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SUMMARY

In 1964, a mine drainage pollution control demonstration project was undertaken near Elkins, West Virginia. The area contained a large drift mine (3,000 acres) which had been extensively surface mined along the outcrop. The objective of the project was to determine the effect on the water quality of "air" sealing and diverting water away from the underground mine and reclaiming the surface mines. Some 450 subsidence holes were filled, over 12.5 miles of surface mines were reclaimed and 101 seals constructed. Approximately 640 acres of land were disturbed during reclamation which were revegetated in the spring of 1968. This paper reports the effectiveness of the reclamation work for the first two years following construction.

The reclamation and revegetation of the surface mines and refuse piles have shown some benefits, however, an equilibrium condition has not been established and the long term effects have yet to be determined. While some areas have shown trends of continued improvement, others showed an improvement the first year, followed by some deterioration the second year.

Air sealing, under the conditions at Elkins was unsuccessful, except for one site, the oxygen concentration behind the seal has not decreased and the pollution loads have not decreased.

For the combined watershed of Roaring Creek and Grassy Run there has been over a 1,500 ton decrease in the acidity load for the base year 1966. However, none of the streams in either watershed has returned to its unpolluted state.

INTRODUCTION

An authoritative report on acid mine drainage was issued by the Committee of Public Works of the U.S. House of Representatives.(1) Recognizing the extent of the problem, the report pointed out that elimination of this form of pollution would restore vast quantities of water for municipal and industrial use, propagation of fish, aquatic life, and wildlife, recreational purposes, and other uses. After pointing out that most of the various methods developed to abate acid mine drainage had been abandoned because of high costs and technical failure in field applications, the Committee concluded that mine sealing was the most promising method.

The report recommended: (1) a sealing program directed at sealing abandoned mine shafts and other drainage openings, (2) a stepped-up research program by federal, state, and interstate organizations to develop other abatement measures, and (3) a stream and acid flow regulation program employed where sealing or other methods are unable to sufficiently reduce the acid content of the stream to meet water quality requirements for all legitimate purposes.

The report also called for a demonstration program to evaluate mine sealing procedures and results, suggesting that the work be done in "three appropriate watersheds containing between 50 and 100 abandoned coal mines each from which acid water is draining." Funds for the demonstration grant, $5 million, were authorized by Congress in 1964.

The work was to be under the direction of the Water Supply and Pollution Control Program of the Department of Health, Education, and Welfare, the forerunner of the Federal Water Pollution Control Administration (FWPCA) which later was transferred to the U.S. Department of the Interior. Other participating agencies were the U.S. Bureau of Mines (USBM), U. S. Geological Survey (USGS), U.S. Bureau of Sport Fisheries and Wildlife (USSFW), and West Virginia (W. Va.) agencies in charge of mining, water pollution, and reclamation.

In March 1964, the first demonstration project site was selected in the Roaring Creek–Grassy Run watershed near Elkins, West Virginia. The area contained a large drift mine (3,000 acres) and a number of smaller underground mines (Figure 1). The outcrop had been extensively surface mined and contained over 1,000 acres of disturbed land. The surface mines had intercepted the underground mine workings of the large mine and were diverting water into it. Since the coal dipped from the Roaring Creek watershed toward the Grassy Run watershed, water was diverted from one watershed to the other through the underground mine. Upon passing through the underground mine the water flushed out pollutants.

Roaring Creek and Grassy Run were discharging over 12 tons per day of acidity to the Tygart River. Chemical characteristics of the two streams are presented in Table I.

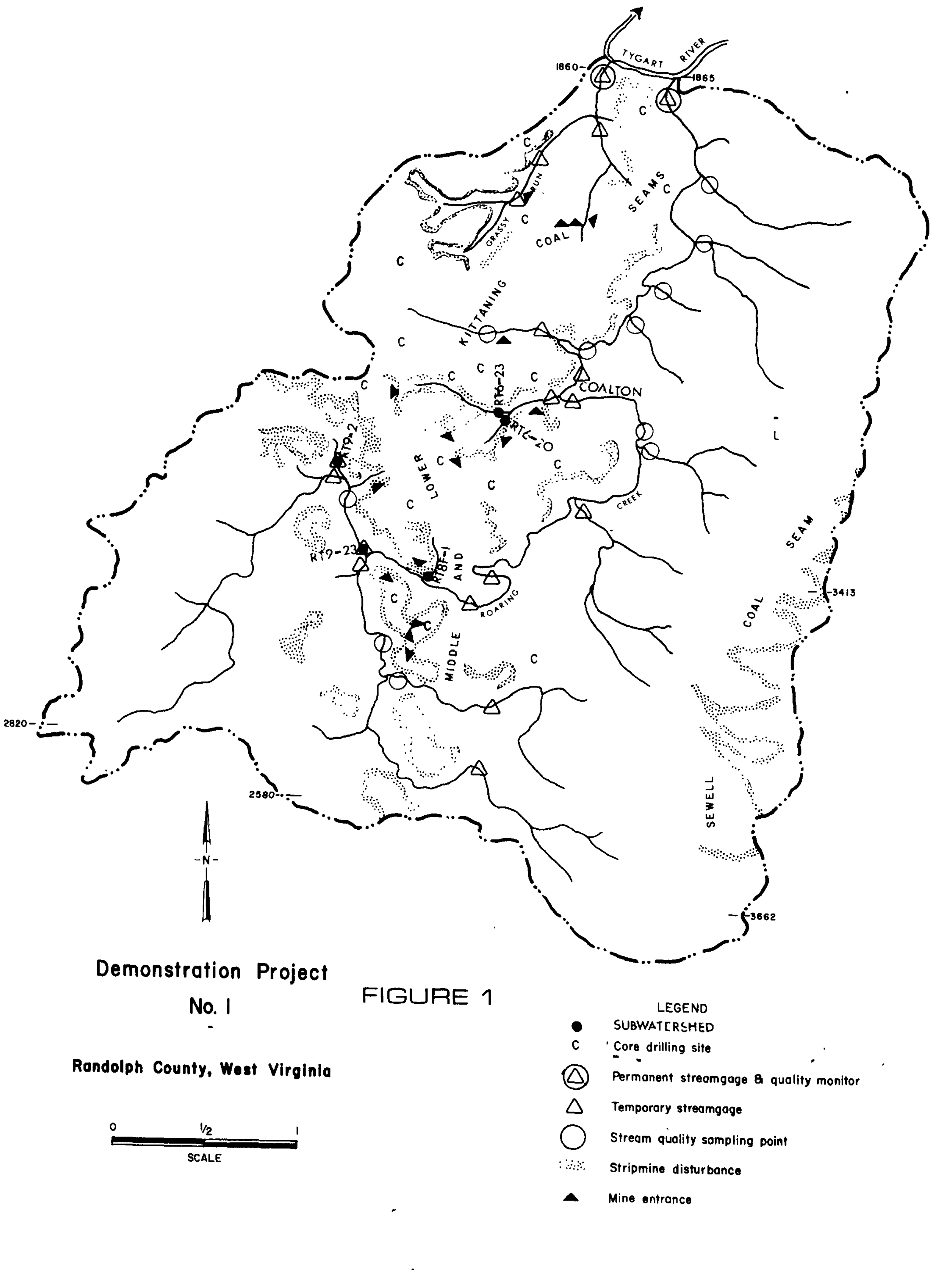
TABLE I

Water Quality Characteristics[a]

	Grassy Run		Roaring Creek	
	mg/l	Tons/day	mg/l	Tons/day
pH[b]	2.55	—	3.3	—
Acidity, (Hot), $CaCO_3$	656	10.6	110	1.8
Iron, Total	110	1.8	5	0.08
Iron, Ferrous	4	0.06	1	0.01
Sulfate	992	16.0	168	2.7
Hardness, $CaCO_3$	446	7.2	99	1.6
Calcium, $CaCO_3$	293	4.7	76	1.2
Aluminum	38	0.6	12	0.2
Specific Conductance[c]	1,723	—	530	—
Flow[d]	6	—	40	—

a. Average values for period March 1964 to June 1966
b. Unit not mg/l, median value
c. Units - micromhos per cm
d. Units - cubic feet per second

The demonstration project was carried out in three phases: (1) site selection, preconstruction evaluation, and reclamation planning, (2) construction of mine seals and regrading and revegetation of surface mines, and (3) project evaluation. Phase 1, begun in March 1964, and completed in July 1966, was devoted to water quality surveillance (FWPCA); stream gaging (USGS); surface mapping, investigation of mine conditions, and designing control measures and reclamation planning (USBM); securing land permits (W. Va.) and awarding the construction contract (FWPCA, USBM). Sealing of the mines and concurrent reclamation measures (Phase 2) were begun in July 1966 and terminated in September 1967. Disturbed areas were revegetated in the spring of 1968. Phase 3, evaluation of the effectiveness of mine sealing and reclamation measures is continuing.



Demonstration Project

No. 1

FIGURE 1

Randolph County, West Virginia

CONTROL MEASURES

The following control measures were carried out:

1. Air sealing of the underground mine: Since oxygen is necessary for the oxidation of pyrite and the production of iron and acidity, preventing oxygen from reaching the pyrite should reduce or eliminate acid pollution. Air sealing was to be accomplished by filling all bore holes, subsidence holes, and other air passages into the mine. "Wet" mine seals, which allow water to leave the mine, but prevent air from entering, were to be constructed at all openings discharging water.

2. Water diversion: Since water is the transport media for carrying acid and iron from the mining environment, reducing the amount of water passing through a surface or underground mine will reduce the amount of pollution. To prevent water from entering underground mines, subsidence holes were to be filled, streams were to be rechanneled away from mines, and "dry" seals, a solid seal through which water could not pass, were to be constructed in mine portals.

3. Burying of acid-producing spoils and refuse: Since these materials were major contributors to pollution they were to be buried in surface mine pits.

4. Surface mine reclamation: Although surface mines were to be regraded primarily to prevent water from entering the underground mine, regrading also reduces the time that water is in contact with acid-producing material in the surface mine itself. During regrading burying the highly acid material was planned.

5. Revegetation: All disturbed areas were to be revegetated to prevent erosion and stabilize the backfills.

The design of the seals and various types of backfills used on the project has been reported previously.(4)

The project was not completed. Those mines on the south half of the Roaring Creek Watershed, upstream of Coalton (see Figure 1) were reclaimed as planned. However, no reclamation took place north of Coalton in the Roaring Creek Watershed and none took place in the Grassy Run Watershed. Thus, any improvement in water quality would occur in the southern subwatersheds of Roaring Creek. It was also possible that some improvement might occur in Grassy Run since the reclamation in Roaring Creek should have diverted water from the underground mine which drained to Grassy Run.

A summary of the work performed is presented in Table II.

TABLE II

Reclamation Work Performed

Reclamation		
Surface Mines Reclaimed	12.5	Miles
Backfill, Total	3.6	Million Cubic Yards
Subsidence Holes Filled	450	
Mine Seals	101	
Grass Planted Only	322	Acres
Grass Hydroseeded Only	16	Acres
Trees Planted Only	57	Acres
Hydroseed Grass and Trees Planted	195	Acres
Grass and Trees Planted	120	Acres

RESULTS

The climatic conditions play an important role in the evaluation of pollution control techniques. Not only are there the seasonal variations in flow volumes and concentration (see Figures 2 - 5) but, variations between years. For example, during 1964 and 1965, the two years before reclamation, the acidity concentration of Roaring Creek at its mouth was 88 mg/l and 141 mg/l, respectively, and the acid load (March - December period) was 1,289 tons and 1,311 tons respectively. The difference between these years was that the precipitation in 1964 was 41.58 inches as compared to 34.06 inches in 1965 (Table III). Thus, the choice of a base year becomes critical in making evaluations. This important point should be kept in mind during the following discussion.

Due to the complexity of the situation in the reclaimed area, it was divided into five subwatersheds for evaluation. The location of each monitoring point for a subwatershed is shown in Figure 1. In general, the monitoring point was at the mouth of a small stream system. Each subwatershed is described below.

Subwatershed RT8F-1 - A sampling point at the mouth of this 202-acre subwatershed was used to measure the effect of reclamation on 49 acres of surface mines. One underground mine discharge is located in the area and it has not been sealed.

During wet periods the underground discharge contributed only a small percentage of the pollution load (from 1 to 25 percent) while during dry periods (summer and late fall) it often contributed 100 percent of the pollution load. Because of the variable contribution from the underground mine, determining the effectiveness of the surface mine reclamation is difficult. In our analysis, we have assumed that the contribution from the underground mine was the same for both the before and after periods and thus, a constant factor (in actuality the underground discharge has had a slightly lower acidity and sulfate concentration following reclamation).

The data collected at this sampling point are summarized in Figure 2 and Table IV. During 1968, there was a marked improvement in the acidity and sulfate concentrations. However, during 1969, the concentration levels have increased over those of 1968, but have not reached those of the pre-reclamation period. This increase may partially be due to the reduced affect of the lime that was applied in 1968 during revegetation. If the present trend continues, the water quality may approach that of pre-reclamation periods.

The acid and sulfate load during 1968 was significantly reduced below that of 1966, but during 1969, the iron and sulfate load had returned to levels near or above the 1966 level and only acidity still showed a significant reduction.

Subwatershed RT 9-2 - This 692 acre watershed contained 160 acres of surface mines (23 percent of land area) all of which were reclaimed. One underground discharge is located in the watershed, however, its acid load contribution is minor (less than one percent). In Table V and Figure 3, the data collected at the mouth of the watershed are summarized.

The data show that during 1968 and 1969, the concentration of acidity and sulfate was less than the pre-reclamation period of 1964 - 1966. During 1969, there has been a small increase in acidity over 1968 and a small decrease in sulfate. These latter changes are well within a range that can be expected, due to yearly variations.

The importance in the choice of a base year is apparent from the load data presented in Table V. If the dry year 1965 is chosen, the acidity load decreased much less in 1968 and 1969 than if 1966 is chosen, which had similar precipitation to 1968 and 1969. The sulfate load was higher during 1968 than during the pre-reclamation years, however, in 1969 the load was less. These data may indicate that a large portion of the sulfates was leached from the freshly disturbed soil in 1968 and that a continued decrease in sulfate can be expected.

TABLE III

Elkins, West Virginia
Precipitation Data
Inches of Precipitation

	Long Term* Average	1964	1965	1966	1967	1968	1969
January	3.62	3.20	5.31	3.49	1.05	1.88	3.01
February	3.27	3.07	1.94	3.10	3.03	1.80	2.13
March	4.14	3.95	4.51	1.44	7.69	4.28	2.26
April	3.48	5.61	6.90	6.63	3.24	1.54	3.34
May	4.57	1.47	1.45	1.68	7.67	7.30	2.76
June	5.19	5.01	2.21	1.98	2.83	2.05	3.83
July	5.49	5.19	2.27	3.24	4.55	3.46	6.82
August	4.23	3.55	1.74	4.84	5.10	4.07	5.60
September	3.07	4.20	2.89	5.14	3.33	3.01	1.60
October	3.03	0.94	2.51	2.46	3.44	3.21	1.64E
November	2.75	2.00	1.43	2.63	3.55	3.20	1.73E
December	3.08	3.39	0.90	2.45	4.47	3.04	4.99E
ANNUAL	45.92	41.58	34.06	39.08	49.95	38.84	39.71E

* 64 Years of Record
E Estimated not Offical

TABLE IV

Summary Data Subwatershed RT8F-1

Mean Concentration Mg/l (S.D.[a])	Acidity	Iron	Sulfate
Before Reclamation			
1965 - 1966	199 (78)	19 (12)	290 (86)
After Reclamation			
1968	74 (31)	10 (5)	159 (37)
1969	123 (33)	16 (8)	211 (70)
Load, tons			
Before Reclamation			
1965	b	b	b
1966	39	4.7	52.1
After Reclamation			
1968	12.5	1.6	26.0
1969	23.7	4.5	64.5

a. Standard Deviation
b. Incomplete Data

TABLE V

Summary Data Subwatershed RT 9-2

Mean Concentration Mg/l (S.D.[a])	Acidity	Iron	Sulfate
Before Reclamation			
1964 - 1966	178 (63)	5 (2)	313 (105)
After Reclamation			
1968	86 (28)	4 (1.4)	225 (64)
1969	96 (26)	5 (1.8)	208 (90)
Load, tons			
Before Reclamation			
1965	187	6.4	338
1966	243	7.5	436
After Reclamation			
1968	153	7.2	450
1969	131	8.0	268

a. Standard Deviation

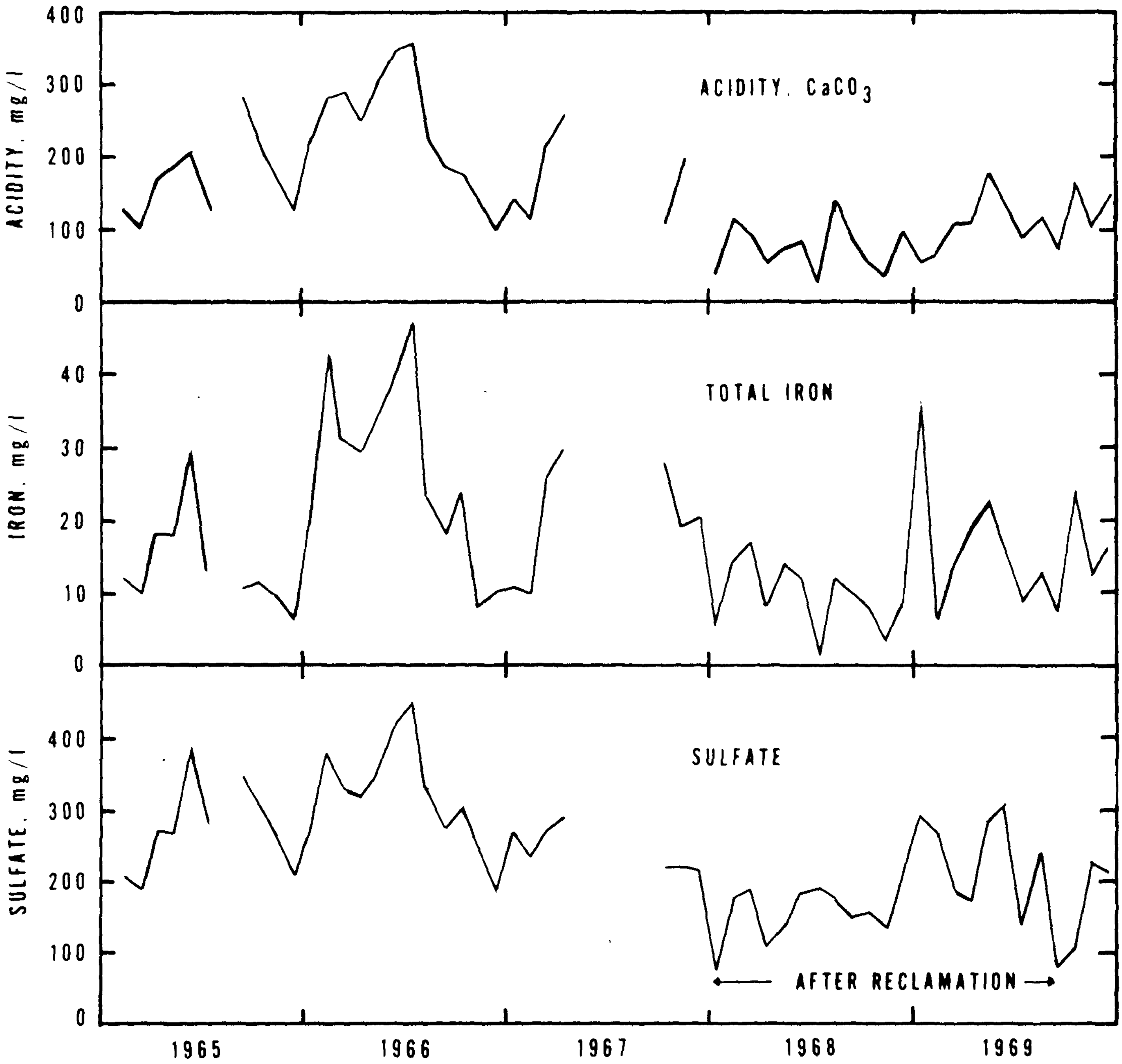


FIGURE 2
RUNOFF CHARACTERISTICS WATERSHED RT8F-1

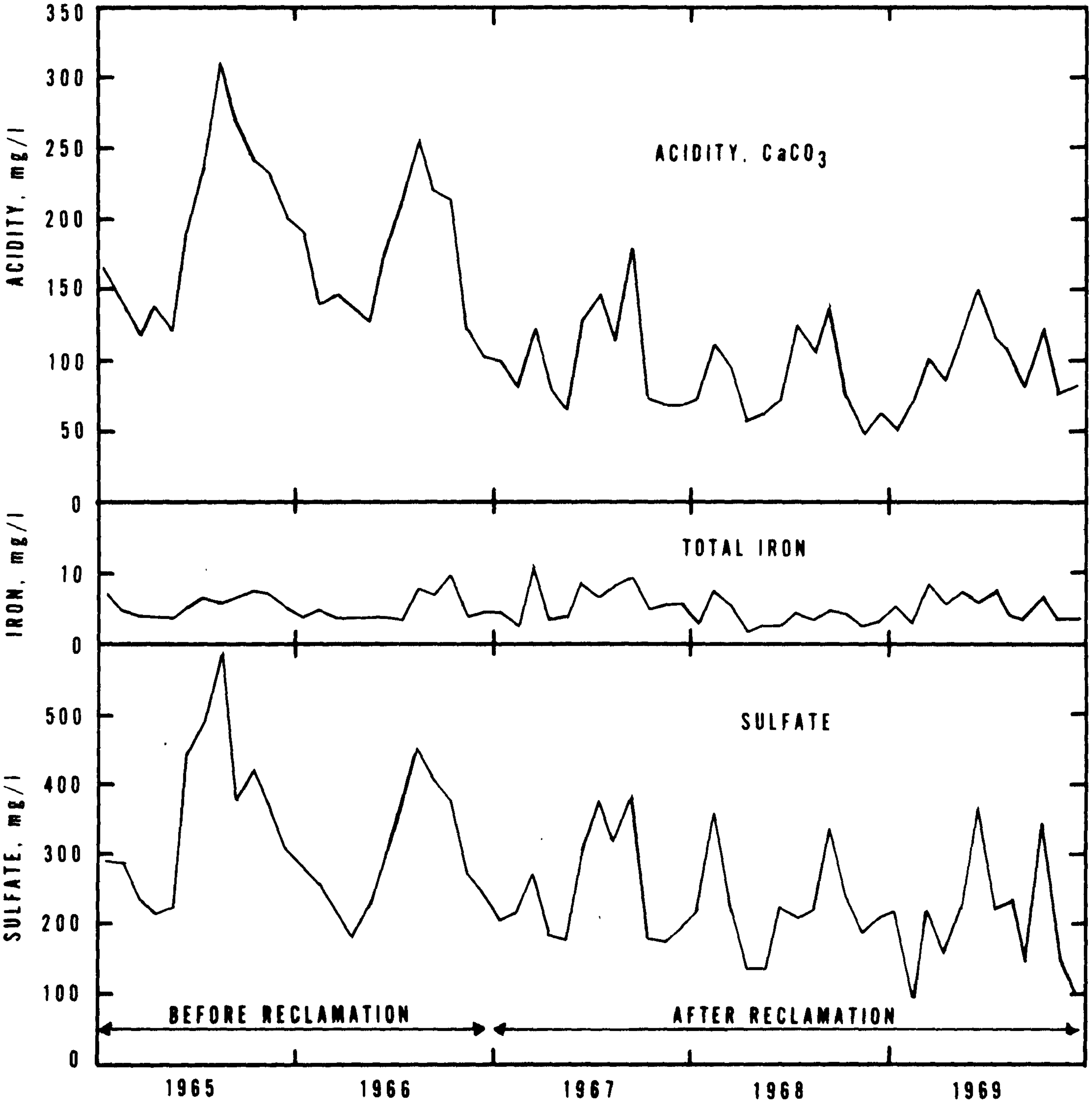


FIGURE 3
RUNOFF CHARACTERISTICS WATERSHED RT9-2

Subwatershed RT 9-23 - This 3,749 acre watershed contained 256 acres of surface mines (7 percent of land area) which were reclaimed. One insignificant underground mine discharge was present in the area. A summary of the water quality is presented in Table VI and Figure 4.

The concentration data as illustrated in Figure 4 are difficult to interpret. Each year there is a sharp increase in concentration during the summer when the flow rate is low, with the exception of 1967 which had somewhat higher rainfall. Overall, as seen in Table VI, there has been a decrease in concentration from the prereclamation period of 1964 - 1966 and a longterm trend of a smaller concentration of acidity and sulfate. The load data show that the 1969 loads are less than for either 1965 or 1966.

TABLE VI

Summary Data Subwatershed RT 9-23

Mean Concentration Mg/l (S.D.[a])	Acidity	Iron	Sulfate
Before Reclamation			
1964 - 1966	100 (62)	5 (3)	163 (97)
After Reclamation			
1968	65 (48)	5 (4)	140 (128)
1969	56 (30)	4 (2)	84 (40)
Load, Tons			
Before Reclamation			
1965	446	33	792
1966	653	46	979
After Reclamation			
1968	429	29	844
1969	316	23	525

a. Standard Deviation

Subwatershed RT 6-20 - This 211 acre watershed contained 45 acres of surface mines (21 percent of land area) and two underground mine discharges. As shown in Figure 5 and Table VII, there has been no improvement in the water quality, in fact, the water has degraded in quality and the long term trend indicates it will get even worse. An analysis was made to determine the source of the pollutants (Table VIII). Before reclamation approximately 54 percent of the pollution load came from the underground mines and the remainder from the surface mines. Following reclamation in 1968, there was a 91 percent decrease in the acid, 89 percent in iron and 33 percent in sulfate attributable to surface mines. At the same time there has been over 100 percent increase in these pollutants from the underground mines. In 1969, the acid load from surface mines increased over 1968, but was still 55 percent less than 1966. The iron load also raised slightly while the sulfate load decreased slightly.

Both the underground mines have had their portals sealed with "wet" seals. However, the mines are not sealed to air movement, as the oxygen content of the atmosphere within the mine is the same as without. Air probably moves into the mine through subsidence holes, cracks, etc., in the overburden. Since over 75 percent of the pollution came from one of the mines, RT 6-12, a further analysis of that

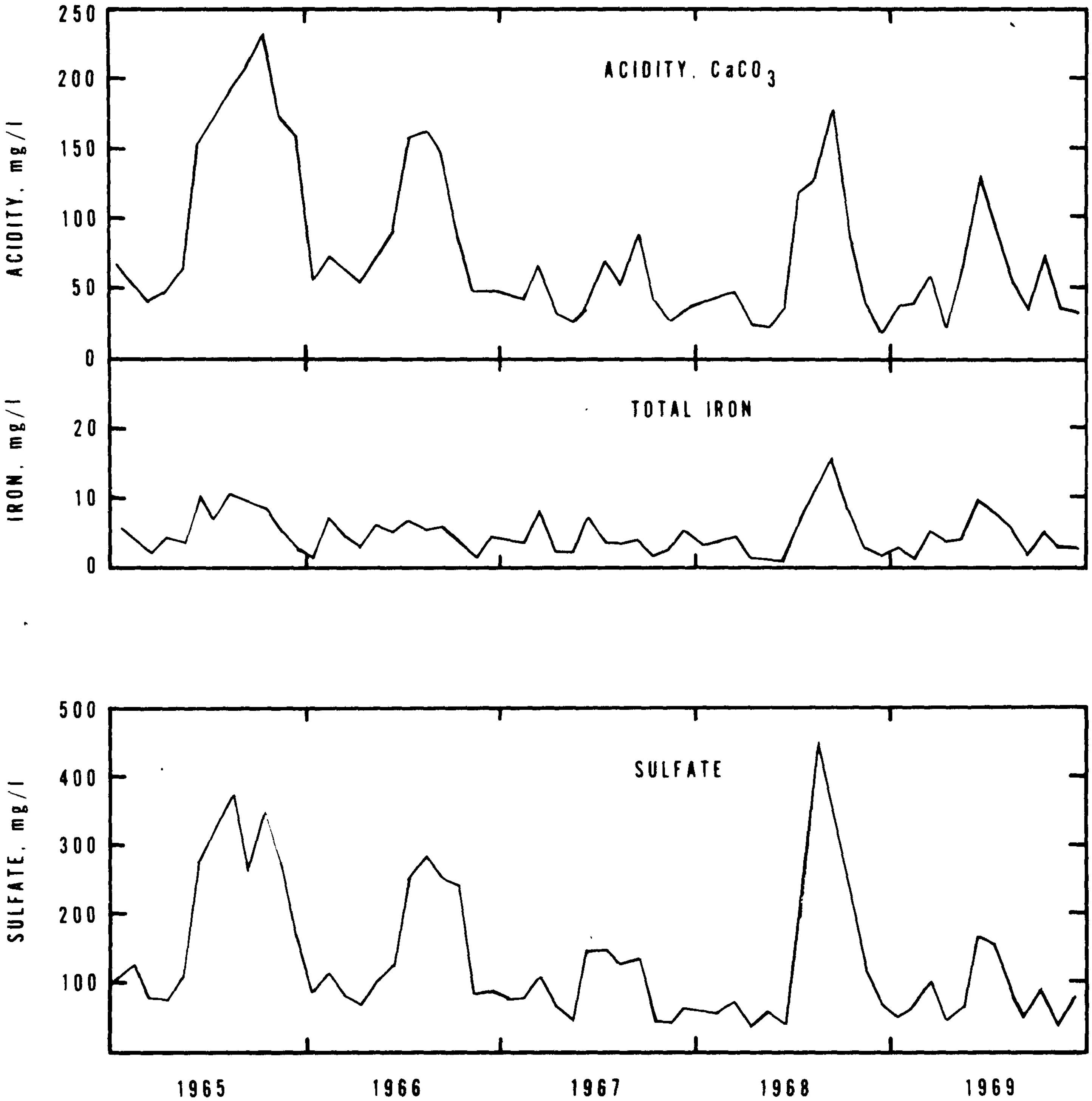


FIGURE 4

RUNOFF CHARACTERISTICS WATERSHED RT9-23

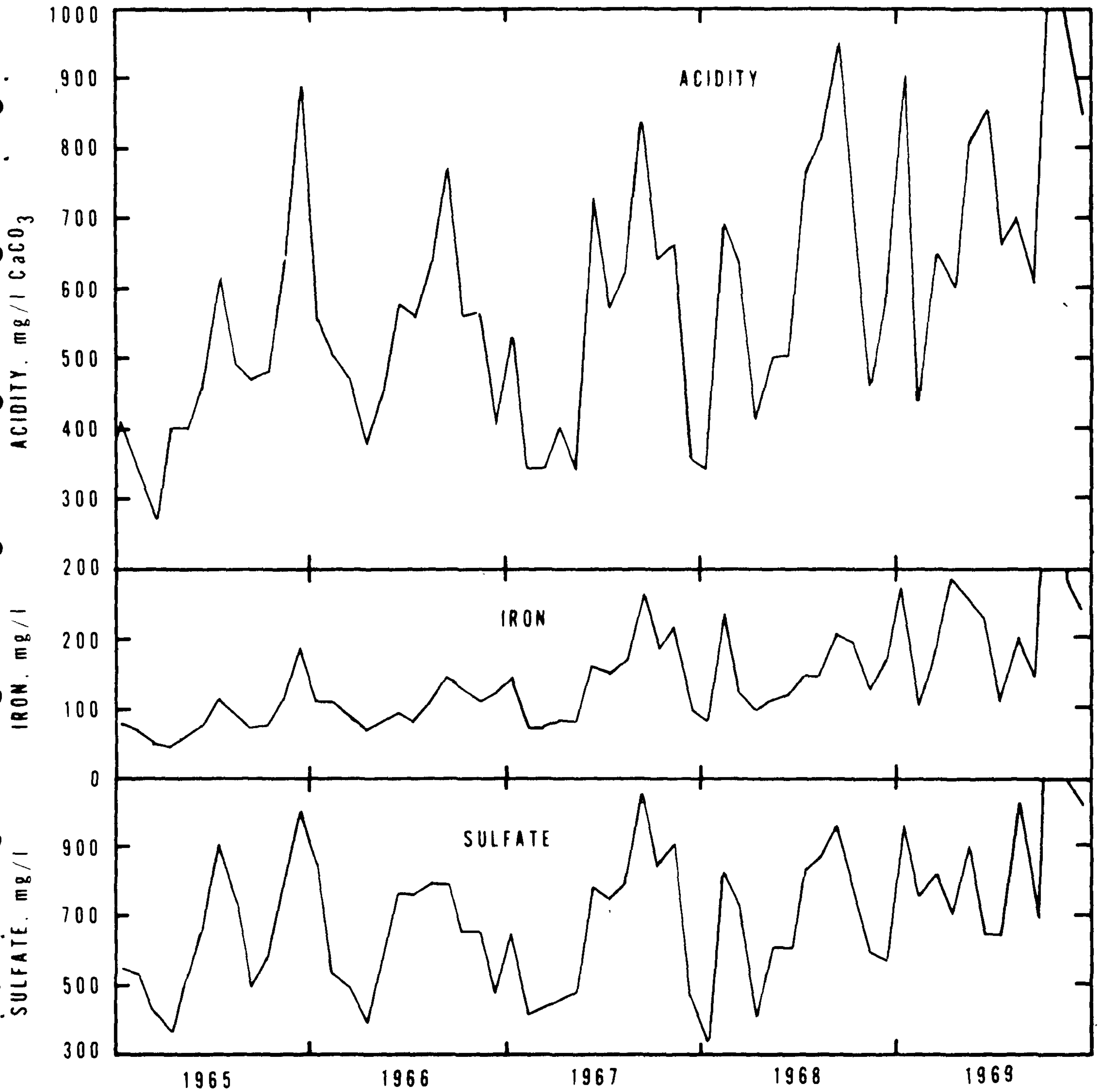


FIGURE 5
RUNOFF CHARACTERISTICS WATERSHED RT 6-20

TABLE VII

Summary Data Subwatershed RT 6-20

Mean Concentration Mg/l (S.D.[a])	Acidity	Iron	Sulfate
Before Reclamation			
1964 - 1966	486 (183)	91 (40)	616 (225)
After Reclamation			
1968	613 (173)	148 (43)	686 (177)
1969	783 (227)	232 (101)	881 (236)
Load, tons/day			
Before Reclamation			
1965	113	21	152
1966	149	33	168
After Reclamation			
1968	183	48	211
1969	183	55	216

a. Standard Deviation

TABLE VIII

Pollution Loads and their Source - Subwatershed RT 6-20

	Before Reclamation 1966		After Reclamation 1968		After Reclamation 1969	
	Tons	Percent of Total	Tons	Percent of Total	Tons	Percent of Total
Acidity,						
Total	148.7	-	183.8	-	182.9	-
Underground Mines	80.5	54	167.5	91	152.1	83
Surface Mines*	68.2	46	6.3	9	30.8	17
Iron,						
Total	33.2	-	48.0	-	54.5	-
Underground Mines	18.3	55	46.3	96	50.6	92
Surface Mines*	14.9	45	1.7	4	3.9	8
Sulfate,						
Total	168.0	-	211.3	-	215.9	-
Underground Mines	89.7	53	169.7	80	168.2	77
Surface Mines*	78.3	47	51.6	20	47.7	23

* Considered to be the difference between underground mine load and total load.

discharge was made (Table IX). A slight increase in the concentration of pollutants and flow volume has occurred with the exception of aluminum. No explanation for this increase has been obtained. The water quality from the second "sealed" mine has shown no improvement either.

In summary, the surface mine reclamation appears to have reduced the pollutants from that source, while on the other hand the underground mine seals are ineffective and for some unknown reason the pollution load is even greater than in the past.

TABLE IX

Water Quality Underground Mine Drainage RT 6-12

	Before Sealing(1)		After Sealing(2)	
	Mean	S.D.*	Mean	S.D.*
Flow, cfs	0.127	0.169	0.16	0.14
pH	2.6	-	2.8	-
Acidity, $CaCO_3$, Mg/l	977	533	1,031	440
Iron, Mg/l	238	157	291	135
Sulfate	1,002	536	1,055	386
Hardness, $CaCO_3$, Mg/l	231	165	327	106
Aluminum, Mg/l	64	29	50	22

* Standard Deviation
(1) 23 Samples, March 64 - June 66
(2) 44 Samples, September 67 - July 69

Subwatershed RT 6-21 - The control site is located at the mouth of Kittle Run, one of the worst areas in the project. The streambed had been completely destroyed during mining when the overburden was deposited in the creek. Surface runoff and underground mine drainage in the headwaters were partly directed into underground mines. Thus, the sample site at the mouth of the creek was not indicative of the total pollution contribution. During reclamation 140 acres of surface mines were regraded and planted, several refuse piles and garbage dumps were buried, six clay seals were installed in deep mine openings and two wet seals were constructed. The streambed also was reestablished, thus directing all of the runoff past the control point.

In Table X, the data collected at the control site are reported. It should be remembered that the before reclamation data do not show the total pollution load of the watershed since part of the water was directed into the underground mine upstream from the control point. Thus, the load values would have been greater than those reported.

In Table XI, the source of pollution following reclamation is reported. It is interesting to note that even though the area contributing to the discharge from the watershed was greater after reclamation, the acid and sulfate load was less. The volume of water discharged increased from 18.35 million cubic feet in 1966, to 22.55 million cubic feet in 1968, but decreased to 16.08 in 1969. At the same time the pollution load from the underground mines remained the same or increased. It can be concluded from these data that the reclamation of the surface mines and the burial of the refuse piles resulted in a reduction in pollution. The increase in surface mine contribution from 1968 to 1969 may be due to normal yearly variations or show a decreased benefit of the lime applied to the soil during revegetation.

The discharge from underground mine RT 6-9 has increased in volume (see Table XII) and decreased in acid, iron, and sulfate. Although the concentration has decreased, the increase in flow has resulted in an increase in the pollution load (Table XI and XII).

TABLE X

Summary Data Subwatershed RT 6-21

Mean Concentration Mg/1 (S.D.[a])	Acidity	Iron	Sulfate
Before Reclamation[b]			
1965 - 1966	1,555 (400)	328 (85)	1,768 (432)
After Reclamation			
1968	1,127 (241)	309 (64)	1,179 (240)
1969	1,060 (227)	330 (108)	1,243 (309)
Load, Tons			
Before Reclamation[b]			
1965	684	148	829
1966	868	175	944
After Reclamation			
1968	683	192	737
1969	575	183	652

a. Standard Deviation.
b. The before and after reclamation data are not directly comparable, because some of the pollution load developed in the watershed prior to reclamation was diverted to the underground mine and thus, did not pass the control point.

TABLE XI

Pollution Loads And Their Sources Subwatershed RT 6-21

	1966	1968		1969	
	Tons	Tons	Percent of Total	Tons	Percent of Total
Acidity,					
Total	868	683	-	575	-
Mine RT 6-9	59	266	38	221	38
Mine RT 6-23	242	246	36	163	28
Total Underground	301	512	74	384	66
Surface Mines	**	171*	26	191*	34
Iron,					
Total	175	192	-	183	-
Mine RT 6-9	14	72	37	62	33
Mine RT 6-23	54	64	33	51	27
Total Underground	68	136	70	113	61
Surface Mines	**	56*	30	70*	39
Sulfate,					
Total	944	737	-	652	-
Mine RT 6-9	79	248	33	220	33
Mine RT 6-23	268	274	37	194	29
Total Underground	347	522	70	414	63
Surface Mines	**	215*	30	238*	27

* Assumed to be difference between total and underground.
** Cannot be determined because not all water in watershed drained past control point during pre-reclamation.

The cause of the increased flow has not been determined. Samples of the air behind the "wet" seal contained the same concentration of oxygen as the air outside the mine, thus, air must have access to the mine.

Mine RT 6-23 also had no reduction in the oxygen content inside the "wet" seal. An increase in flow was recorded at this mine (Table XII). The acid, iron, and sulfate concentrations have been reduced. Thus, an increase in flow and a decrease in concentration results in the pollution load from the mine being approximately the same for both the before and after period (Table XI and XII).

Mine Seals - Eleven "wet" seals were constructed in the large 2,000 acre underground mine complex and one in a small isolated mine. The sealing of the large mine was not completed. All of the portals on the south half of the mine were sealed, but several were left open on the north half. The subsidance over large parts of the mine was not corrected. Thus, it is not surprising that air samples collected from behind the "wet" seals contained the same oxygen concentration as the air outside the mine. The quality and quantity of water discharging from nine mine openings have been monitored and the results reported in Table XII.

The first eight openings, reported in Table XII, were in the large 2,000 acre mine. The data have an overall trend that indicates the concentration of acidity and sulfate has reduced slightly and the flow increased, resulting in an overall increase or no change in the pollution load. The concentration figures shown are averages and the actual data varied to such a degree that it is questionable if there are any actual changes due to mine sealing. The increase in flow noted at several sites probably is due to better measurements of flow after reclamation. Before reclamation, there were often seeps at the base of highwalls and toes of spoils that could not be measured. As a result of reclamation this water was forced out the main portal.

Mine RT 9-11 was a small isolated mine (only a few acres) and all its known openings had been sealed. Unlike the large mine, it was felt that a better than average effort had been extended to seal off all air entrances to the mine. As seen in Table XIII, the oxygen content within the mine had been reduced, but not eliminated. During the latter months of 1969, a marked increase in the oxygen content occurred. No explanation has been found for this happening. A marked reduction in acid and sulfate concentration occurred shortly after the mine was sealed, even before the oxygen concentration was reduced. This reduction is felt to be due to a change in the hydraulics of the mine, since two feet of water were ponded in it as a result of the seal, and not a reduction in acid formation. The quality of the water has been fairly constant since the initial decrease and has appeared to reach an equilibrium.

CONCLUSION

The Elkins Mine Drainage Demonstration Project has produced both encouraging and discouraging results. The reclamation and revegetation of surface mines and refuse piles have resulted in a decrease in the pollution load from that source. Not all the changes occur overnight and several years may be required before all of the residual pollutants are leached from the reclaimed spoil. Soil samples collected from the spoil indicated that a reserve of 2,000 pounds per acre of sulfate remains to be leached in the upper six inches. In some areas the pollution load the second year after reclamation was higher than the first. This change may be due to normal yearly variations or to the decreased effect of the lime applied during revegetation.

The air sealing of underground mines to eliminate all oxygen cannot be accomplished under the conditions encountered at Elkins. Even under the best conditions the oxygen was reduced to only seven percent. With each change in barometric pressure, air moves in or out of the mine. In a large complex mine with a tendency for subsidance, no reduction can be expected. Air sealing as practiced at Elkins was not successful.

TABLE XII

Characteristics of the Discharge From Underground Mines Before (1966) and After Air Sealing

Mine Seal Number	Acidity 1966	Acidity 1968	Acidity 1969	Sulfate 1966	Sulfate 1968	Sulfate 1969	Discharge 1966	Discharge 1968	Discharge 1969
	Concentration, Mg/1						Million Cubic Ft. Per Year		
RT 6-9	1,958	1,615	1,615	2,740	1,494	1,608	1	5.5	4.5
RT 6-23	1,942	1,455	1,312	2,114	1,567	1,560	4.3	5.7	4.1
RT 6-12	977	1,031	955	1,002	1,055	1,098	4.1	4.5	4.8
RT 6A-1	712	437	474	586	509	520	0.6	0.8	0.4
RT 6-3	217	195	181	427	412	358	3.4	3.9	4.7
RT 6-6[b]	264	2,193	2,422	408	2,022	2,380	2.3	0.8	0.2
RT 6-5	307	217	225	486	425	412	27.9	27.7	24.7
RT 5-2	837	664	a	1,147	799	a	4.5	6.6	a
RT 9-11[c]	591	331	348	1,035	685	674	0.9	1.5	1.4
	Load Tons/Year								
RT 6-9	59	266	221	79	248	220			
RT 6-23	242	246	163	268	274	194			
RT 6-12	65	129	135	68	136	152			
RT 6A-1	17	11	6	10	13	6			
RT 6-3	20	22	23	38	45	51			
RT 6-6[b]	25	39	18	22	34	17			
RT 6-5	240	171	172	399	350	315			
RT 5-2	118	119	a	81	159	a			
RT 9-11[c]	18	16	16	26	33	30			

a. Bulkhead seal constructed September 1969.
b. The concentration was lower and volume higher during 1966 because surface runoff was measured along with the mine discharge.
c. All mine seals, but RT 9-11 are into the 2,000 acre mine, RT 9-11 is into a small isolated mine.

TABLE XIII

Effectiveness of Mine Seal RT 9-11

	Oxygen Within Mine, Percent	Acidity (Hot) $CaCO_3$, mg/l	pH	Iron, mg/l	Sulfate, mg/l
Before Sealing[b] (Mean)	—	591 (65)[c]	2.8[d]	93 (25)[c]	1,035 (155)[c]
Minimum	—	438	3.1[e]	48	710
After Sealing					
Oct. 67	—	388	3.1	86	835
Nov. 67	9.1[a]	365	3.2	83	770
Dec. 67	—	325	3.2	87	785
Jan. 68	7.8[a]	315	3.1	75	655
Feb. 68	—	328	3.2	69	700
March 68	8.8[a]	332	3.2	77	703
April 68	—	277	3.3	60	625
May 68	10.8[a]	344	3.3	64	620
June 68	—	382	3.0	81	860
July 68	7.0[a]	354	3.2	73	780
Aug. 68	—	318	3.2	70	665
Sept. 68	—	360	3.0	74	680
Oct. 68	7.2[a]	279	3.2	74	630
Nov. 68	7.6[a]	247	3.2	78	660
Dec. 68	—	269	3.2	66	590
Jan. 69	—	373	3.3	62	700
Feb. 69	—	320	3.2	58	585
March 69	—	357	3.2	70	650
April 69	—	319	3.2	118	602
May 69	—	332	3.1	93	597
June 69	—	367	3.2	63	770
July 69	—	339	3.1	67	605
Aug. 69	—	357	3.0	60	685
Sept. 69	7.0	432	2.6	60	860
Oct. 69	—	309	3.4	86	700
Nov. 69	14.0	340	2.8	71	735
Dec. 69	15.5	333	3.2	56	600

a. Data collected by U. S. Bureau of Mines.
b. March 1964 - August 1967.
c. Number in parenthesis is standard deviation.
d. Median value.
e. Maximum value.

The final analysis of the effectiveness of the remedial measures is the pollution load of Roaring Creek and Grassy Run. In Table XIV, these loads are presented.

The Roaring Creek discharge shows a reduction of the acid load of 754 tons in 1968 and 781 tons in 1969, if 1966 is considered the base year. If 1965 is considered the base year, then there has been an increase in the acid load. It is suggested that 1966 is a better base year since it has a precipitation level similar to 1968 and 1969 while 1965 has approximately five inches less.

Although no remedial work was performed in the Grassy Run watershed, the work performed in Roaring Creek was to have diverted water from the underground mines that drain to Grassy Run, thus, reducing the pollution load. As shown in Table XIV, there has been a reduction. Oddly, there have been no significant trends in the discharge from this watershed, the discharges for 1965, 1966, 1968, and 1969 being 195, 190, 248, and 166 million cubic feet per year, respectively.

If 1966 was considered the base year, then there was a decrease in the acid load for the Roaring Creek - Grassy Run area of 1,507 tons in 1968 and 2,990 tons in 1969.

However, even with these decreases, it is quite evident that these creeks are still highly polluted and far from being recovered. They can only return to that condition when an effective method of controlling underground discharges can be developed.

TABLE XIV

Pollution Load Roaring Creek and Grassy Run, 1964 - 1969

Year	Acidity, Tons/year		Sulfate, Tons/year	
	Roaring Creek	Grassy Run	Roaring Creek	Grassy Run
Before Reclamation				
1964	1,500[a]	1,823[b]	2,119[a]	2,775[b]
1965	2,397	3,303	4,131	5,320
1966	3,576	3,467	5,416	4,683
During Construction				
1967	4,908	4,737[c]	7,603	6,144[c]
After Reclamation				
1968	2,822	2,915	4,663	4,141
1969	2,795	2,393	3,207	3,480

a. Only 10 months, March - December
b. Only 9 months, April - December
c. Only 9 months, January - September

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