the stream, but not to a large extent. The high reading at Crl (a control stream) suggests that stream concentration of manganese may be independent of exposed spoil banks. Considering the low solubility of the manganous oxide ore deposits of the district (Miller, 1944; Goldschmidt, 1958), one would not expect high manganese concentrations in these streams.

MANGANESE TOXICITY TO RAINBOW TROUT

Many of the heavy metals are known to be toxic to many species of fish. According to Jones (1939), the heavy metals precipitate the gill secretions and cause death by suffocation. Jones found 40 ppm $MnNO_3$ the lethal limit (that concentration at which the experimental fish lived for 10 days) to stickleback.

Clemens and Sneed (1959) reported that 500 ppm manganese disodium versenate (4 ppm manganese) was "tolerated" by fingerling catfish for four days. On the other hand, Thomas (1915) found 12 ppm MnCl fatal to killfish (*Fundulus heteroclitus*) in six days in fresh water.

The median tolerance limit (TL_m) for rainbow trout fingerlings is about 16 ppm manganese (Fig. 5). The conditions of the toxicity study are summarized in Table 2. The 96-hour TL_m is only a useful measure

FIG. 3. Spoil banks remaining after abandonment of manganese strip mines

FIG. 4. Reclaimed area of spoil bank which has been graded and seeded with grasses and trees

TABLE 1. Summary of water chemistry (expressed as parts per million, except pH) at all stations on the Cripple Creek watershed, summer, 1967.

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	..	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	0.82	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	6.6	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

TABLE 2. 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

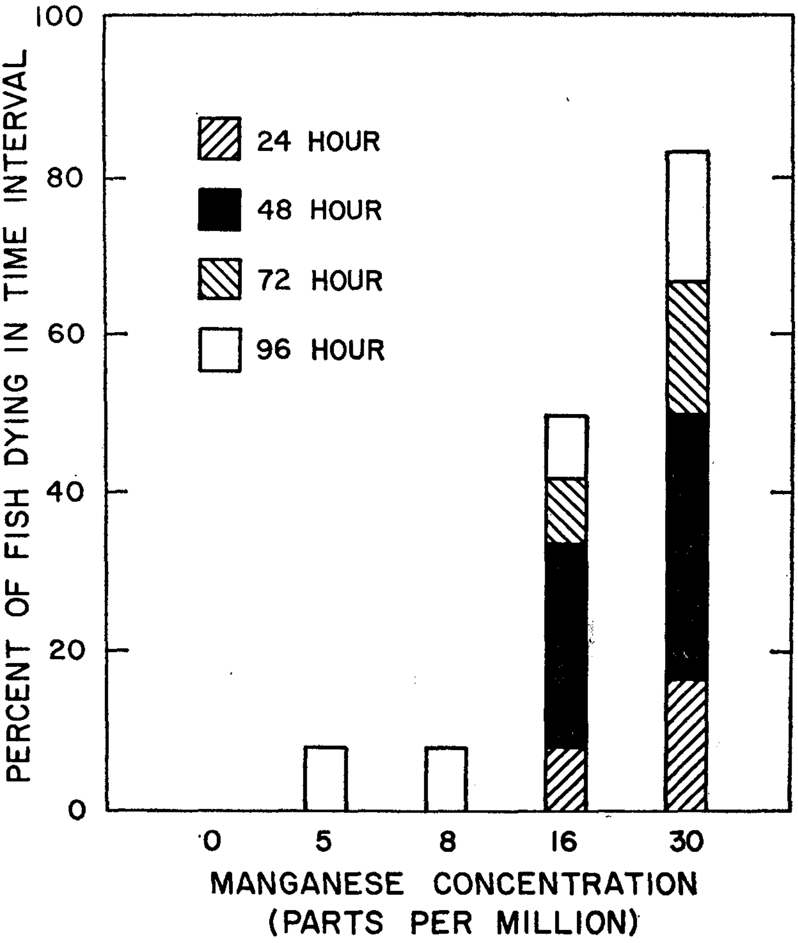

FIG. 5. Manganese toxicity to rainbow trout fingerlings.

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). 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 experiment is most useful only when viewed in the light of the results of the on-the-site sampling in the study streams.

PHYSICAL ASPECTS

McNeil and Ahnell (1964) 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. Streambed permeability is important to the fisheries biologist because it is within the gravel of the stream substrate that the various salmonid fishes deposit their spawn. Survival of the spawn is dependent, among other things, on the amount of oxygen circulation through the redd (Wickett, 1958). The oxygen content of the intragravel water is directly proportional to the velocity of intragravel currents, which is in turn dependent upon permeability.

McNeil and Ahnell (1964) found that permeability was high where bottom material contained less than 5 percent by volume of sands and silts which pass through a 0.833 millimeter sieve, and that low permeability occurs when more than 15 percent of the material passes through this sieve size.

None of the substrates sampled were found to be of high permeability (Fig. 6). On the other hand permeability of substrates at stations K1 and C3 (which lie below the mined areas on Glade Mountain) compare favorably with those of the control streams. This may be in part due to the influence of White Rock Creek (a control stream which enters Killinger Creek between stations K2 and K1), and of a large spring between K1 and C3. In addition, it is felt that the volume of sand and silt on affected streams was actually much higher than the sampling showed. This conclusion is based on losses of some fine material during sampling.

The results also show that station B2 has a much higher than average proportion of sand and silt in its substrate than the other stations. This fact alone seems to indicate that substrate permeability is much lower at this station. On the other hand, the profusion of benthos and the evidence of trout reproduction at station B2, does not support this conclusion. If other size classes of substrate material are considered, it is discovered that the substrate at station B2 contains a much greater proportion than average of intermediate size material (gravel and rubble), and a much smaller than average proportion of larger rocks. This would seem to suggest that the ratio of gravel and rubble to sand and silt might be a better measure of permeability than merely the percent of sand and silt, particularly in streambeds containing a great variation in particle size classes.

Bedload, along with turbidity, is a measure of the sediment transport of a stream. That portion of the sediment which is carried by sliding or rolling along the streambed is considered bedload. As Cordone and Kelley (1961) 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.

Bedload on study streams in the Cripple Creek watershed was sampled during three one-week 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 K2, a much greater portion of the total bedload was collected during normal flow than at other stations (Fig. 7).

On Killinger Creek average bedload at station K2 was about five and one-half times greater than at station K3, which lies above the mined areas. From station K2 bedload decreased somewhat at the next two stations downstream, probably due to dilution from White Rock Creek and Cedar Springs, which enters Cripple Creek just above station C3. From station C3 bedload increased downstream as the flow volume increased.

Bedload of Blue Spring Creek 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, much less fine silt reaches the stream. Bedload, on the other hand, is still relatively high because of the large amount of sand and silt which has accumulated in the stream channel and which has yet to be flushed out. Bedload is also increased by agriculture along Blue Spring Creek.

In addition, bedload at the lower station on Blue Spring Creek showed a much greater percent of fine silt (less than .210 mm diameter) than did the upper station (Fig. 8). This seems to indicate further that much of the finest silt has been flushed from the upper portion of Blue Spring Creek but is still abundant in the lower portion. It appears that since

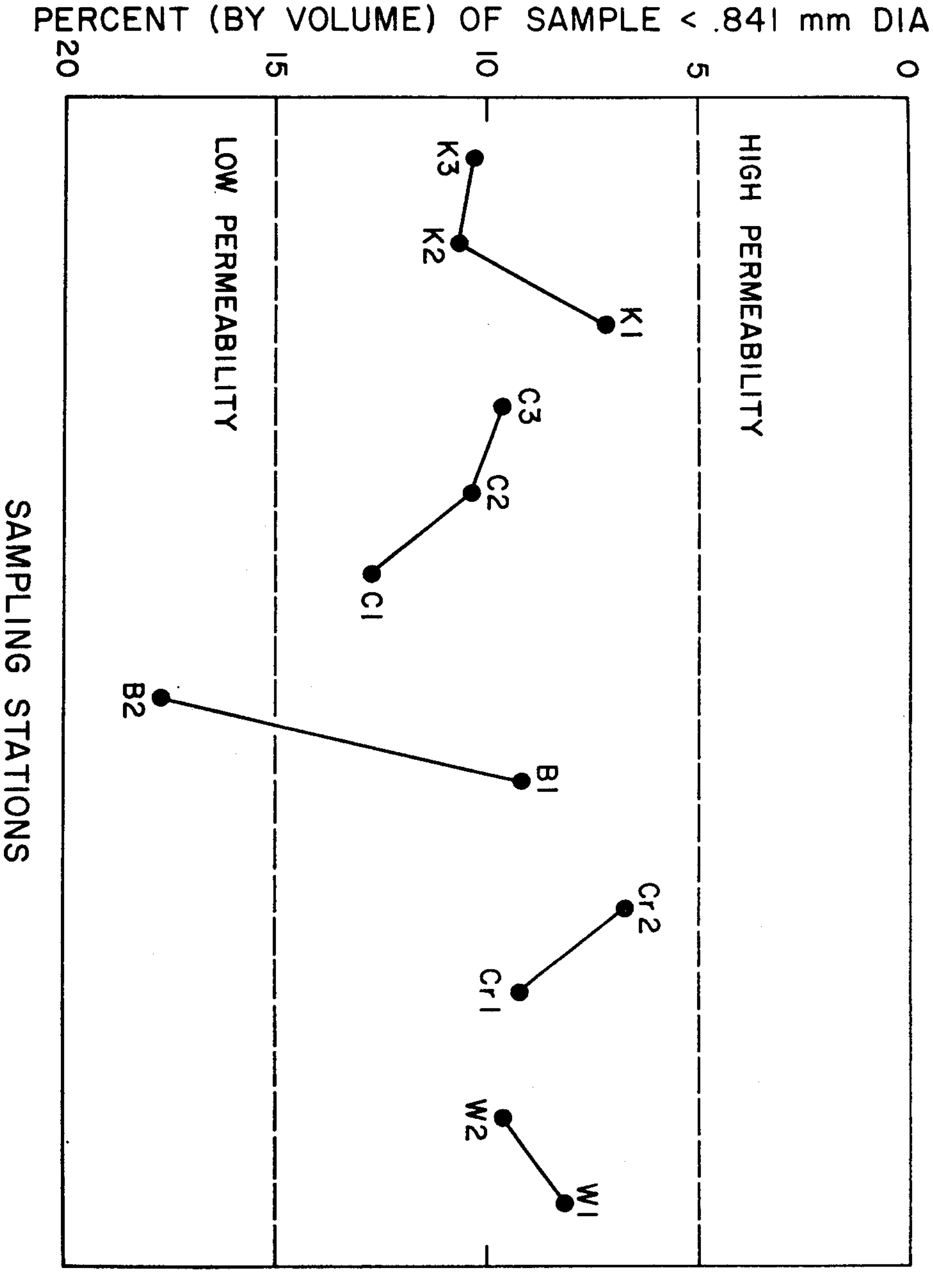

FIG. 6. Permeability of substrate of sampling stations.

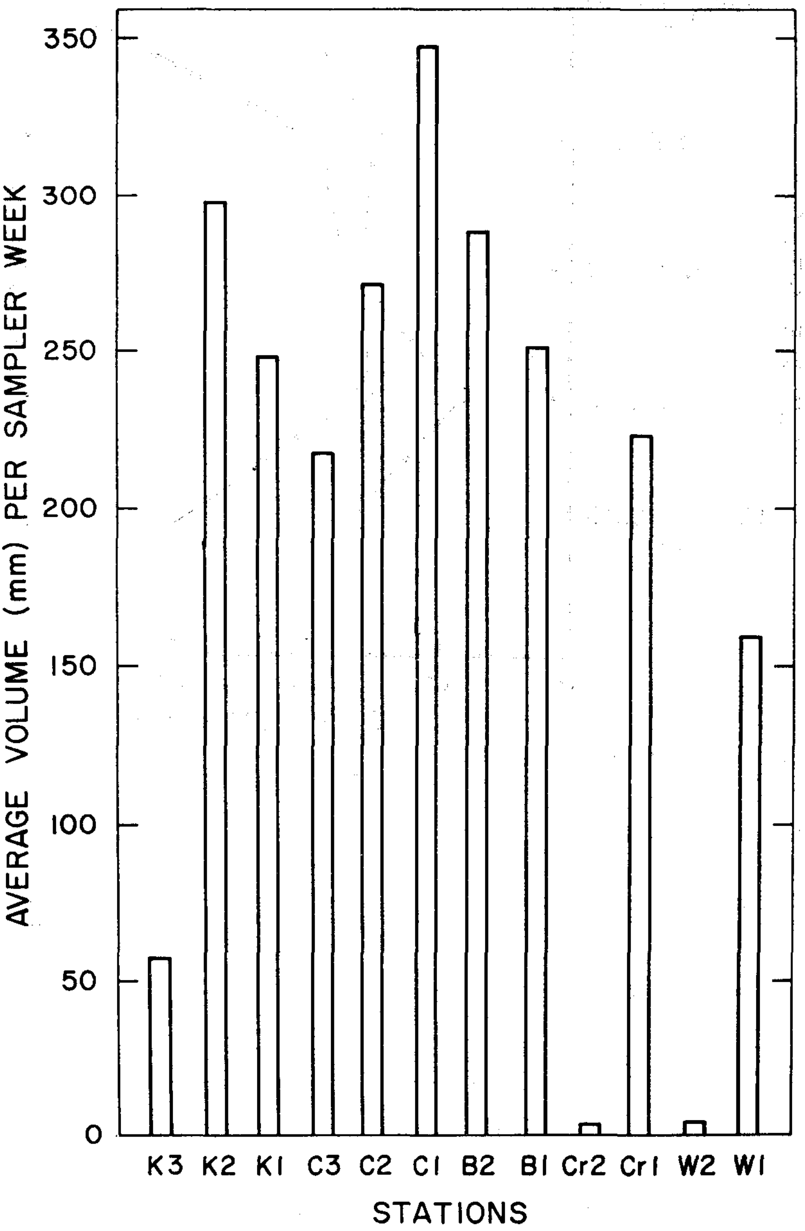

FIG. 7. Bedload as measured in milliliters of sediment deposited in collection chambers at the sampling stations.

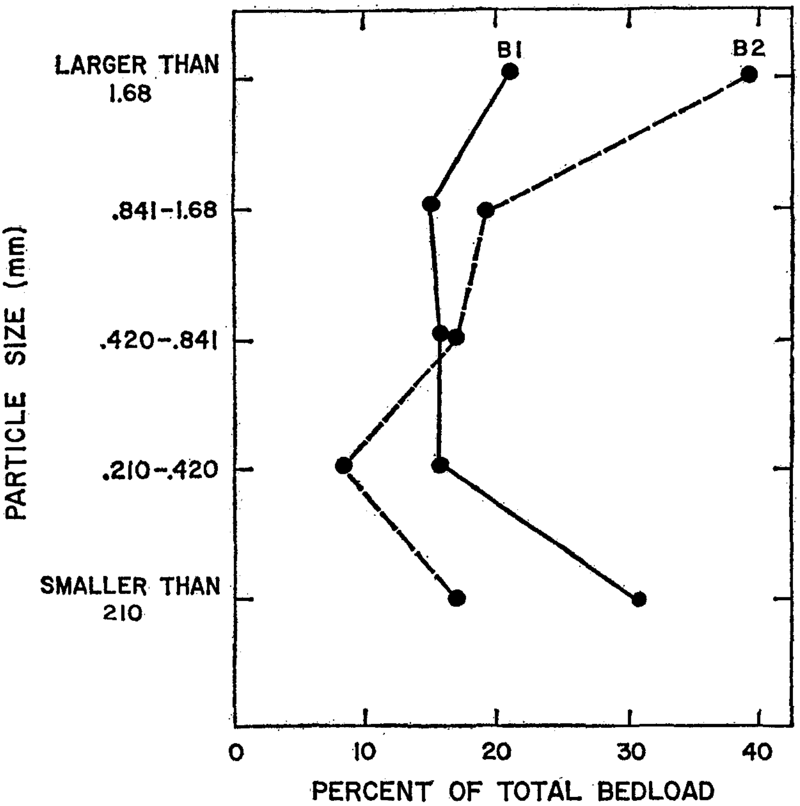

FIGURE 8. Comparison of bedload composition in the upper and lower stations of Blue Spring Creek.

reclamation has minimized the influence of mine silt, the stream is gradually being flushed free of silt which has accumulated from that source.

Turbidities observed in the study streams are shown in Fig. 9. Station K2 was considerably more turbid than any other station at both sampling periods. Even at low flow the water at station K2 was noticeably milky. Cripple Creek also had high turbidities, but Blue Spring Creek was relatively clear, even during the period of above normal flow. It is probable that turbidities lethal to fish rarely, if ever, occur in these streams. Wallen (1951) found various fish species survive turbidities of 100,000 ppm for one week or more. However, turbidity in Killinger Creek may be high enough for short periods of time to physically injure the gills of fish to some extent.

BIOLOGICAL ASPECTS

Siltation can have numerous adverse effects on aquatic fauna. These effects can be direct by suffocation of benthic organisms (Tebo, 1955) and fish spawn (Shelton and Pollock, 1966). Probably more important are indirect effects, which destroy the environment through alteration of substrate type. 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 sub-

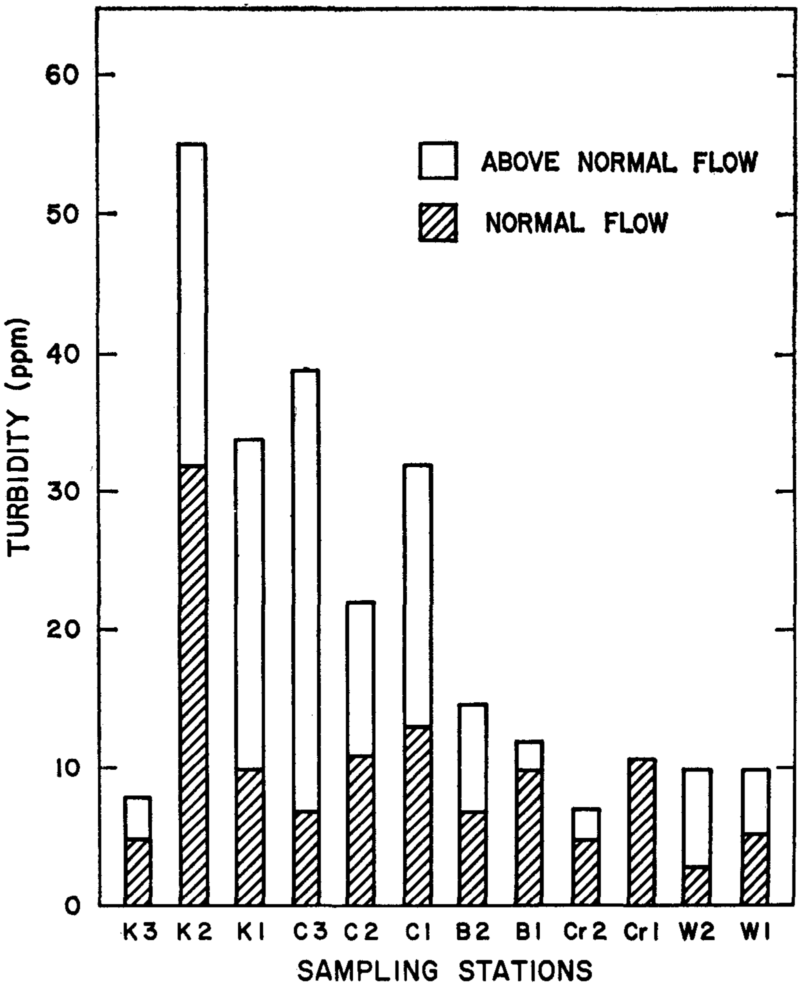

FIGURE 9. Turbidity of streams during normal and above normal flows.

strate (Hynes, 1963). In addition, the scouring action of the shifting sands may destroy aquatic plants (Jones, 1964).

The results of benthic sampling in the study streams are shown in Table 3. A reduction of about 90% by volume and more than 85% by number of organisms per square foot was noted between station K3 (which lies above the influence of mined areas) and station K2 (below these areas). At station K1 the quantity of organisms had increased significantly but was still less than half that observed at station Crl, a comparable control station. Rubble handled at both stations K1 and K2 was coated with a slippery layer of fine clay silt, and very little plant life was observed at these stations.

Farther downstream, on Cripple Creek, benthic collections also showed the effects of siltation. Volume of benthos at station C3 was only slightly greater than at K1. Station C2 (below the mouth of Blue Spring Creek) showed an appreciable reduction from C3 in number and volume of organisms. This again indicates that, although Blue Spring Creek drains

TABLE 3. Summary of benthic collections (average per square foot) taken on Cripple Creek and tributaries, spring and summer, 1967.

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

a reclaimed area and is not receiving much silt from mined areas, it still contributes large amounts of sediment to the main stream. Farther downstream, at station C1, volume and numbers of benthic organisms increased sharply, indicating that the stream is recovering downstream from the effects of silt.

Quantity of benthos was especially high at station B2 on Blue Spring Creek. This appears to lend more evidence that since reclamation of the Iron Mountain strip mines, Blue Spring Creek is recovering from the effects of siltation.

Of the benthic organisms found at the sampling stations, 87.1 percent belonged to one of the five major orders of aquatic insects; that is, Trichoptera, Coleoptera, Plecoptera, Ephemeroptera, and Diptera. Of these, the Coleoptera and Plecoptera occurred in smallest numbers.

When this study was begun, it was postulated that perhaps certain organisms could be found at the family level that would indicate a distinct positive or negative affinity for silt in the environment. An analysis of the data collected reveals little correlation between numbers of a particular family present at any given station and the relationship of that station to a source of strip mine silt. However, several families show a distinct reduction in number between stations K3 and K2, above and below the mined areas, respectively. No families showed a significant increase between these stations. Table 4 shows the distribution of those families which showed the most apparent variation between stations directly affected by mine silt and unaffected stations. Although all these families showed a drastic reduction in numbers of organisms between the unpolluted station K3 and the heavily silted K2, variations among other stations are not so apparent. Probably the Heptageniidae show the

TABLE 4. Distribution and numbers of individuals from selected families of benthic organisms found on the Cripple Creek watershed.

	Station											
Family	K3	K2	K1	C3	C2	C1	B2	B1	Cr2	Cr1	W2	W1
Elimidae	12	3	3	29	13	45	12	40	3	44	0	0
Baetidae	47	10	31	124	82	180	238	67	28	355	12	105
Heptageniidae	70	16	24	15	21	36	11	15	17	91	46	184
Chironomidae	19	2	100	274	55	227	152	42	23	171	3	14

most clearly defined response to silt. Whereas the other families showed a rather quick recovery downstream from the source of silt, this family showed only slight recovery. Heptageniidae were also scarce on Blue Spring Creek which drains the reclaimed area, but were abundant in both control streams.

The blacknose dace is the most abundant species in these streams (Table 5); it was found at all but one station and in the greatest number of all species. Although most abundant in a control stream, the blacknose dace was also found in large numbers at stations K1 and K2, 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; Forbes and Richardson, 1920).

Several other fish species appear to be doing well in the silted study streams. These include the rosyside dace, redbelly dace, creek chub, and white sucker. All of these except the rosyside dace were found to be most numerous at station K1.

Although certain non-game species appeared in greatest numbers in the silted streams, no game fish were taken from Killinger Creek below the mined areas. In Cripple Creek, the only game fish were an occasional stocked trout and three species of Centrarchidae at station C3, 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: K3, above the mined areas on Killinger Creek, and W2 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.

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), 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.

White Rock Creek, the second control stream, yielded few fish species. This is probably due to two factors unrelated to strip mining. First of all, much of the lower portion of this stream is known to dry up during long periods of drought. Secondly, re-invasion of this section is restricted by a corrugated metal culvert installed at the stream mouth where it flows under a state road. The culvert creates a small fall, at the base of which is a broad slab of concrete. Lacking a plunge pool, it would be very difficult for fish to attain sufficient speed to hurdle this small fall.

Overall, sampling in the study streams revealed that cyprinid fishes far outnumber all other types. According to Everhart (1958) 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 web 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.

SUMMARY

Abandoned strip-mines within the Cripple Creek study area have caused silt pollution in several streams. No evidence was found to support the theory that manganese ions were in solution in toxic concentrations to the endemic stream biota. Siltation was evident on Cripple Creek and two tributaries. Siltation was evident in Blue Spring Creek, which drained a fully reclaimed area, but there were signs of recovery; turbidity compared with control streams, and bedload data indicated that much of the finer silt has washed out of the upper portion of the stream. High production of benthic organisms and evidence of trout spawning further indicates that reclamation has been very effective.

TABLE 5. Distribution of fish and total numbers caught in Cripple Creek, and tributaries, 1967.

						Stations-						
Common name	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

Killinger Creek, although it drained an area that was more than half reclaimed, showed striking evidence of siltation. Benthic production dropped sharply below the mined areas, and game fish were entirely absent, while turbidity and bedload increased sharply.

In conclusion, reclamation has been very effective in this watershed to the extent that it has been completed. However, it appears that partial reclamation is not enough; until every acre of Glade Mountain is revegetated, there is little hope that the lower portion of Killinger Creek will be more than a mere drainage ditch.

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PHOSPHORUS DYNAMICS IN PONDS[1]

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INTRODUCTION

Phosphorus is generally recognized as a key nutrient in the fertility of fish ponds. This nutrient frequently limits plant production and ultimately influences fish production. Conversely, too much phosphorus is sometimes responsible for excessive production of blue-green algae or other nuisance plant species in ponds. Since phosphorus is extremely important in pond management schemes, an understanding of its physicochemical and biological dynamics is valuable to fishery biologists. This report is a description of phosphorus relationships in ponds. The discussion is a general consideration of the phosphorus cycle rather than an exhaustive review. No attempt was made to summarize data on correaltions between phosphorus fertilization and fish production.

SOURCES OF PHOSPHORUS

When a pond is constructed, the newly inundated soil and vegetation is the only *in situ* supply of phosphorus. However, there are a number of possible inputs of phosphorus. The relative importance of each input will vary between ponds.

Watershed. Runoff from the watershed may contain considerable quantities of phosphorus. Fippin (1945) reported an average annual loss of 5.3 lb./acre of phosphorus from row crops in the Tennessee River Valley. Drainage from Illinois farm land (Englebrecht and Morgan,

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