RECLAMATION OF TOXIC MINE WASTE UTILIZING SEWAGE SLUDGE CONTRARY CREEK DEMONSTRATION PROJECT

ADDENDUM REPORT

by

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in the problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

Land disturbed by man's activities can create many environmental problems. This report describes a project in which one of man's waste, sewage sludge, was utilized to reclaim land disturbed by mining. Sludge, with the assistance of limestone and fertilizer, was successful in establishing vegetation and controlling erosion on mine waste dumps that had been barren for over 50 years.

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ABSTRACT

Three abandoned pyrite mines in Louisa County, Virginia that had been inactive since the early 1920's contained approximately 12 hectares virtually barren of any vegetation. The toxic nature of the mine waste resulted in the continuous leaching of acid and heavy metals into a small stream known as Contrary Creek rendering it essentially void of aquatic life. The severe acid mine drainage problem along this stream and associated fish kills downstream had been recognized for years. The Virginia State Water Control Board was prompted to seek a solution to the problem in 1968 when plans were announced to construct a reservoir as a source of cooling water for a nuclear power plant on the North Anna River into which Contrary Creek drained.

Two of the mine sites comprising about 8 hectares were reclaimed with funds from a demonstration grant from the United States Environmental Protection Agency with the Virginia State Water Control Board contributing matching funds through in-kind services and the Soil Conservation Service providing technical assistance. The third mine site was reclaimed by a mining firm. Reclamation began in 1976 and consisted of regrading mine spoils, constructing diversions, applying soil amendments including wastewater sludge, lime, fertilizer and seeding. The purpose of the reclamation was to reduce the acid mine drainage into Contrary Creek and stabilize the mine waste to minimize erosion.

Severe droughts in 1976 and 1977 and the highly toxic nature of the mine waste necessitated a six-year maintenance program involving application of soil amendments and reseeding to establish vegetation. The first significant progress did not occur until 1978-79. Abnormally low precipitation in 1980-81 continued to encumber the project. Development of a viable soil layer was a slow and tedious process, but by the beginning of the 1983 growing season about 90 percent of the reclaimed areas appeared to have established a more or less permanent cover. Ky-31 fescue grass was the most successful planting with weeping lovegrass exhibiting a tolerance for drought. The use of sludge was the most essential factor in promoting vegetation.

Results of a seven-year monitoring program indicated little overall improvement in the water quality of Contrary Creek in terms of pH and acidity. There did appear to be a pronounced trend in the reduction of heavy metals, especially when periods of similar stream flow levels are compared under prereclamation and postreclamation conditions. Further improvement is expected as a more productive soil cover establishes, but acid mine drainage will continue to leach from the toxic wastes beneath the stream banks. It will likely require several more years to realize any overall improvement. Five

years of monitoring of the Contrary Creek arm of Lake Anna showed acid mine drainage to have a pronounced influence for a short distance out into the reservoir but apparently insignificant effect elsewhere in the lake. Semi-annual biologic surveys until early 1982 revealed negligible improvement in the biota of Contrary Creek to date.

Average cost of reclamation including all maintenance for the two mine sites funded from the demonstration grant was approximately $15,000 per hectare.

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ACKNOWLEDGEMENTS

The State Water Control Board is most grateful for the assistance and advice provided by the Soil Conservation Service of the United States Department of Agriculture throughout the life of the project. Special thanks are extended to Lowry Abell and Jack Warren of Louisa County Field Office who continued to provide on-site assistance with the project maintenance and were most helpful in making recommendations on soil amendments, seeding and erosion control.

Ronald D. Hill, Environmental Protection Agency Project Officer, provided guidance from the inception of the project through all the planning and actual reclamation work to the completion of the Final Addendum Report.

Richard Ayers of the Division of Ecological Studies of the Virginia State Water Control Board conducted the biologic studies throughout the project.

INTRODUCTION

This report is an addendum to a comprehensive report that was completed on the Contrary Creek project in 1981.* It summarizes the work described in the comprehensive report and updates the work that was done subsequent to 1980. The reader is referred to the comprehensive report which will hereafter be referred to as the "Main Report" for details of the entire project prior to 1981.

The project involved the reclamation of two abandoned pyrite mine sites along Contrary Creek in Louisa County, Virginia (Fig. 1) under a cooperative effort of the Environmental Protection Agency (EPA), Soil Conservation Service (SCS), and Virginia State Water Control Board (SWCB). The objective of the project was to demonstrate means by which acid mine drainage (AMD) emanating into Contrary Creek could be abated by reclaiming the mine waste sites using sewage sludge. The construction work was funded by an EPA demonstration grant with the SWCB providing matching funds through in-kind services including project management, monitoring, and documentation. The SCS agreed to provide technical assistance.

Approximately 8 hectares were reclaimed at two sites known as the Sulphur and Boyd Smith Sites (Fig. 1). The Sulphur was the largest and by far in the worst condition. A third site upstream known as the Arminius was reclaimed by a mining company (Fig. 1).

CONCLUSIONS

(1) A fair to good vegetative cover had established reasonably well over about 90 percent of reclaimed mine sites by the beginning of the 1983 growing season. Some highly toxic spots remained on the stream banks, and several scattered areas with a very thin soil cover were quite vulnerable to drought. Two dry years in early phases of reclamation severely hampered the project and abnormally low precipitation in 1980-81 had detrimental effects.

(2) The repeated application of digested wastewater sludge along with lime and fertilizer was essential in promoting vegetation. It is doubtful that a fraction of vegetative success would have been achieved without the use of sludge.

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*Reclamation of Toxic Mine Waste Utilizing Sewage Sludge - Contrary Creek Demonstration Project by K. R. Hinkle. EPA Report 600/2-82-061, Cincinnati, Ohio, August 1982. Available from NTIS - PB82-227-521

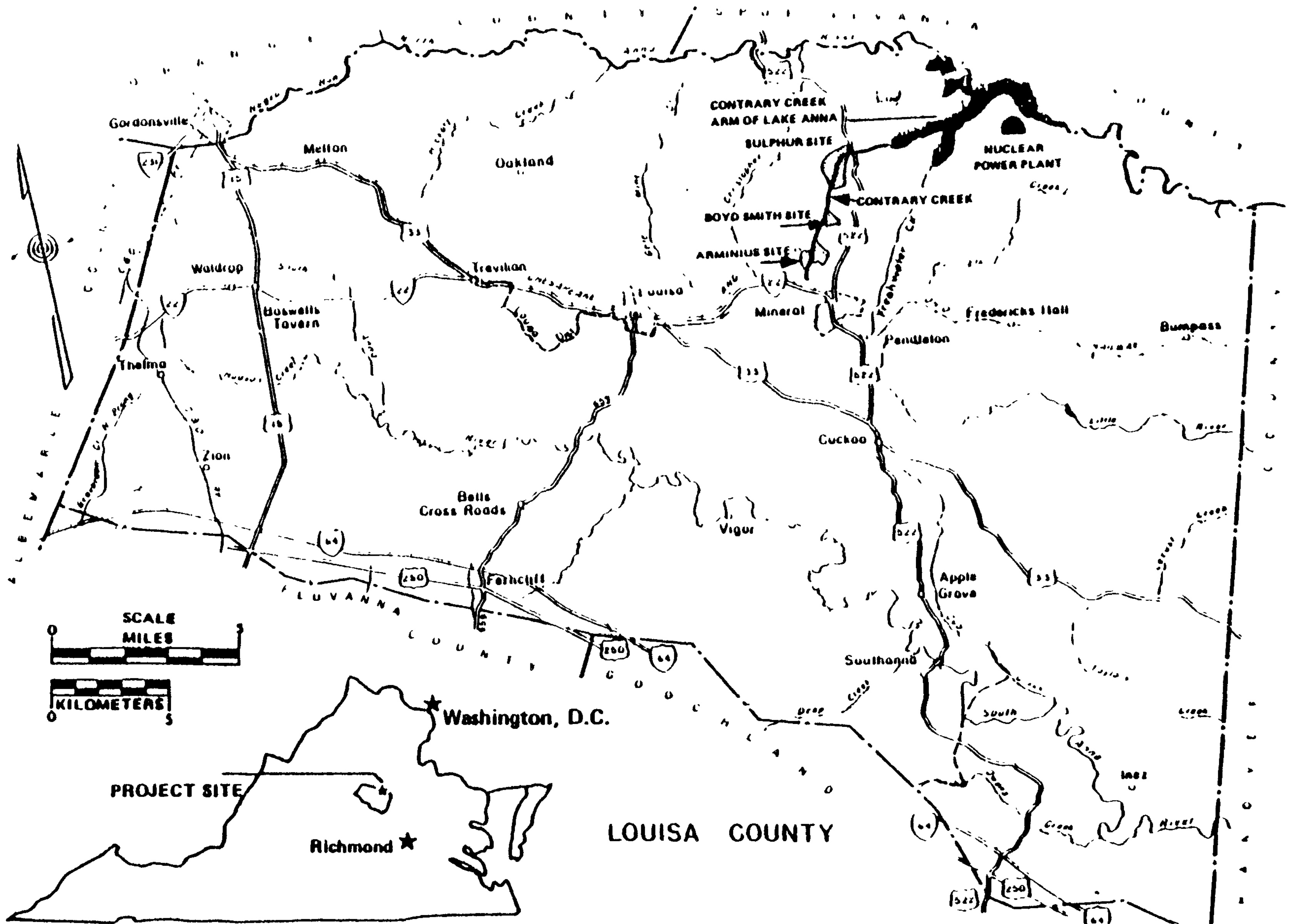


FIG. 1 LOCATION OF PROJECT

(3) No health hazards or ill effects to the environment are known to have resulted from the use of sludge.

(4) Soil analyses indicate a continued overall improvement in the ability of the soil to support vegetation. However, the viable layer of soil is limited to a few inches in some places with extremely toxic materials beneath. A thicker layer of productive soil should gradually build up with time.

(5) Heavy and repeated application of lime apparently was instrumental in raising the soil pH. A pronounced pattern that emerged was a direct relationship between potash deficiency and difficult areas to vegetate.

(6) The reduction of erosion with concomitant decrease in surface runoff of AMD was one of the first achievements realized in the reclamation program.

(7) Ky-31 fescue proved to be the most successful planting over the long term. Weeping lovegrass exhibited a tolerance for hot dry weather and was essential in establishing a grass mat. Legumes did not show appreciable success. Numerous volunteer plants began to appear and aspen trees began to invade after three to four years of reclamation. Early attempts at planting pine seedlings had very limited success.

(8) There appeared to be little overall improvement in the water quality of Contrary Creek six years after reclamation began. There did seem to be a trend toward reduction in heavy metals, but pH, acidity, and sulfate remained at about the same levels. Extreme fluctuations in flow levels over the course of the regular monitoring program had pronounced impact upon the data generated.

(9) The Sulphur Site remains the major contributor of AMD along Contrary Creek, but certain metals appear peculiar to each mine site. Water quality tends to deteriorate downstream as Contrary Creek passes each mine site.

(10) The principal causes of AMD still affecting the stream are sudden flushouts of oxidation products from the stream bed, especially the downstream reach below the Sulphur Site, and from stream banks when rainstorms occur after prolonged dry periods. AMD continues to seep from the banks between storms.

(11) Biologic studies have shown no significant improvements in the ability of the AMD affected part of Contrary Creek to support a healthy and diverse macroinvertebrate community since reclamation began. Since sensitive organisms do inhabit the unaffected tributaries of the stream, there is potential for benthic life to be restored if the AMD is reduced.

(12) In view of the very toxic nature of the AMD entering Contrary Creek, it will probably require several more years to realize overall improvement in the water quality.

(13) The Contrary Creek arm of Lake Anna immediately below the mouth of the stream is affected by AMD, but the impact upon the main body of the lake appears negligible.

(14) Including initial construction and all subsequent maintenance, approximately $15,000 per hectare was spent on actual reclamation work.

RECOMMENDATIONS

(1) A project of this type will in all probability require several years of intense maintenance to assure permanent survival of vegetation. Regular inspections are necessary to determine maintenance needs including reseeding of problem areas and placement of erosion controls. Soil tests should be conducted at least annually to evaluate progress and to determine soil additives needed. Fall seeding is generally more successful than spring seeding because of the risk of drought during the summer months. Close surveillance should be made of the reclamation sites for 5 to 10 years to observe progress and any evidence of damage that may reverse the project effort.

(2) Whenever feasible, wastewater sludge should be used in the reclamation of lands severely affected by mine wastes. The positive effects that sludge has in promoting vegetative growth on highly toxic areas have been well demonstrated in this project. Large urban areas that generate huge volumes of sludge and have problems obtaining disposal sites are the best sources to use. If work schedules permit and the terrain is favorable, it is desirable to have sludge dumped directly upon application areas rather than stockpiled nearby because of the extra handling involved. On mine sites such as the one studied, potash levels should be evaluated for deficiencies.

(3) Water quality monitoring of the regular stream stations and key tributaries should continue on a limited basis. The monitoring station below the Sulphur Site should be retained as a permanent flow gaging station. Biologic studies should continue biennially. All monitoring data should be evaluated for long-term changes.

(4) The downstream reach of Contrary Creek between the Sulphur Site and Lake Anna would be the area to concentrate upon, in the event it would ever be feasible to do any additional reclamation work.

(5) The vast amount of quantitative and qualitative data generated by the comprehensive monitoring program in conjunction with this project may have beneficial uses to other water studies aside from AMD. Few streams of this small size have likely been monitored so intensely in terms of quality and flow.

BACKGROUND

Deep shaft pyrite mines were worked at all three sites between 1880 and 1923. It was during this period that massive tailing piles were created along Contrary Creek resulting in a severe AMD problem which left the stream practically devoid of aquatic life. With the exception of trial plantings by the SCS and the Virginia Division of Forestry in the 1950's and 1960's, the mine waste sites remained essentially in this condition until the reclamation project began in 1976.

The project was prompted by the construction of a reservoir (Lake Anna) for a nuclear power plant downstream from Contrary Creek (Fig. 1). It was feared that the continued influx of AMD which included heavy metals would result in a buildup of contaminants in the new reservoir.

The SWCB had done some preliminary stream sampling of Contrary Creek in the early 1970's which confirmed the severity of the AMD problem and identified the heavy metals present. Prior to reclamation, the SWCB conducted more intensive water quality studies to determine prevailing conditions. Table 1 shows average concentrations of approximately 25 sample collections along Contrary Creek in 1974 and 1975. These sampling points were established as regular monitoring stations when the full-scale monitoring program began in October 1975. The Main Report should be consulted for detailed water quality data collected from 1975 until 1980.

Prereclamation biologic studies by Virginia Polytechnic Institute and State University (VPI & SU) had also confirmed the severe impact of AMD on the aquatic life of Contrary Creek. Biologic surveys were part of the SWCB monitoring program.

The SWCB had decided to apply for an EPA grant under Section 107 of PL 92-500 in 1973. An engineering firm was hired to do a feasibility study on the best means of reclaiming the mine waste areas and to make monitoring recommendations. Initially all three mine sites were considered in the grant proposal. In the midst of efforts to obtain a grant, Callahan Mining Corporation advised the SWCB that in connection with their mineral exploration in the area, they would assume responsibility for reclaiming the Arminius Site. Thus, the grant request involved only the Sulphur and Boyd Smith Sites. The Sulphur Site is owned by Glatfelter Pulp Wood Company and the Boyd Smith Site is privately owned. Deeds of easement were executed with the property owners concurrent with the grant application.

RECLAMATION AND MAINTENANCE

An EPA grant was awarded to the SWCB in 1975 to reclaim the Sulphur and Boyd Smith Sites. The provision of the grant was for 60 percent Federal funding to cover contractual services with the Commonwealth of Virginia providing 40 percent matching funds through in-kind services. The SCS prepared

TABLE 1. AVERAGE WATER QUALITY ANALYSES OF CONTRARY CREEK PRIOR TO RECLAMATION (mg/l)[a]

Monitoring Station	pH	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
Above all Mine Sites	6.8	13	9	0.02	1.1	0.01	0.06	0.2
Below Arminius Site	6.0	12	98	0.11	2.1	0.02	0.52	4.8
Below Boyd Smith Site	4.8	34	149	0.22	2.6	0.03	1.54	3.8
Below Sulphur Site	3.7	126	229	0.76	24.1	0.08	1.71	4.0
Mouth of Contrary Creek	3.3	169	267	1.20	23.1	0.05	1.45	3.5

[a]Based upon the average of approximately 25 samples collected in 1974 and 1975.

plans and specifications for the reclamation work, provided an on-site inspector during the construction work, and continued to lend technical expertise and assistance throughout the project.

A contract was awarded to do the reclamation work after sealed bids had been submitted. Work began in April 1976 and consisted essentially of (1) clearing debris, stumps, and brush; (2) regrading and smoothing the mine wastes; (3) constructing diversions; (4) excavating the stream channels; (5) stabilizing stream banks with riprap; (6) applying sewage sludge, lime, and fertilizer as soil amendments; and (7) seeding and mulching.

The utilization of sewage sludge is a fairly unique characteristic of this project. Few reclamation projects have used sludge on the scale that was done at Contrary Creek. All sludge used was trucked from the Blue Plains Sewage Treatment Plant in Washington, D.C., a round-trip of about 180 miles. The plant generates approximately 275 tonnes of anaerobically digested sludge daily which is concentrated to approximately 20 percent solids. Because of the high cost of sludge disposal in the Washington, D.C. area, the District agreed to deliver the sludge free of charge and continued to do so for the subsequent maintenance. On the basis of cost estimates in the 1974 feasibility study for hauling sludge, this resulted in a savings to the project of approximately $100,000.

For the purposes of this project, the Sulphur Site was divided into work areas as depicted in Fig. 2. Approximately 6 ha (15 ac) were reclaimed at this site where massive tailing piles stood along the banks of Contrary Creek. A description of prereclamation conditions and brief summaries of the remedial work done are presented in Table 2.

Conditions at the Boyd Smith Site were considerably less severe than at the Sulphur Site. About 2 ha (5 ac) were covered with 1 to 2 m (3 to 7 ft.) of tailings which choked a tributary of Contrary Creek. Reclamation here essentially consisted of smoothing for incorporation of the soil amendments and riprapping part of the tributary.

All reclamation work including seeding was completed by early July 1976, but the late seeding coupled with meager rainfall the remainder of the summer resulted in sparse germination. A complete reseeding was done the following spring, but unfortunately one of the worst droughts of the century followed. This not only negated the spring seeding but destroyed some of the small patches of vegetation from the original seeding. See Tables 3-5 for precipitation records in the project area.

The year of 1977 was the beginning of a long-term maintenance program which continued until 1982. The original grant period to cover the reclamation of the Sulphur and Boyd Smith Sites was for three years. However, the nature of the problem involving extreme toxicity of the mine tailings and the severe AMD combined with the recurrent droughts necessitated extending the grant period to a total of seven years. This was possible because initial reclamation work had been done for considerably less cost than estimated.

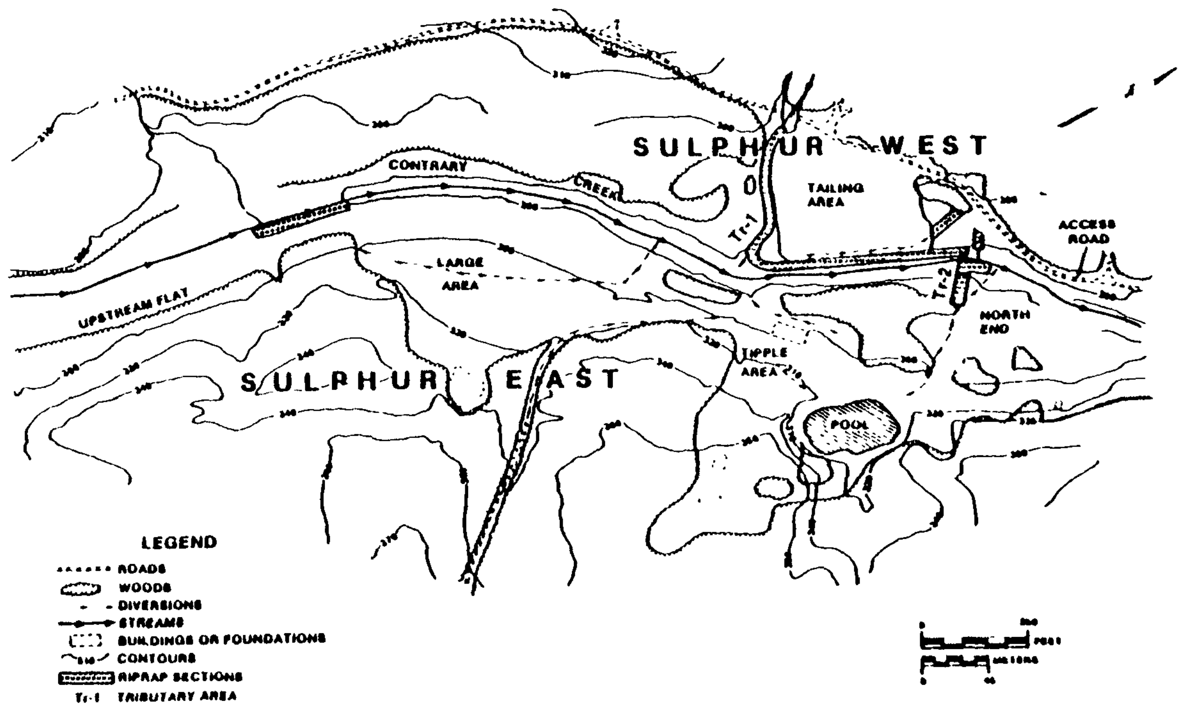


Fig. 2 Various Work Areas of Sulphur Site

TABLE 2. CHARACTERISTICS OF SULPHUR SITE

Work Area		
Sulphur East	Size (ha)[a]	Conditions
Upstream Flat	0.55	Flood plain area along creek. Used to deposit mine waste dredged from creek when channel was cleaned and straightened.
Large Area	2.20	Denuded mine waste disposal area with numerous piles of waste. Poor surface drainage. Rill and gully erosion evident, collapsed mine shaft. Reclamation work included grading to gentle slope (8.5%) installation of diversion ditch, and filling of shaft.
Tipple Area	0.75	Very steep slope covered with mine waste below tipple ruins. Reclamation work: installation of diversion ditch and small amount of grading.
North End	0.85	Mine waste disposal area with one large pile of waste. Reclamation work: levelling and grading of waste, improvement of tributary channel and riprap.
Sulphur West		
Tailing Area	1.15	Large tailing area retained by cribbing from creek. Rose about 9 meters (30 feet) above stream bed. Several large piles of waste severely eroded. Reclamation: grading of area, riprapping along creek, diversion ditch along creek.
Tr-1	0.41	Flood plain area adjacent to creek and tributary. Reclamation: grading and riprapping of tributary.

[a] To convert hectares (ha) to acres (ac) multiply by 2.471

TABLE 3. AVERAGE MONTHLY PRECIPITATION AT LOUISA WEATHER STATION - 1941 - 1979 (cm)[a]

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
7.8	7.3	9.7	7.5	9.2	9.6	11.7	11.6	8.4	8.2	8.0	9.2	108.2

TABLE 4. MONTHLY PRECIPITATION AT LOUISA WEATHER STATION 1975 - 1982 (cm)[a]

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1975	8.4	5.9	16.4	4.6	8.5	26.7	20.2	7.8	24.0	4.8	5.1	9.9	142.3
1976	9.3	3.9	7.2	-4.1	8.2	11.6	6.8	10.9	10.7	22.3	3.7	4.8	103.4
1977	4.3	1.0	6.2	4.6	3.6	3.7	5.2	5.3	5.2	11.5	14.7	12.6	77.9
1978	21.7	0.7	10.3	9.3	12.1	14.6	13.7	21.0	6.0	2.9	6.6	9.2	128.1
1979	14.1	13.0	9.6	8.5	8.7	10.0	2.3	12.7	19.7	13.9	8.2	2.1	122.3
1980	11.5	2.7	9.7	5.3	7.9	1.4	8.4	11.0	2.2	8.0	6.4	1.0	75.5
1981	0.3	7.8	3.4	5.4	10.3	5.4	16.4	9.1	7.0	9.7	1.8	9.1	85.6
1982	7.0	12.7	10.1	7.4	5.0	12.8	7.5	11.0	10.1				

TABLE 5. MONTHLY PRECIPITATION AT CONTRARY CREEK RAIN GAGE - 1980 - 1982 (cm)[a]

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1980	11.7	1.9	10.9	4.7	8.6	0.3	7.7	17.3	2.2	8.3	6.2	0.6
1981	0.2	6.6	1.7	5.0	8.2	4.1	13.1	5.7	5.4	10.7	0.9	9.6
1982	5.8	---	8.5	5.5	5.3	---	4.1	10.7	---			

[a]To convert centimeters to inches multiply by 0.394

[b]Incomplete records are available where no measurements appear

Maintenance consisted primarily of spring and fall seeding with additional applications of sludge, lime, and fertilizer. Lime and fertilizer application rates were determined on the basis of periodic soil analyses which will be discussed further elsewhere in this report. Summaries of lime and fertilizer application rates are shown in Tables 6 and 7, respectively. Additional sludge was incorporated in the more difficult areas to vegetate as needed. A summary of the sludge application rates appears in Table 8, and sludge composition is presented in Table 9.

Maintenance also included placing several additional sections of riprap along the channel of Contrary Creek and in some drainageways as well as periodic staking of straw bales for added erosion control. Irrigation water from a nearby beaver pond was applied to portions of the Sulphur Site during dry periods from 1978 to 1980.

The most successful planting was Ky-31 fescue grass which was the mainstay of the vegetation. Weeping lovegrass proved to be very drought tolerant and made its best showing during the hot summer months when the Ky-31 became dormant. Korean and sericea lespedeza were also used in the seed formula but showed only limited success. Various types of small grains were used for nurse crops. Typical seedings are shown in Table 10.

Both the Sulphur and Boyd Smith Sites were planted with pine seedlings during the first years of reclamation, but hardly any survived the droughts. Glatfelter Pulp Wood Company has continued trial plantings of loblolly pines at the Sulphur Site and may eventually try another full-scale planting. Numerous varieties of volunteer weeds and some trees began to invade the reclaimed areas around 1978.

At the Arminius Site, the mine area upstream from Sulphur and Boyd Smith, a similar reclamation and maintenance program was carried out until 1982 by a private consultant for Callahan Mining Corporation. Sludge from the Blue Plains STP was also used at this site where around 3 ha (7 ac) were reclaimed.

MAINTENANCE SUBSEQUENT TO 1980

This section gives details of the maintenance after 1980. For complete details on the maintenance prior to 1981, the reader is referred to the Main Report.

1981

The only maintenance done in 1981 was bushhoging of the Sulphur Site and placing a new section of riprap along the main channel of Contrary Creek at the Sulphur Site. The bushhog work was done in August to remove tall weeds and promote growth of the grass cover. Care was taken to preserve young trees. The riprap work consisted of placing a 250-ft. section of stone along the east side of the stream channel where bank erosion was starting to cut into the

TABLE 6. SUMMARY OF LIME APPLICATION RATES[a] (t/ha)[b]

1976	1977	1978		1979		1980		1982
		Spring	Fall	Spring	Fall	Spring	Fall	Spring
8.9	13.4-31.2	22.3	11.1-33.4	4.5-17.8	8.9-22.3	8.9	8.9	8.9

[a]A range of application rates indicates that the lower rate was applied to all areas and the upper rate was the maximum applied to areas.

[b]To convert t/ha to tons/ac multiply by 0.449.

TABLE 7. SUMMARY OF FERTILIZER TYPES AND APPLICATION RATES (Kg/ha)[a]

1976		1977		1979		1980		1982
				Spring	Fall	Spring	Fall	Spring
10-10-10	38-0-0	10-10-10	38-0-0	6-6-12	6-0-12	6-0-12	6-6-12	5-10-10
1121	448	561	448	1121	1121	1121	1121	1121

[a]To convert Kg/ha to lbs/ac multiply by 0.892

TABLE 8. SUMMARY OF SLUDGE APPLICATION[a]

Year	Total t (wet)	Avg. % Solids	Total t (dry)	Total ha Sludged	t/ha (dry)	tons/ac (dry)
1976	7257	22	1596	6.6	200-260	90-116
1977	1769	19.9	352	1.6	220	99
1978	544	20.3	110	0.8	136	62
1979	308	19.5	60	0.7	82	37
TOTAL	9878		2118			

[a]To convert tonnes/ha to tons/ac, multiply by 0.449

TABLE 9. COMPOSITION OF SLUDGE USED AT CONTRARY CREEK (ppm - dry weight)

	pH	Cu	Zn	Pb	Hg	Cd	Cr	Ni
SWCB Data(a) 1976	6.5	785	2529	550	5.1	17.0	659	29
Blue Plains(b) STP Data 1976-79	6.1	678	1604	477	3.8	14.9	717	42

(a)Average of 40 daily composite samples.
(b)Average of monthly composite samples.

TABLE 10. TYPICAL SEEDING[a] FORMULA USED AT CONTRARY CREEK

Species	Kg/ha
Tall Fescue (Ky-31)	67.3
Weeping Lovegrass	2.2
Korean Lespedeza	11.2

[a]To convert Kg/ha to lbs/ac, multiply by 0.892

Upstream Flat. Stone was placed according to the same specifications described in the Main Report for the original reclamation work. Material dredged from the stream channel was used as bedding. Table 11 shows costs of the 1982 maintenance.

1982

Since the grant period was to end in July 1982, it was decided that a final lime and fertilizer application would be given to the Boyd Smith and Sulphur Sites in the spring of 1982. Prior to liming and fertilizing, the stream banks and scattered bare areas were hand seeded in late March. Ky-31 fescue and weeping lovegrass were sown at the rate of 67.3 kg/ha (60 lbs/ac) and 2.2 kg/ha (2 lbs/ac), respectively.

In May all of the Sulphur Site and the north side of the Boyd Smith Site were limed at the rate of 8.9 t/ha (4 tons/ac) and had 5-10-10 fertilizer applied at the rate of 1121 kg/ha (1,000 lbs/ac). Straw bales were staked in erosion-prone areas. A summary of the 1982 maintenance costs is presented in Table 12. Glatfelter Pulp Wood Company planted 3500 loblolly pines at Sulphur as their effort continued to establish a tree crop.

Another aerial survey consisting of stereo coverage in black and white, color and infrared along with oblique slides was done of the entire project area by the Virginia Department of Highways and Transportation (VDH&T). This was the fourth aerial survey of the project, including a 1974 prereclamation flight. Figs. 3 and 4 compare prereclamation and postreclamation aerials of the Sulphur Site.

VEGETATIVE PROGRESS

1981

After an unusually dry winter, several heavy rains in the late spring and early summer resulted in some of the best growth to date. Although total precipitation for the year was considerably below normal (see Tables, 3, 4, 5), there was a general improvement in vegetative cover at both the Sulphur and Boyd Smith Sites because rain came during crucial parts of the growing season. Notable areas of improvement were the Tipple Area and the Large Area of Sulphur East. Ky-31 continued to be the most successful planting and the weeping lovegrass made its usual good showing in mid-summer. Aspen trees continued to invade the Large Area of Sulphur East. A few bare spots remained on some apparently highly toxic areas of the Tailing Area of Sulphur West.

The Boyd Smith Site continued to build a stable soil layer and develop an excellent grass mat over virtually all of the reclaimed areas except along portions of the tributary dividing the site.

TABLE 11. MAINTENANCE COSTS - 1981

Riprap		
109.85 tons @ $10.00/ton		$1098.50
10 hours of loader time @ $40.00/hr.		400.00
	Subtotal	$1498.50
Bushhog work		$190.00
	Grand Total	$1688.50

TABLE 12. MAINTENANCE COSTS - 1982

59.45 tons lime @ $22.50/ton		$1337.63
8 tons fertilizer @ $130.00/ton		1040.00
35 straw bales @ $3.00/bale		105.00
	Subtotal	$2482.63
60 lbs. tall fescue @ $0.60/lb.		$36.00
2 lbs. weeping lovegrass @ $5.00/lb.		10.00
4 hrs. labor @ $6.00/hr.		24.00
	Subtotal	$70.00
	Grand Total	$2552.63

Fig. 3 Sulphur Site before reclamation in 1974

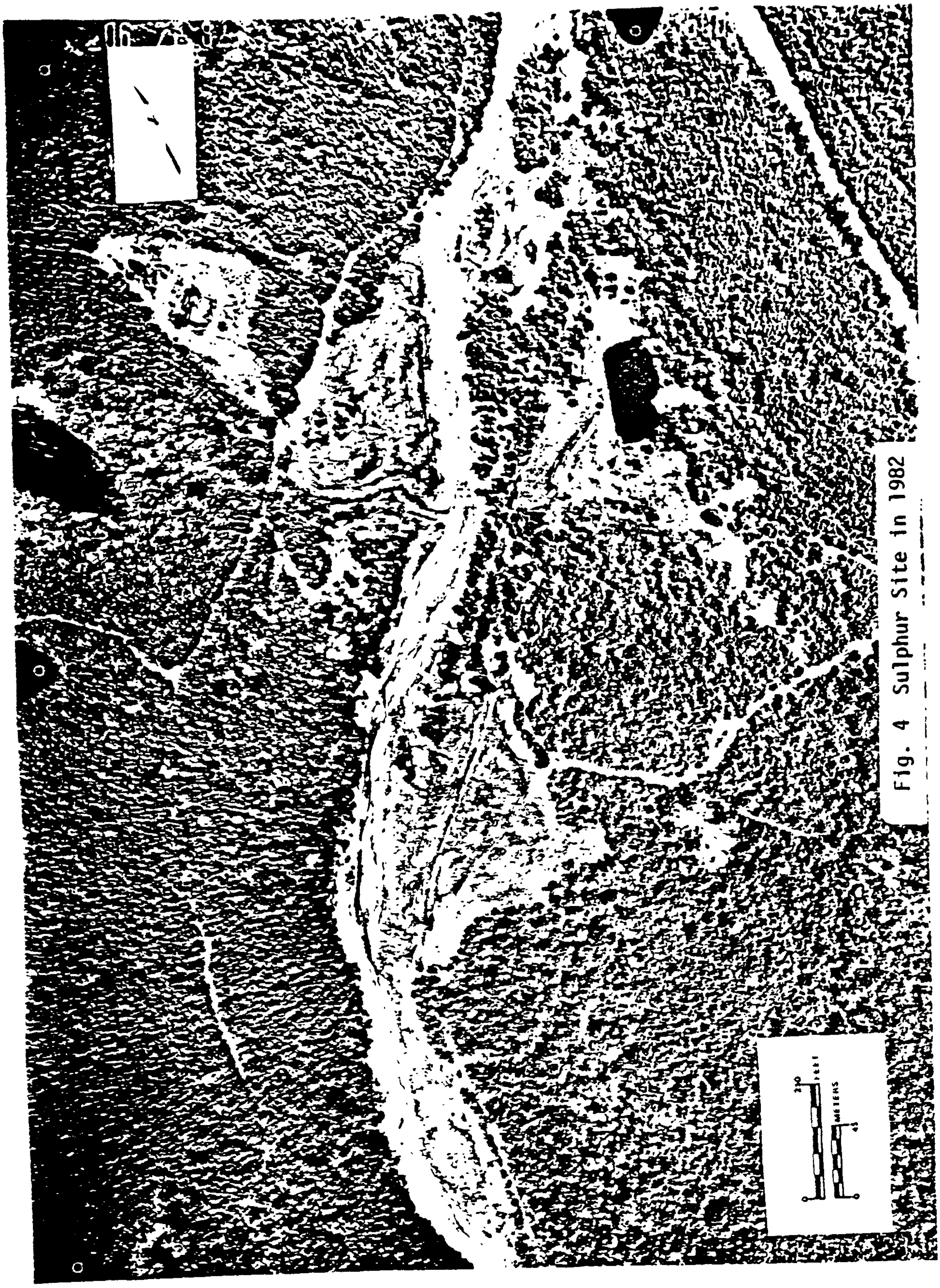


Fig. 4 Sulphur Site in 1982

1982

This year was probably the best overall growing season since the reclamation project began. Abundant rain throughout much of the spring and summer enhanced vegetative cover over both reclamation sites. The plantings exhibited good growth and numerous species of volunteers flourished. Some new varieties also began to appear.

The most decided improvement was along the bank of Contrary Creek adjacent to the Tailing Area of Sulphur West which has always been the most difficult area for grass to germinate and establish. This area appeared to benefit significantly from the spring seeding and had better than a 50 percent cover by fall. High toxicity still left a few isolated spots of the Tailing Area bare. Tr-1 has become choked with several varieties of shrubs and small trees which is probably one of the more encouraging results of the reclamation effort. (See Figs. 3 and 4)

Growth increased over the Boyd Smith Site with notable improvement along the tributary where grasses and seedlings continued to encroach upstream. This site appears well on its way to establishing permanent cover.

SOIL ANALYSES

The SCS and SWCB have continued to collect composite soil samples annually over the various work areas of the project. The same sampling procedures and analytical methods were used as described in the Main Report for the earlier soil studies. The samples collected by the SCS were tested for nutrient availability to determine lime and fertilizer requirements. Those collected by the SWCB were analyzed for pH and water-extractable heavy metals.

The 1980-82 nutrient availability for the various work areas compared with prereclamation conditions is shown in Table 13. Note that the pre-reclamation tests were for just one composite sample from each Sulphur West and Sulphur East. It can be seen that dramatic increases in the nutrient availability were realized after the reclamation began. Calcium (CaO) and Magnesium (Mgo) improved rapidly and appear to have stabilized. Phosphate (P_2O_5) and potash (K_2O) results have been somewhat erratic but there has been an overall increase in availability.

As related in the Main Report, there appears to be a distinct correlation between potash deficiency and difficult areas to vegetate. Several areas appeared to show a direct relationship between increase in potash availability and marked improvement in grass cover, e.g., the Tipple Area and Tr-1 of the Sulphur Site. The abrupt rise in phosphate noted in July 1981 and the sudden drop in February 1982 is puzzling. However, there does not appear to be as pronounced a relationship between phosphate and plant growth as is the case with potash.

TABLE 13. SOIL DATA - pH AND NUTRIENT AVAILABILITY IN LBS/AC[a]

Area	Date	pH	P_2O_5	K_2O	CaO	Mgo
SULPHUR WEST	11-75	2.4	(L-)	(L-)	L-	H
Tailing Area						
Grassed	8-80	6.1	32 (M-)	124 (M)	VH	VH
	7-81	3.0	275 (VH)	4 (L-)	VH	VH
	2-82	6.9	26 (M-)	101 (M-)	VH	VH
Bare	8-80	3.1	275 (VH)	38 (L)	VH	VH
	2-82	6.4	16 (L)	7 (L-)	VH	
Tr-1	8-80	6.2	128 (H)	275 (H)	VH	VH
	7-81	3.0	275 (VH)	7 (L-)	VH	VH
	2-82	5.9	25 (L+)	91 (M-)	VH	VH
SULPHUR EAST	11-75	2.2	(L-)	(L-)	VH	VH
Large Area	8-80	6.6	32 (M-)	124 (M)	VH	VH
	7-81	4.8	215 (H+)	67 (L+)	VH	VH
	2-82	6.9	50 (M)	198 (M+)	VH	VH
Tipple Area	8-80	5.7	209 (H+)	110 (M-)	VH	VH
	7-81	3.8	275 (VH)	30 (L)	VH	VH
	2-82	7.0	30 (M-)	175 (M)	VH	VH
Upstream Flat	8-80	6.3	60 (M)	186 (M+)	VH	VH
	7-81	4.4	275 (VH)	121 (M-)	VH	VH
	2-82	6.7	21 (L+)	136 (M)	VH	VH
North End	8-80	6.0	32 (M-)	41 (L)	VH	VH
	7-81	3.5	275 (VH)	11 (L-)	VH	VH
	2-82	5.8	8 (L)	4 (L-)	VH	VH
BOYD SMITH	11-75	3.1	(L-)	(L-)	L-	H+
	8-80	6.2	128 (H+)	275 (H)	VH	VH
	7-81	6.5	53 (M)	358 (H+)	VH	VH
	2-82	5.5	112 (H-)	162 (M)	VH	VH

[a] VH - Very High, H - High, M - Medium, L - Low
Analyzed by the Cooperative Extension Service at Virginia Polytechnic Institute and State University in Blacksburg, Virginia

Table 14 presents pH and metal analyses that have been conducted from the various work areas over the duration of the project. It is apparent that significant improvement in soil conditions has been achieved over the years since reclamation began in 1976. pH levels have been raised and heavy metal concentrations lowered. The soil in some places such as the Large Area of Sulphur East and the Boyd Smith Site showed relatively rapid improvement shortly after reclamation began and appear to have stabilized. Others like Tr-1 of Sulphur West and the Tipple Area of Sulphur East did not show marked improvement until after several years of intense efforts.

One of the most difficult areas to realize improvement was the Tailing Area of Sulphur West where separate soil samples have been collected in recent years from the grassed and barren areas. Although gains have been tedious, it appears that pH is slowly rising and that metals are being lowered in this stubborn area. The application of sludge and lime have undoubtedly been the major factor in raising the pH and lowering metals content. It is also likely that the sludge tied up the heavy metals thus affecting soil changes.

In summary, the soil analyses indicate a continued overall improvement of the soil cover and its ability to support vegetation. However, the viable layer of soil is limited to a few inches near the surface while extremely toxic conditions still exist beneath. Thus, the thin production soil layer that has been able to develop over most of the reclaimed areas still remains vulnerable to drought. With continued growth and the decomposition of vegetative matter each year, a thicker layer of more productive soil should gradually build up. Soil analyses should be continued annually.

WATER QUALITY

The mechanisms by which AMD entered Contrary Creek are shown in Fig. 5. The major contribution during dry periods was the leaching of AMD by water percolating through the waste and the leaching of the waste deposited in the stream bed. A smaller source was AMD flowing from underground workings. During precipitation events, runoff carried AMD from the waste piles.

The reclamation of the mining waste was expected to reduce the AMD load in Contrary Creek in several ways:

1. Removal of toxic mining waste from the stream bed at the Sulphur Site would eliminate this source of AMD.

2. Grading to facilitate rapid runoff and minimize infiltration would reduce the volume of water leaching the mine waste.

3. Development of a vegetative stabilized cover over the toxic mine waste would:

   a. Eliminate the erosion and rapid transport of mine waste into the stream.

TABLE 14. SOIL DATA pH AND METALS ON DRY WEIGHT BASIS[a] (mg/kg)

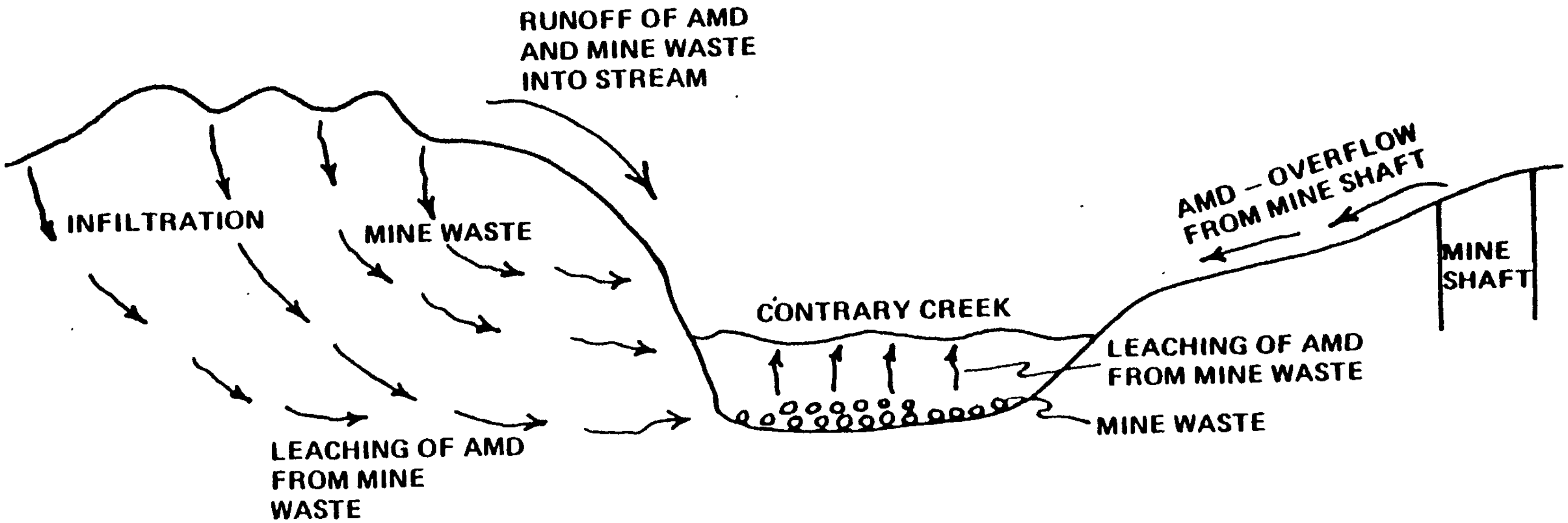
Area-Date	pH	Cu	Fe	Pb	Mn	Zn
SULPHUR WEST						
Tailing Area						
11-76	4.1	50	30		74	262
6-77	3.1	62	34	--	17	82
3-78	5.1	0.1	7.8	0.2	6.8	6.6
6-78	5.9	1.0	24	0.2	3.6	1.5
Grassed						
2-80	4.9	0.2	0.4	0.2-	2.6	3.4
7-81	7.2	0.3	0.1-	0.2	0.1	0.1
2-82	5.6	0.2	0.1	0.2	0.8	0.02
Bare						
3-79	4.5	3.2	7.6	0.1-	6.4	28.0
7-81	5.7	9.6	0.1-	0.2	5.8	32.0
2-82	5.7	0.5	0.1-	0.2	0.3	0.1-
Tr-1						
11-76	3.7	288	220	4.6	152	3940
3-78	3.6	226	340	2.4	7.4	366
3-79	6.5	0.9	0.2-	0.002	2.9	1.6
2-80	5.3	0.6	0.6	0.2-	4.8	17.8
7-81	7.2	0.7	0.1-	0.4	26.0	24.0
2-82	5.6	0.3	0.4	0.2-	1.5	1.3
SULPHUR EAST						
Large Area						
11-76	5.5	8.6	4.2	--	31.4	18.8
3-78	7.3	0.3	6.2	0.2	0.5	0.1
3-79	5.9	0.3	3.6	0.005	1.9	1.2
2-80	5.2	0.2	0.8	0.2	1.7	3.4
7-81	7.4	1.3	0.1	0.6	0.1-	0.8
2-82	6.4	0.4	0.1	0.2	0.6	0.54
Tipple Area						
3-78	3.2	5.0	80	0.2	0.8	6.2
6-78	3.0	28	620	0.2-	3.0	24
3-79	5.9	0.1	0.6	0.001	3.9	2.0
2-80	4.7	1.1	4.8	0.2-	4.6	10.2
7-81	7.3	0.3	0.1-	0.2	0.1-	0.1
2-82	6.5	0.2	0.1	0.2-	0.04	0.26

(continued)

TABLE 14. (continued)

Area-Date	pH	Cu	Fe	Pb	Mn	Zn
Upstream Flat						
11-76	7.3	2.0	--	--	31.6	54.0
3-78	6.7	0.1	5.0	0.2	6.6	4.0
7-78	5.7	1.0	5.0	0.2-	14.4	3.2
3-79	5.4	1.9	0.6	0.2-	25.9	150
2-80	5.5	0.6	0.8	0.2-	12.2	12.8
7-81	7.2	0.5	0.1-	0.2	0.1	3.2
2-82	6.0	0.4	0.1	0.2-	10.0	24.0
North End						
3-79	--	0.2	0.8	0.2-	2.2	3.8
2-80	4.9	0.1	0.4	0.2-	7.2	0.7
7-81	7.2	0.5	0.1-	0.2	0.1	3.2
2-82	6.1	0.3	0.1	0.2-	0.8	0.3
BOYD SMITH						
11-76	5.4	0.7	0.6	--	30.6	19.6
6-78	7.1	0.3	1.0	0.2-	1.6	0.8
3-79	5.7	1.1	0.2	0.011	7.0	19.6
2-80	5.0	1.0	0.4	0.2-	6.0	12.6
7-81	7.3	0.7	0.1-	0.2-	0.9	8.8
2-82	6.1	0.5	0.9	0.2-	7.4	1.6

[a]Water extraction of soluble salts for metals.
These analyses were conducted by the Virginia Division of Consolidated Laboratory Services, Richmond, Virginia.
A (-) indicates less than.



(NOT TO SCALE)

Fig. 5 Sources of acid mine drainage into Contrary Creek

b. Reduce the water available for leaching of the mine waste as a result of plant transpiration.

c. Reduce oxygen contact with the pyrite in the mine waste and thus reduce the formation of AMD by development of a soil cover with vegetation.

4. The sludge and lime added to the mine waste would neutralize and treat the AMD previously generated in the mine waste and reduce further generation.

Monitoring

A regular monitoring program to evaluate the effects of the demonstration project began prior to reclamation. The program involved semi-monthly sampling of five stream stations as described below and shown in Fig. 6.

MS-1 - Control station above all mine sites

MS-2 - Below Arminius Site

MS-3 - Below Boyd Smith Site

MS-4 - Below Sulphur Site

MS-5 - Mouth of Contrary Creek just above Lake Anna

Each station except MS-5 was equipped with a continuous flow recorder. Two sampling stations were also established in the Contrary Creek arm of Lake Anna (Fig. 6). The lake sampling was terminated in 1980 and the stream sampling was reduced to once monthly, weather permitting.

The regular monitoring included analyses for pH, acidity, sulfate and the heavy metals of concern. Quarterly summaries of data collected subsequent to water year 1980 can be found in Appendix A. BOD and fecal coliform analyses were done to determine if the use of wastewater sludge had any effects on the water. A complete analysis including total solids, specific conductance, and less common metals was conducted once annually. (See Appendix A for update.) Other quality monitoring included periodic sampling of various tributaries draining into Contrary Creek and a special study by the University of Virginia to pinpoint sources of AMD along the stream and to determine effects of heavy rainstorms.

Results

Tables 15 and 16, respectively, give summaries by water year of concentration and load data from the regular stream monitoring program. In terms of pH, acidity, and sulfate there appears to be little overall change in the water quality over the course of the monitoring program. There does

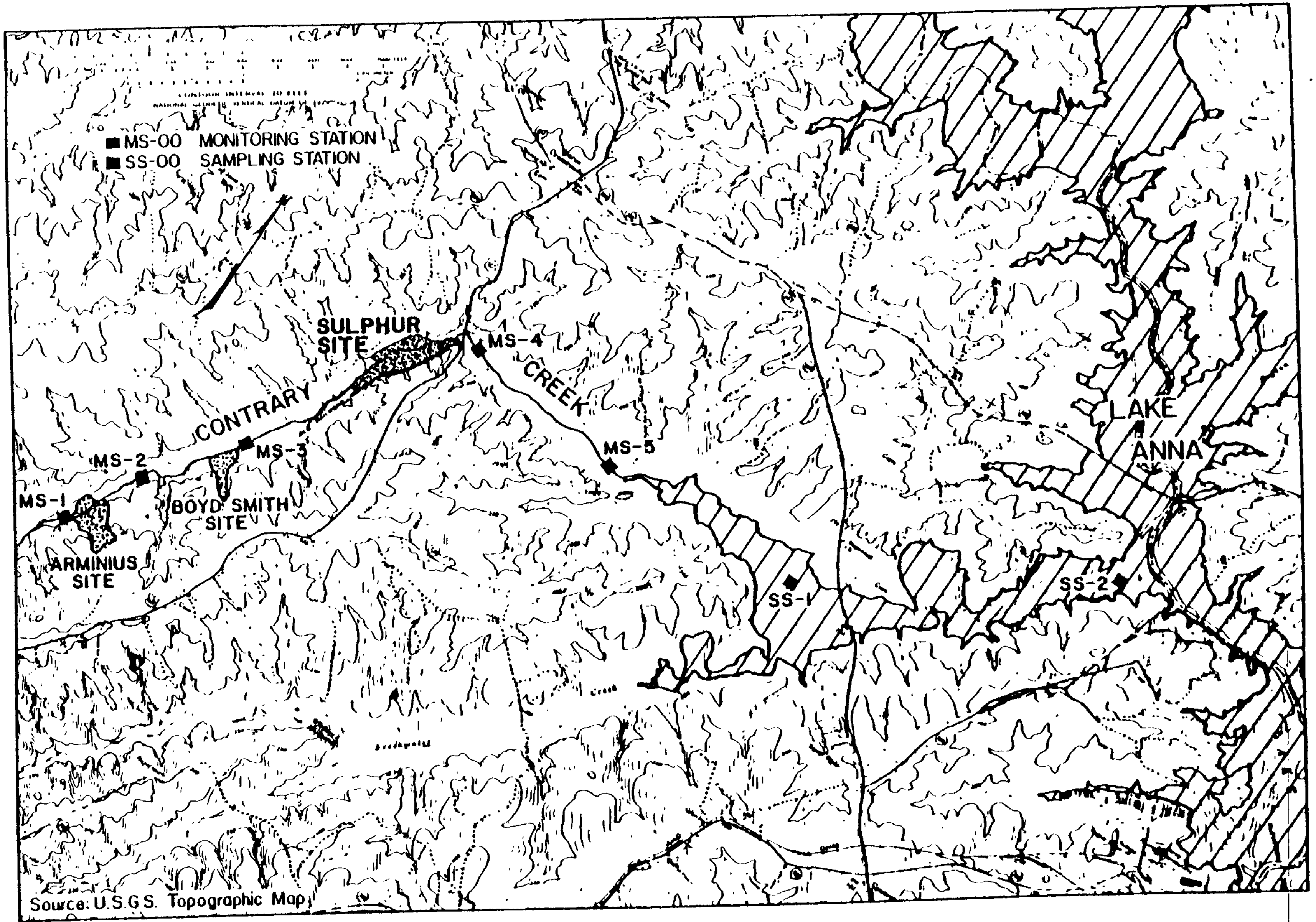


Fig. 6 Contrary Creek Monitoring Stations

TABLE 15. AVERAGE ANNUAL CONCENTRATIONS BY WATER YEAR AT STREAM STATIONS (mg/l)

Station	Water Year	Flow (l/s)[a]	pH	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
MS-1	1976	46.7	6.6	8	7	0.02	1.1	0.02	0.1	0.1
	1977	32.6	7.2	8	10	0.02	0.9	0.01	0.2	0.1
	1978	73.9	6.9	9	16	0.04	1.3	0.01	0.2	0.2
	1979	66.6	6.4	25	13	0.05	1.6	0.01	0.1	0.2
	1980	50.8	6.6	10	11	0.04	1.3	0.01	0.1	0.2
	1981	12.8	6.5	15	12	0.02	1.1	0.01	0.1	0.1
	1982	40.6	6.3	14	17	0.06	2.0	0.01	0.2	0.3
MS-2	1976	54.9	5.4	22	93	0.15	2.3	0.03	0.8	5.9
	1977	36.3	5.3	89	321	0.82	3.5	0.20	2.5	18.3
	1978	87.2	5.7	27	80	0.14	1.6	0.02	0.6	4.6
	1979	82.4	5.9	38	81	0.09	1.5	0.02	0.7	5.0
	1980	68.2	5.8	29	166	0.15	1.6	0.03	0.8	8.1
	1981	16.4	5.3	44	183	0.11	1.4	0.03	1.0	9.8
	1982	48.8	5.7	16	76	0.13	1.8	0.03	0.7	3.9
MS-3	1976	94.3	4.9	21	131	0.26	3.3	0.09	2.3	4.7
	1977	62.6	5.3	38	192	0.30	1.7	0.05	3.1	5.8
	1978	140.2	4.9	28	120	0.22	1.7	0.03	1.5	3.7
	1979	140.5	5.0	41	116	0.14	1.4	0.02	1.6	3.4
	1980	115.5	5.3	19	124	0.23	1.5	0.02	1.9	3.4
	1981	31.5	5.0	39	148	0.34	1.0	0.02	1.8	5.5
	1982	79.7	4.8	31	142	0.18	1.7	0.02	1.5	4.0
MS-4	1976	147.8	3.9	134	240	0.95	37.3	0.07	2.1	4.8
	1977	94.6	3.8	238	376	1.73	54.9	0.13	2.5	7.9
	1978	206.5	3.7	160	224	1.17	31.3	0.07	1.6	5.7
	1979	198.8	3.6	217	196	0.79	25.5	0.07	1.7	4.3
	1980	153.1	3.8	178	255	0.78	29.0	0.04	1.9	4.5
	1981	52.7	3.7	211	250	0.90	32.0	0.05	2.0	7.3
	1982	112.9	3.6	130	235	0.97	26.3	0.05	1.6	4.5
MS-5	1976		3.4	173	241	1.28	33.8	0.08	1.9	4.6
	1977		3.4	322	468	3.22	58.0	0.13	2.7	8.3
	1978		3.4	183	246	2.11	38.6	0.07	1.6	5.6
	1979		3.3	236	178	1.19	24.9	0.07	1.7	4.0
	1980		3.4	216	328	1.15	27.0	0.47	2.2	4.6
	1981		3.5	234	254	1.85	18.3	0.07	1.9	8.1
	1982		3.6	126	151	2.23	19.7	0.05	0.3	4.1

[a] No continuous flow records available for MS-5

TABLE 16. AVERAGE ANNUAL FLOW AND LOADS BY WATER YEAR AT MS-1, MS-2, MS-3, AND MS-4 (kg/d)[a]

Station	Water Year	Flow (l/s)	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
MS-1	1976	48.7	43	34	0.09	3.7	0.03	0.4	0.3
	1977	32.6	85	21	0.03	2.5	0.04	0.4	0.2
	1978	73.9	63	66	0.30	6.1	0.04	0.9	1.1
	1979	66.6	184	97	0.41	6.9	0.08	0.8	1.9
	1980	50.8	41	55	0.20	5.0	0.03	0.6	0.9
	1981	12.8	17	10	0.02	1.3	0.01	0.1	0.1
	1982	40.6	40	61	0.20	4.3	0.03	0.9	0.9
MS-2	1976	54.9	83	306	0.54	8.8	0.10	2.4	18.5
	1977	36.3	82	311	0.58	8.2	0.26	3.2	24.7
	1978	87.2	193	479	0.97	11.2	0.15	3.7	26.5
	1979	82.4	321	432	0.73	9.3	0.20	3.6	26.4
	1980	68.2	96	400	0.51	9.6	0.09	3.0	23.8
	1981	16.4	61	226	0.15	1.8	0.03	1.2	13.5
	1982	48.8	63	242	0.54	5.2	0.06	2.1	13.8
MS-3	1976	94.3	137	830	1.8	26.0	0.55	13.4	30.5
	1977	62.6	132	540	1.1	11.3	0.18	8.5	22.0
	1978	140.2	320	1177	2.0	21.2	0.36	15.5	39.5
	1979	140.5	617	1026	2.0	19.3	0.32	15.1	32.2
	1980	115.5	160	699	1.4	16.9	0.16	12.5	27.5
	1981	31.5	120	396	1.1	2.3	0.05	4.3	16.8
	1982	79.7	201	718	1.3	10.5	0.11	6.7	19.2
MS-4	1976	147.8	1130	2188	8.4	313	0.6	18.5	46.0
	1977	94.6	1080	1709	8.8	371	1.0	14.2	46.5
	1978	206.5	2421	3242	18.9	493	1.4	26.2	87.5
	1979	198.8	3186	2633	11.4	354	1.0	20.7	58.5
	1980	153.1	1543	2300	7.7	281	0.4	17.8	46.3
	1981	52.7	884	1106	3.9	133	0.2	8.7	35.0
	1982	112.9	1116	1885	9.9	228	0.4	11.2	38.5

[a]No continuous flow records available at MS-5.

seem to be a trend toward reduction in heavy metals. Fig. 7 depicts concentrations and loads of copper and zinc at MS-2, MS-3 and MS-4.

Wide fluctuations in flow volumes had considerable effect upon the concentration and load data recorded. For instance, the extremely low flows during the dry summer of 1977 (see Table 4) caused sharp increases in concentrations at all stations. It is noteworthy that the rise in concentrations was less pronounced in 1981 even though annual average flow dropped to about half that recorded in 1977. This would indicate that there was apparently some reduction in AMD between 1977 and 1981. Comparing the MS-3 and MS-4 monitoring data for the spring quarters of 1977 and 1981 when the average quarterly flows were nearly the same, there appears to be a decided improvement in nearly all water quality parameters except pH (Table 17).

Conclusions

Overall, it is apparent that water quality still deteriorates downstream past the mine sites with the Sulphur Site the major contributor of AMD. Certain heavy metals appear peculiar to each mine site. Iron increases dramatically at the Sulphur Site while the Arminius Site appears to be the major contributor of zinc. The Boyd Smith Site shows significant increases in manganese. The project included no abatement measures on the downstream reach of Contrary Creek between the Sulphur Site (MS-4) and Lake Anna (MS-5).

The reduction of mine waste erosion and overland flow of AMD to the stream has been accomplished. Since the surface soil now has a higher pH and lower concentration of heavy metals, the runoff quality is undoubtedly improved. Thus, the remaining major sources of AMD are the wastes in the stream bed downstream from the Sulphur Site. Leaching of the mine waste material from the stream banks and sudden flushouts of AMD by heavy rainstorms following prolonged dry periods are also still a significant problem.

Because of the long existence of the mine waste banks, we can assume that they are saturated with pyrite oxidation products - AMD. Thus, even if all new production of AMD was eliminated, a significant time would be required to leach the AMD material from the mine waste. The reduction in infiltration will only extend this time period. The effectiveness of the soil cover in reducing acid production is surely debatable, and several years will be required to collect the information needed to make any conclusions based on stream water quality. The sludge and limestone applied to the mine waste should neutralize some of the AMD in place. Several years may be required for this chemical front to move through the mine waste and be reflected in stream water quality.

Another factor that must be taken into account is the recurrent droughts that plagued the project, especially in the initial critical stages. The slow tedious establishment of vegetation in turn seriously delayed the chances of realizing any early improvement in the water quality.

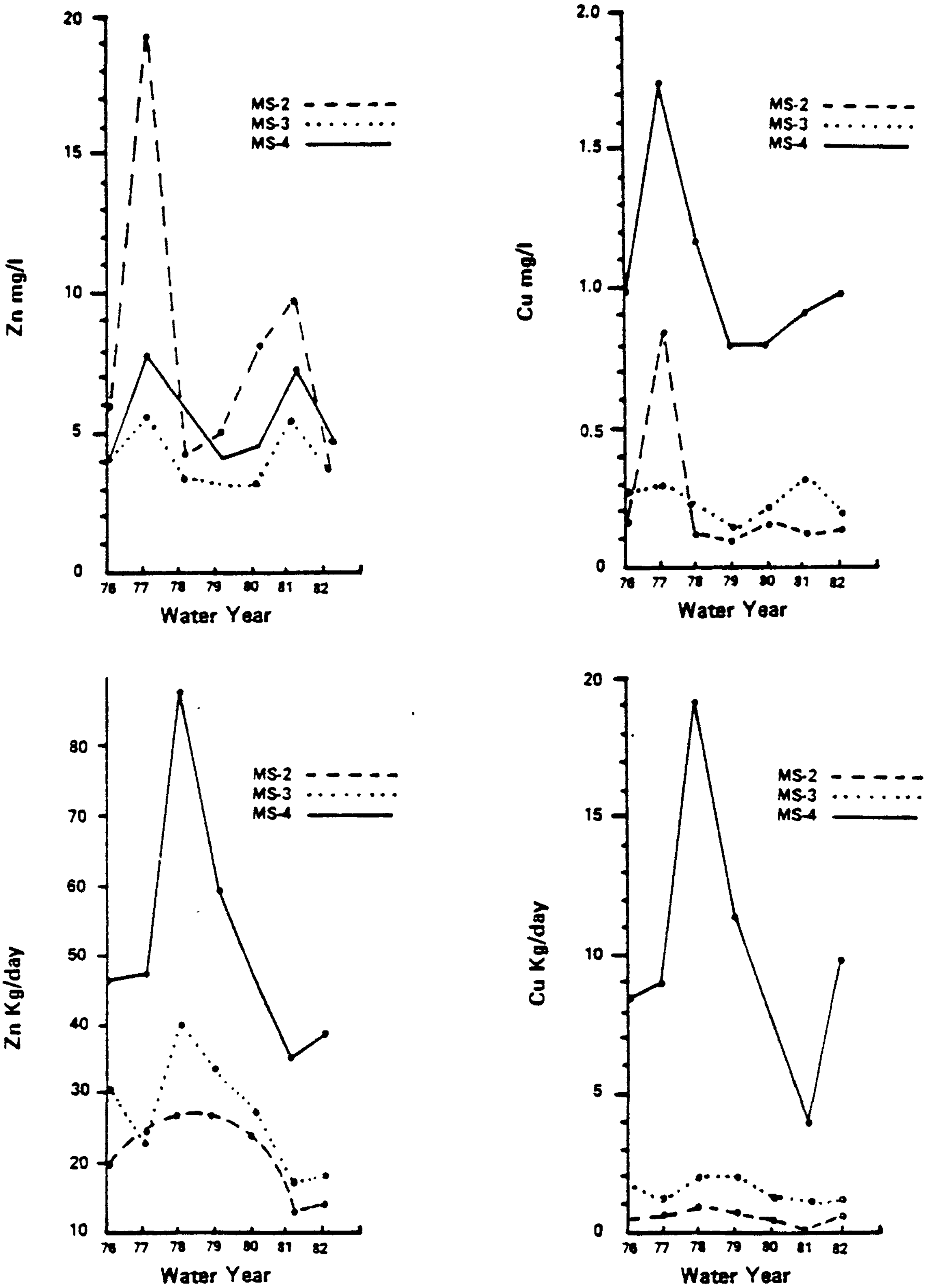


Fig. 7 Average annual concentrations and loads of zinc and copper at MS-2, MS-3 and MS-4

TABLE 17. COMPARISON OF AVERAGE CONCENTRATIONS AND LOADS AT MS-3 AND MS-4 DURING THE THIRD QUARTERS OF WATER YEARS 1977 AND 1981

Station	MS-3		MS-4	
April - June Qtr.	1977[a]	1981[b]	1977[a]	1981[b]
Avg. Flow (l/s)	36.8	36.3	59.8	54.4
pH	5.8	5.7	3.7	3.7
	Concentrations (mg/l)			
Acidity	31	10	171	90
SO_4	153	106	288	185
Cu	0.15	0.37	1.1	0.5
Fe	1.4	1.1	37	9
Pb	0.032	0.017	0.085	0.028
Mn	1.97	1.07	1.8	1.3
Zn	4.0	2.9	6.0	3.4
	Loads (Kg/d)			
Acidity	99	31	884	423
SO_4	486	332	1488	870
Cu	0.5	1.2	5.7	2.4
Fe	4.5	3.4	469	42
Pb	0.10	0.05	0.4	0.1
Mn	6.3	3.4	9.3	6.1
Zn	12.7	9.1	31	16

[a]Based upon 6 sample collections.

[b]Based upon 3 sample collections.

So far as can be determined from BOD and fecal coliform analyses, the extensive use of wastewater sludge at all three mine sites did not affect the water of Contrary Creek or Lake Anna in any adverse manner nor create any health hazards. The Contrary Creek arm of Lake Anna is obviously degraded by AMD as far out as SS-1 in the lake, but the main body of the reservoir appears to be unaffected. The lake abounds in sport fish, and there have been no known detrimental effects by AMD on the nuclear power plant which uses the reservoir for cooling water.

In view of the very toxic nature of the AMD entering Contrary Creek, it is concluded that improvement in the water quality will be slow. It will probably require several more years to realize overall improvement.

Recommendations

It is recommended that the regular water quality analyses except BOD and fecal coliform be continued at the five stream stations on a semi-annual basis. Periodic analyses should also be conducted from key points in the tributaries entering Contrary Creek at the reclamation sites. MS-4 should be retained as a permanent flow gaging station. The vast amount of monitoring data generated in connection with the project may have potential use for other water studies aside from AMD studies.

BIOLOGIC STUDIES

As part of the monitoring program, the Division of Ecological Studies (DES) of the SWCB continued to perform semi-annual benthic surveys of Contrary Creek through the spring of 1982. Cursory qualitative studies were done in the fall and quantitative surveys were done in the spring. Refer to Appendix B for the results of the cursory qualitative survey conducted in October 1981. The same sampling methods and analytical procedures were used as described in the Main Report for earlier studies. The sample stations are shown in Fig. 8.

The recent biologic studies have indicated little change in the aquatic life in the stream from that found in earlier studies. While sensitive and facultative organisms remained dominant at the control station above the affected area, benthics continued to be sparse or non-existent downstream below the mine sites.

The benthic survey did reveal an increase in the density of some pollution tolerant organisms in the severely affected downstream reach of Contrary Creek. A population of bloodworm midges which are very tolerant has been observed at the downstream station (B-1A) just upstream from Lake Anna. It is believed that this may be attributed to upstream migration of these organisms from Lake Anna where they are abundant. This may indicate a trend of colonization upstream from the lake. It is also speculated that the alderfly and dragonfly which are predators on the bloodworm midge may be increasing their abundance in this part of the stream due to the increase in food supply.

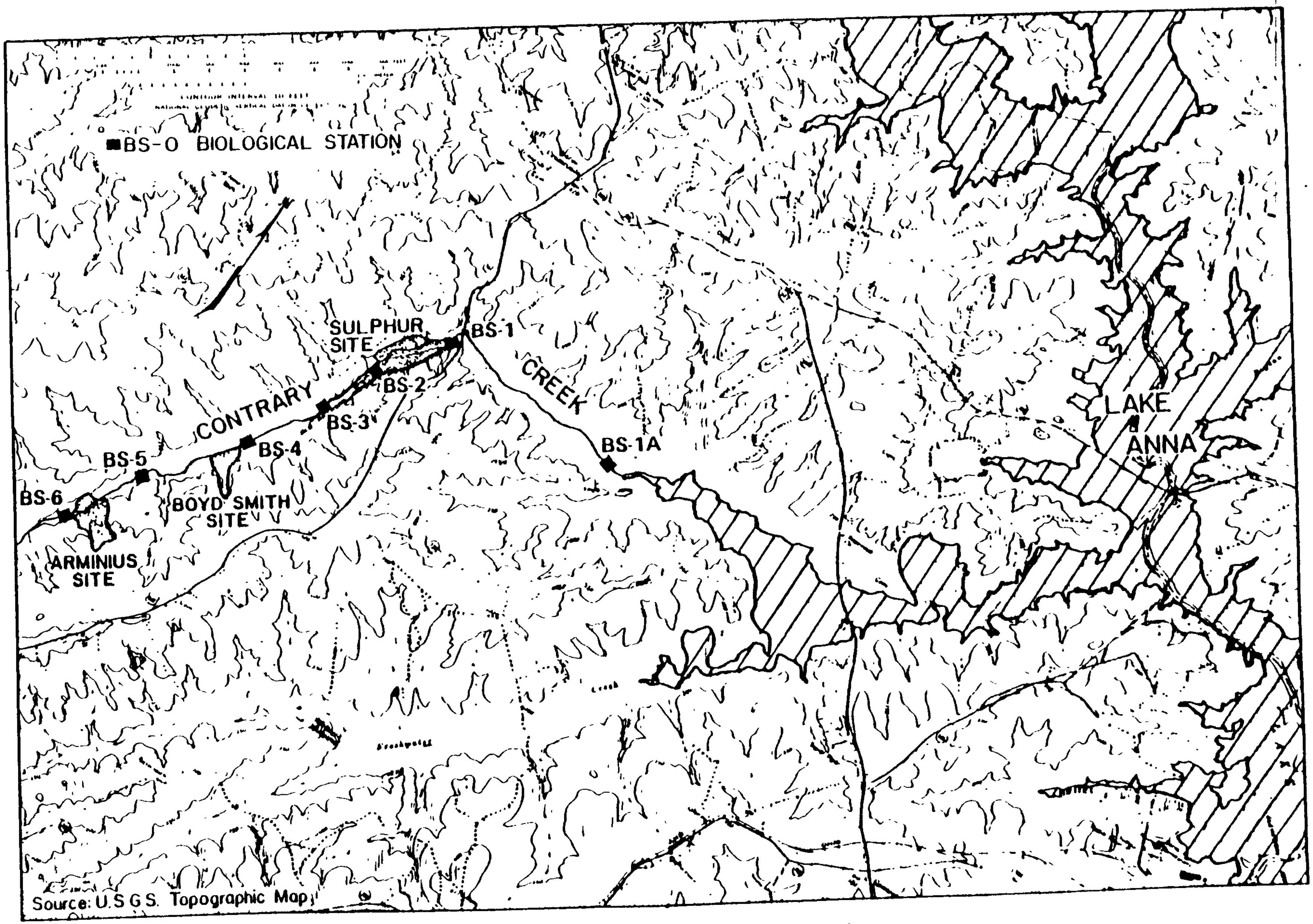


Fig. 8 Contrary Creek Biological Stations

In summary, there appears to be no significant improvement in the ability of Contrary Creek to support a healthy diverse macroinvertebrate community since the reclamation work was done. Sensitive organisms do inhabit the unaffected tributaries draining into some of the most acidic reaches of Contrary Creek. Thus, there is potential for benthic life to be restored in the main stream if the AMD problem is reduced. It is recommended that biologic surveys be continued biennially.

COSTS

The original grant agreement between EPA and the SWCB provided for 60 percent Federal funding to cover contractural services with the SWCB providing matching funds through in-kind services which included administration, monitoring, and preparation of reports. During the final two years of the project, the grant was amended to 54:46 Federal-State ratio.

Approximately $121,000 was expended on the construction work and follow-up maintenance over the seven-year grant period. This was over $100,000 less than the original estimate for the initial construction work. One of the major factors in the cost savings was free sludge from the District of Columbia. Another was the availability of a local contractor to perform the bulk of the maintenance.

For more details on the costs, the reader is referred to the Main Report. Total cost of the entire project including Federal and State matching funds was approximately $327,000.

REFERENCES

1. Hill, R. D., K. R. Hinkle, M. L. Apel. Reclamation of Pyritic Waste. In: Proceedings of the 1982 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. University of Kentucky, Lexington, Kentucky. P. 687-697, 1982.

2. Hill, R. D., K. R. Hinkle, R. S. Klingensmith. Reclamation of Orphan Mined Lands with Municipal Sludges - Case Studies. In: Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land, W. E. Sopper and S. N. Kerr, eds. The Pennsylvania State University Press, University Park, Pennsylvania, 1979.

3. Hinkle, K. R. Use of Municipal Sludge in the Reclamation of Abandoned Pyrite Mines in Virginia. In: Utilization of Municipal Wastewater and Sludge for Land Reclamation and Biomass Production, W. E. Sopper, E. M. Seaker, and R. K. Bastian, eds. The Pennsylvania State University Press, University Park, Pennsylvania, 1982.

4. Hinkle, K. R. Reclamation of Toxic Mine Waste Utilizing Sewage Sludge - Contrary Creek Demonstration Project. U. S. EPA Report, EPA 600/2-82-061, Cincinnati, Ohio, 1982.

APPENDIX A

WATER QUALITY DATA AT STREAM STATIONS

Concentration values were determined by averaging the monthly sample collection data. Load values were computed by multiplying average concentration by quarterly averages of daily flows.

TABLE A-1 SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-1

Quarter	1	2	3	4	1	2	3	4
	Flow (1/s)				pH			
Water Year[a]								
1981	9.1	17.0	17.3	7.9	6.6	6.6	5.5	6.1
1982	18.7	96.6	43.0	4.0	5.8	5.7	6.8	6.8
	Concentration (mg/1)				Load (kg/d)			
			Acidity					
1981	16	33	0	11	13	48	0	8
1982	7	12	11	26	11	100	41	9
			Sulfate					
1981	10	11	9	18	8	16	3	12
1982	26	16	18	8	42	133	67	3
			Copper					
1981	0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.03
1982	0.12	0.04	0.07	0.02	0.19	0.33	0.26	0.01
			Iron					
1981	1.1	0.8	1.6	0.7	0.9	1.2	2.4	0.5
1982	2.3	0.7	1.8	3.0	3.7	5.8	6.7	1.0
			Lead					
1981	0.008	0.008	0.005	0.007	0.01	0.01	0.01	0.00
1982	0.025	0.007	0.006	0.002	0.04	0.06	0.02	0.01
			Manganese					
1981	0.09	0.09	0.07	0.25	0.1	0.1	0.1	0.2
1982	0.42	0.15	0.17	0.11	0.7	1.3	0.6	1.0
			Zinc					
1981	0.1	0.0	0.1	0.2	0.1	0.0	0.1	0.1
1982	0.5	0.2	0.3	0.0	0.8	1.7	1.1	0.0

[a]Water year begins October 1 and ends September 30. 1st quarter, Oct. - Dec; 2nd quarter, Jan. - March; 3rd Quarter, April - June; 4th quarter, July - Sept.

TABLE A-2 SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-2

Quarter	1	2	3	4	1	2	3	4
	Flow (l/s)				pH			
Water Year								
1981	13.6	23.2	19.3	9.4	5.4	6.0	6.1	3.5
1982	21.2	118.9	50.1	5.1	5.2	5.4	6.1	6.2
	Concentration (mg/l)				Load (kg/d)			
			Acidity					
1981	44	61	14	56	52	122	23	45
1982	22	14	15	11	40	143	65	5
			Sulfate					
1981	450	73	69	139	529	146	115	113
1982	113	44	63	32	206	452	273	36
			Copper					
1981	0.16	0.11	0.07	0.08	0.19	0.22	0.12	0.06
1982	0.20	0.12	0.12	0.06	0.37	1.23	0.52	0.03
			Iron					
1981	1.2	1.1	1.3	1.9	1.4	2.2	2.2	1.5
1982	3.5	0.8	1.8	0.9	6.4	8.2	7.8	0.4
			Lead					
1981	0.033	0.007	0.008	0.087	0.04	0.01	0.01	0.07
1982	0.048	0.008	0.014	0.028	0.09	0.08	0.06	0.01
			Manganese					
1981	1.19	0.53	0.21	2.06	1.4	1.1	0.4	1.7
1982	0.73	0.40	0.61	0.88	1.3	4.1	2.6	0.4
			Zinc					
1981	8.7	13.4	3.6	13.3	10.2	26.9	6.0	10.8
1982	5.9	2.7	3.5	3.8	10.8	27.7	15.1	1.7

TABLE A-3 SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-3

Quarter	1	2	3	4	1	2	3	4
	Flow (l/s)				pH			
Water Year								
1981	24.1	45.0	36.3	20.7	5.0	4.7	5.7	4.4
1982	38.8	182.4	84.4	13.0	4.8	5.0	4.1	4.9
	Concentration (mg/l)				Load (kg/d)			
				Acidity				
1981	25	88	10	31	52	342	31	55
1982	20	16	63	22	67	252	459	24
				Sulfate				
1981	205	153	106	128	427	595	332	229
1982	183	58	157	166	613	914	1159	186
				Copper				
1981	0.23	0.53	0.37	0.23	0.5	2.1	1.2	0.4
1982	0.24	0.19	0.16	0.12	0.8	3.0	1.2	0.1
				Iron				
1981	1.0	1.1	1.1	0.9	2.1	4.3	3.4	1.6
1982	3.4	1.1	1.7	0.7	11.4	17.3	12.4	0.8
				Lead				
1981	0.028	0.014	0.017	0.024	0.06	0.05	0.05	0.04
1982	0.027	0.015	0.013	0.014	0.09	0.24	0.09	0.02
				Manganese				
1981	2.34	1.20	1.07	2.38	4.9	4.7	3.4	4.3
1982	2.40	0.61	0.99	1.80	8.0	9.6	7.2	2.0
				Zinc				
1981	4.9	10.5	2.9	3.9	10.2	40.8	9.1	7.0
1982	4.7	2.2	2.6	6.3	15.8	34.7	19.0	7.1

TABLE A-4 SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-4

Quarter	1	2	3	4	1	2	3	4
	Flow (l/s)				pH			
Water Year								
1981	45.0	67.1	54.4	44.2	3.5	3.9	3.9	3.3
1982	57.8	246.4	120.9	26.6	3.6	3.7	3.7	3.2
	Concentration (mg/l)				Load (kg/d)			
			Acidity					
1981	234	105	90	418	910	608	423	1596
1982	112	108	113	185	559	2299	1180	425
			Sulfate					
1981	341	215	185	257	1325	1296	870	981
1982	224	167	198	348	1118	3555	2068	800
			Copper					
1981	0.9	0.7	0.5	1.5	3.5	4.1	2.4	5.7
1982	0.9	1.1	0.9	1.0	4.5	23.4	9.4	2.3
			Iron					
1981	23	17	9	79	89	98	42	301
1982	26	21	25	33	130	447	261	76
			Lead					
1981	0.042	0.019	0.028	0.125	0.1	0.1	0.1	0.5
1982	0.087	0.035	0.030	0.048	0.4	0.7	0.3	0.1
			Manganese					
1981	2.3	1.4	1.3	3.1	8.9	8.1	6.1	11.8
1982	1.8	0.8	1.3	2.3	9.0	17.0	13.6	5.3
			Zinc					
1981	5.7	12.9	3.4	7.0	22	75	16	27
1982	4.3	3.7	3.8	6.0	21	79	40	14

TABLE A-5 AVERAGE CONCENTRATIONS BY QUARTER AT MS-5 (mg/l)[a]

Water Year & Quarter	pH	Acidity	SO_4	Cu	Fe	Pb	Mn	Zn
1981								
1	3.1	306	405	2.3	23	0.071	2.0	5.6
2	4.4	63	156	1.3	15	0.041	1.2	17.0
3	3.5	114	217	0.9	14	0.039	1.4	3.7
4	3.0	451	239	2.9	23	0.148	2.9	6.1
1982								
1	---	---	---	---	--	-----	---	---
2	3.6	101	153	1.1	21	0.037	0.9	3.4
3	4.2	67	185	0.9	17	0.035	1.2	3.2
4	3.0	210	114	6.7	21	0.082	2.5	5.7

[a]All values shown for each quarter represent the averages of two analyses with the exception of three analyses in the first quarter of 1981 and only one analysis for the fourth quarter of 1982.

TABLE A-6 WATER QUALITY DATA -
COMPARISON OF SOLIDS AND SPECIFIC CONDUCTANCE
IN OCTOBER 1975 BEFORE RECLAMATION AND IN MAY 1982[a]

Station	Date	Flow (l/s)	Total Solids (mg/l) (Total)	Total Solids (mg/l) (Vol)	Total Solids (mg/l) (Fix)	Suspended Solids (mg/l) (Total)	Suspended Solids (mg/l) (Vol)	Suspended Solids (mg/l) (Fix)	Total Dissolved Solids (mg/l)	Specific Conductance (umhos/cm)
MS-1	10-27-75	22.9	68	37	31	0	0	0	68	47
	5-10-82		68	19	49	5-	5-	5-	68	61
MS-2	10-27-75	34.0	176	21	155	4	2	2	172	170
	5-10-82		157	25	132	14	11	3	143	170
MS-3	10-27-75	59.5	254	78	176	6	2	4	248	240
	5-10-82		197	31	166	12	9	3	185	267
MS-4	10-27-75	84.4	368	79	289	14	6	8	354	390
	5-10-82		397	73	324	35	14	21	362	534
MS-5	10-27-75		392	85	307	10	4	6	382	630
	5-10-82		340	54	286	9	9	0	331	580

[a] A (-) sign indicates that the concentration was below the indicated level of detection.

APPENDIX B

RESULTS OF OCTOBER 1981 CURSORY BIOLOGIC SURVEY

TABLE B-1 CURSORY BIOLOGIC SURVEY - OCTOBER 1981

Station No. & Description	DO mg/l	pH	Temp. °C	Time/ Date	Stream Size W Y D	Substrate	Benthic Macroinvertebrates[a]	Notes/ Comments
BS-1A. 500 m above Lake Anna	7.7	4.5	20	1615 10/14/81	5 m X 10 cm	sand gravel cobble	Bloodworm Midges Chironomidae D Alderflies Sialidae A Water Boatmen Corixidae C Water Beetles Haliplidae F Dytiscidae F Dragonflies Libellulidae F Water Striders Gerridae F	FeOH stain on bottom and 1-3 mm thick deposits on rocks in riffle. Periphytic algae slight.
BS-1. 75 m above Rt. 522	7.5	4.7	20	1520 10/14/81	4 m X 15 cm	sand gravel cobble boulders bedrock	Bloodworm Midges Chironomidae D Dragonflies Libellulidae F Water Striders Gerridae F Whirlegig Beetles Gyrinidae F Midges Ceratopogonidae F	Dark rust colored FeOH deposits in channel. Orange-yellow FeOH deposits 6 mm thick on rocks in riffle. No periphyton.

[a] D - dominant A - abundant C - common F - few X - present

TABLE B-1 CONT'D.

Station No. & Description	DO mg/l	pH	Temp. °C	Time/ Date	Stream Size W Y D	Substrate	Benthic Macroinvertebrates [a]		Notes/ Comments
BS-2. Sulphur Site	8.3	4.5	20	1445 10/14/81	3.5 m X 5 cm	sand gravel grasses cobble	Bloodworm Midges		FeOH 1-2 mm thick. Deposits on bottom darker rust color than before. Filamentous algae growth slight. Bacteria growth slight.
							Chironomidae	C	
							Dragonflies		
							Libellulidae	F-C	
							Aeshnidae	X	
							Alderflies		
							Sialidae	F	
							Water Striders		
							Gerridae	F	
							Back Swimmers		
							Notonectidae	F	
							Water Beetles		
							Dytiscidae	F	
							Midges		
							Ceratopogonidae	X	

[a] D - dominant A - abundant C - common F - few X - present

TABLE B-1 CONT'D.

Station No. & Description	DO mg/l	pH	Temp. °C	Time/ Date	Stream Size W Y D	Substrate	Benthic Macroinvertebrates [a]		Notes/ Comments
BS-3. Between Boyd Smith and Sulphur Sites	11.0	5.5	10	1330 10/14/81	7 m X 30 cm	gravel sand leaves	Whirlegig Beetles		Light bacteria growth on all bottom materials. FeOH light coloring. 3 beaver dams in creek now. Riffles all flooded to pools. No periphyton.
							Gyrinidae	A	
							Backswimmers		
							Notonectidae	C	
							Alderflies		
							Sialidae	F-C	
							Damselflies		
							Coenagrionidae	F-C	
							Caddisflies		
							Phryganeidae	F-C	
							Dragonflies		
							Libellulidae	F	
							Bloodworm Midges		
							Chironomidae	F	
							Water Striders		
							Gerridae	F	

[a] D - dominant A - abundant C - common F - few X - present

TABLE B-1 CONT'D.

Station No. & Description	DO mg/l	pH	Temp. °C	Time/ Date	Stream Size W X D	Substrate	Benthic Macroinvertebrates [a]		Notes/ Comments
BS-4. Boyd Smith Site	10/8	5.8	10	1230 10/14/81	3 m X 15 cm	Bedrock gravel cobble leaves	Bloodworm Midges		Filamentous algae thick on bedrock. Bacteria abundant. FeOH stain on bottom. Trib. from northwest adds considerable flow and raises pH. pH above trib. = 5.0 pH of trib. = 7.5 pH below trib. = 5.8 Bacteria orange above, gray in trib. black where two streams mix.
							Chironomidae	C	
							Backswimmers		
							Notonectidae	F-C	
							Dragonflies		
							Libellulidae	F	
							Damselflies		
							Coenagrionidae	F	
							Hellgrammites		
							Corydalidae	F	
							Water Striders		
							Gerridae	F	
							Caddisflies		
							Phryganeidae	F	
							Midges		
							Ceratopogonidae	X	

[a] D - dominant A - abundant C - common F - few X - present

TABLE B-1 CONT'D.

Station No. & Description	DO mg/l	pH	Temp. °C	Time/ Date	Stream Size W X D	Substrate	Benthic Macroinvertebrates[a]	Notes/ Comments
BS-5. Between Boyd Smith and Arminius Sites	8.6	4.7	9	1130 10/14/81	1.5 m X 5 cm	sand bedrock gravel cobble leaves	Bloodworm Midges Chironomidae A Water Boatmen Corixidae A Water Striders Gerridae C-A Back Swimmers Notonectidae C Caddisflies Phryganeidae C Alderflies Sialidae C Dragonflies Libellulidae F Midges Chironomidae F Mosquito Culicidae X Giant Water Bug Belostomatidae X Water Beetle Dytiscidae X	Most of life found in pools not riffles. Filamentous algae on rocks. Iron bacteria common on rocks. FeOH stain on everything.

[a] D - dominant A - abundant C - common F - few X - present

TABLE B-1 CONT'D.

Station No. & Description	DO mg/l	pH	Temp. °C	Time/ Date	Stream Size W Y D	Substrate	Benthic Macroinvertebrates [a]		Notes/ Comments
BS-6. Above Arminius Site-Control Station	8.5	6.2	7	1030 10/14/81	1 m X 3 cm	gravel leaves cobble bedrock	Mayflies		Density very low-probably due to extremely low flow. Stream barely trickling. Periphyton and brown fungus on rocks.
							Heptageniidae	F-C	
							Stoneflies		
							Perlidae	F-C	
							Water Pennies		
							Psephenidae	F	
							Caddisflies		
							Rhyacophilidae	F	
							Calamoceratidae	F	
							Hydropsychidae	F	
							Crayfish		
							Astacidae	F	
							Water Striders		
							Gerridae	F	
							Midges		
							Chironomidae	F	
							Mosquito		
							Culicidae	X	

[a] D - dominant A - abundant C - common F - few X - present

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
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16. ABSTRACT

Three abandoned pyrite mines in central Virginia that have been inactive since 1923 contained about 12 denuded hectares (ha) and caused severe acid mine drainage (AMD) in a small stream known as Contrary Creek. The AMD which included heavy metals made the stream virtually void of aquatic life. The Virginia State Water Control Board (SWCB) was prompted to seek a solution to this problem when plans were announced in 1968 to construct a reservoir for a nuclear power plant downstream from Contrary Creek. Two of the mine sites comprising about 8 ha were reclaimed with a U.S. Environmental Protection Agency (EPA) demonstration grant in which the SWCB contributed matching funds through in-kind services and the Soil Conservation Service (SCS) provided technical assistance. Reclamation began in 1976 and included the use of sewage sludge as a soil conditioner. Severe droughts in 1976-77 and 1980-81 and the highly toxic nature of the mine waste required a continuing maintenance program to establish vegetation. By the summer of 1983 approximately 90 percent of the reclaimed areas supported a fairly well established grass cover.

A comprehensive monitoring program from 1975 to 1982 indicated a trend toward reduction in heavy metals, but there appeared to be no appreciable improvement in the pH and acidity problem. More improvement is expected as AMD formation is reduced by the gradual development of a thicker soil layer and vegetative cover. Biologic surveys have revealed negligible improvement in the biota.

17. KEY WORDS AND DOCUMENT ANALYSIS		
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