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Utilization of Fly Ash and Coal Mine Refuse as a Road Base Material

Interagency Energy/Environment R&D Program Report

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August 1979

UTILIZATION OF FLY ASH AND COAL MINE REFUSE AS A ROAD BASE MATERIAL

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report evaluates the environmental effects of the use of coal-related waste products, fly ash and coal mine refuse, as road base materials. Fly ash is a waste product from coal-powered, steam-generating, electric energy plants. It was utilized as a stabilizing agent to fill the voids in the refuse. In cases of alkaline fly ash, it would serve to neutralize acidity produced by the pyritic coal mine refuse. The mine refuse and other reject materials are produced from the coal mining process and preparation plants and were used as the load-bearing aggregate. Because of the recent emphasis on the expansion of the coal industry, the technology for utilizing these readily available waste materials as construction material needs reliable definition. The documentation of the cost, effectiveness, physical stability, and chemical characteristics of the leachate percolating through the base material is presented in this report. These data will be of interest to agencies, industry, and individuals who are involved in utilizing waste material for environmentally acceptable construction purposes. For further information, contact the Resource Extraction and Handling Division.

David G. Stephan
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ABSTRACT

The U.S. Environmental Protection Agency conducted a 4-year study on the utilization of two readily available coal-related waste products as road base materials in a parking lot. The materials consisted of fly ash from a coal-powered, steam-generating, electric energy plant and coal mine refuse produced from a coal preparation plant. The construction area was divided into three segments with a drainage monitoring system installed at each site. Chemical characteristics of the effluents discharging from the different base-course mixtures were documented. All materials were mixed and placed with standard highway construction equipment and three areas received the same surface treatment of 7.6-cm (3-in) base course and 2.5-cm (1-in) wearing course of asphaltic concrete.

Area 1 was composed of a 30.5-cm (12-in) deep mixture of 75-percent coal mine refuse (CMR) and 25-percent fly ash (FA). The effluent water quality was found to be environmentally acceptable. A small intermediate area located along the edge of the pavement produced intermittent slugs of undesirably high acid and metal concentrations.

The composition of the Area 2 base material was primarily the same as Area 1 except for the addition of 5 percent by weight of lime in the upper 15.2-cm (6-in) lift. Intermittent slugs of boron concentration were noted during successive winter months.

Area 3 consisted solely of 38.1-cm (15-in) of coal mine refuse. The area continues to produce consistently unacceptable acid and metal concentrations in the discharge.

Effluent quantities from each of the test areas were surprisingly small; i.e., approximately one liter per month from each sampling pipe.

Physical structural characteristics of the road base material indicated that these waste products can be successfully used as a base or subbase material when properly compacted and/or stabilized. Monitoring of the physical and chemical characteristics of the road material began in the summer of 1973 and was discontinued in August 1977.

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ACKNOWLEDGMENTS

The cooperation of the following persons was invaluable to the completion of this project: Ronald D. Hill, EPA, Cincinnati, Ohio; Dr. David Anderson, Pennsylvania State University, State College, Pennsylvania; Al Babcock, Monongahela Power Company, Fairmont, West Virginia; William Harman and Fred Queen, Harman Construction Company, Grafton, West Virginia; and, William Light and Greg Barbe, Christopher Coal Company, Osage, West Virginia.

Special thanks are extended to James L. Kennedy, Harry L. Armentrout, J. Randolph Lipscomb, Robert M. Michael, Ralph S. Herron, Paul H. Moore, Loretta J. Davis, and Daniel L. Light of the EPA Crown Mine Drainage Control Field Site.

SECTION 1

INTRODUCTION

A study was conducted to utilize two coal-related waste products, fly ash and coal mine refuse, as road base materials at the U.S. Environmental Protection Agency's (EPA) Crown Mine Drainage Control Field Site near Morgantown, West Virginia.

Fly ash is a waste product from coal-powered steam-generating stations that supply a major portion of the nation's electric energy requirements. In 1975, total ash collection, which includes fly ash, bottom ash and boiler slag, soared to a record 54 million tonnes/yr (59.5 million tons/yr) resulting from the burning of approximately 363 million tonnes (400 million tons) of coal. Only 14.6 percent of the ash material is being utilized as construction material (concrete, fill material, asphalt mix, etc.) or as a soil amendment for orphaned strip mines and coal mine refuse piles. This material is readily available particularly in the Appalachian Region for road base material. Approximately 1.0 million tonnes (1.1 million tons) of fly ash and 317,000 tonnes (350,000 tons) of bottom ash were collected during 1975 in the Monongahela River Basin. Figure 1 shows the production of ash material in the United States.

Coal refuse, gob, and other reject materials are produced from the coal mining process. Stringent environmental standards require that a large percentage of coal be washed or prepared to make it environmentally acceptable for consumption, thus yielding more refuse. The mining, crushing, and washing process tend to concentrate many impurities in the refuse and gob. Most coal-cleaning methods employ gravity separation to remove impurities; thus, the more dense materials such as clays, shales, and pyrite lenses are removed to the refuse dump. This waste material may be extremely toxic (pyritic in nature) and usually requires special handling and disposal to prevent air and water pollution problems. Average coal mine refuse produced for the six-year period between 1968 and 1973 was 91 million tonnes/yr (100 million tons/yr).

This study was to utilize these two waste products (coal mine refuse and fly ash) in the construction of a parking lot to determine their usefulness as a road base material in lieu of an environmental detriment. An evaluation was made to determine if water percolating through the base material would leach undesirable material and become a pollution problem.

West Virginia University, Monongahela Power Company, and Christopher Coal Company cooperated with EPA in this study. Dr. David Anderson (previously with West Virginia University) designed the base-course mixtures. The

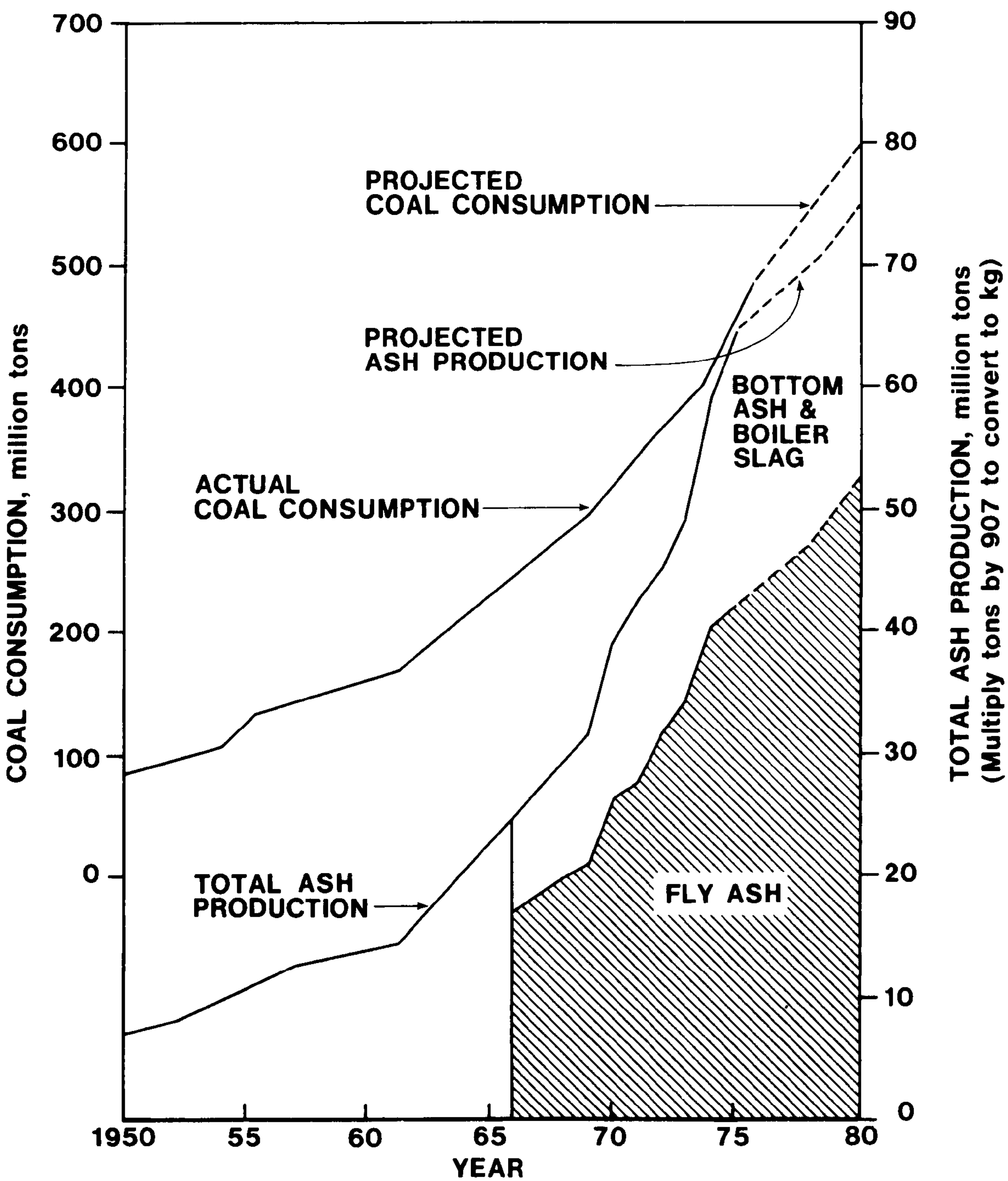

FIGURE 1. Coal consumption and ash production by U.S. electric utilities.

Fort Martin Power Station (Monongahela Power Company) supplied fly ash from their coal-fired power plant, and the Humphrey Cleaning Plant (Christopher Coal Company) supplied coal mine refuse.

DESIGN OF TEST

In each of the base mixtures, the coal mine refuse served as the load-bearing aggregate. In the coal mine refuse-fly ash system, the purpose of the fly ash was 1) to fill the voids and thereby reduce the permeability of the system and 2) to neutralize acidity production from the pyritic refuse material.

In the coal mine refuse-fly ash-lime system, the lime was added 1) to promote pozzolanic or other cementing action that would occur in the fly ash and, 2) to provide an additional buffer for possible acidity production. The lime-fly ash matrix filling the voids was designed to harden appreciably, thereby increasing the strength and decreasing the permeability of the mixture.

The area to be paved was already at finished grade. It was necessary to excavate from 30.5 to 38.1 cm (12 to 15 in) for the base and 10.2 cm (4 in) for the asphalt.

The construction area (Figure 2) was divided into three segments to investigate different base-course mixtures. Area 1, covering 770 sq m (920 sq yd), was the largest of the three and, as the main entrance and parking area, was subject to the heaviest traffic. The base course for Area 1 (Figure 3) was composed of a 30.5-cm (12-in) deep mixture of 75-percent coal mine refuse (CMR) and 25-percent fly ash (FA). The materials were mixed with an end-loader prior to placement, and placed in two 15-cm (6-in) lifts. A three-wheeled steel roller compacted the mixture.

Area 2, with an area of 184 sq m (220 sq yd) was smaller than Area 1 and subject to less traffic. The base was placed in two lifts. The first 15-cm (6-in) lift was the same mixture used in Area 1 (75-percent CMR and 25-percent FA). On the top 15-cm (6-in) lift, five percent of lime (by weight) was mixed with the CMR-FA mixture by repeated blading with a road grader. Weight calculations for lime addition were based on CMR-FA density measured during construction. Typical compacted densities were around 1920 kg/cu m (120 lb/cu ft). At five percent by weight, the lime requirement for Area 2 was approximately 2720 kg (6000 lb) or 15 kg/sq m (27 lb/sq yd). Considerable difficulty was encountered in obtaining adequate in-place mixing of the lime with the CMR-FA mixture, because the lime flowed like water in front of the grader blade. Mixing the constituents before placement of the base would avoid the problem. The lime addition was made to offset possible acidity production of the refuse and to enhance cementing of the fly ash.

Area 3 was the same size as Area 2 but was subject to the least traffic. The base course for Area 3 consisted solely of 38 cm (15 in) of coal mine refuse placed in two lifts (Figure 3).

All three areas received the same surface treatment (Figure 3); i.e., a two-wheeled steel roller individually compacted 7.6 cm (3 in) of base course

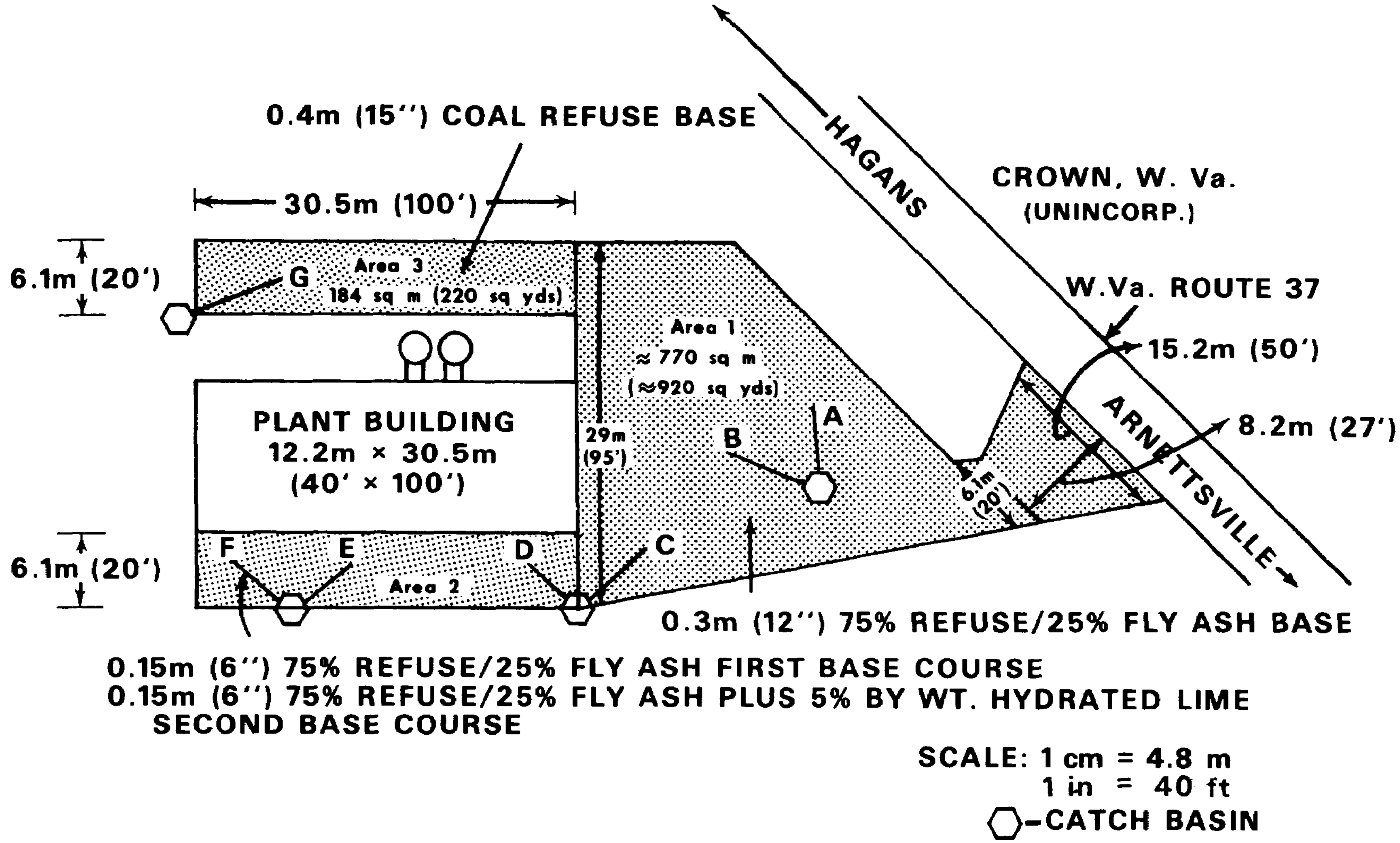

FIGURE 2. Paving sketch for the coal mine refuse-fly ash road base study at the U.S. Environmental Protection Agency's Crown Mine Drainage Control Field Site.

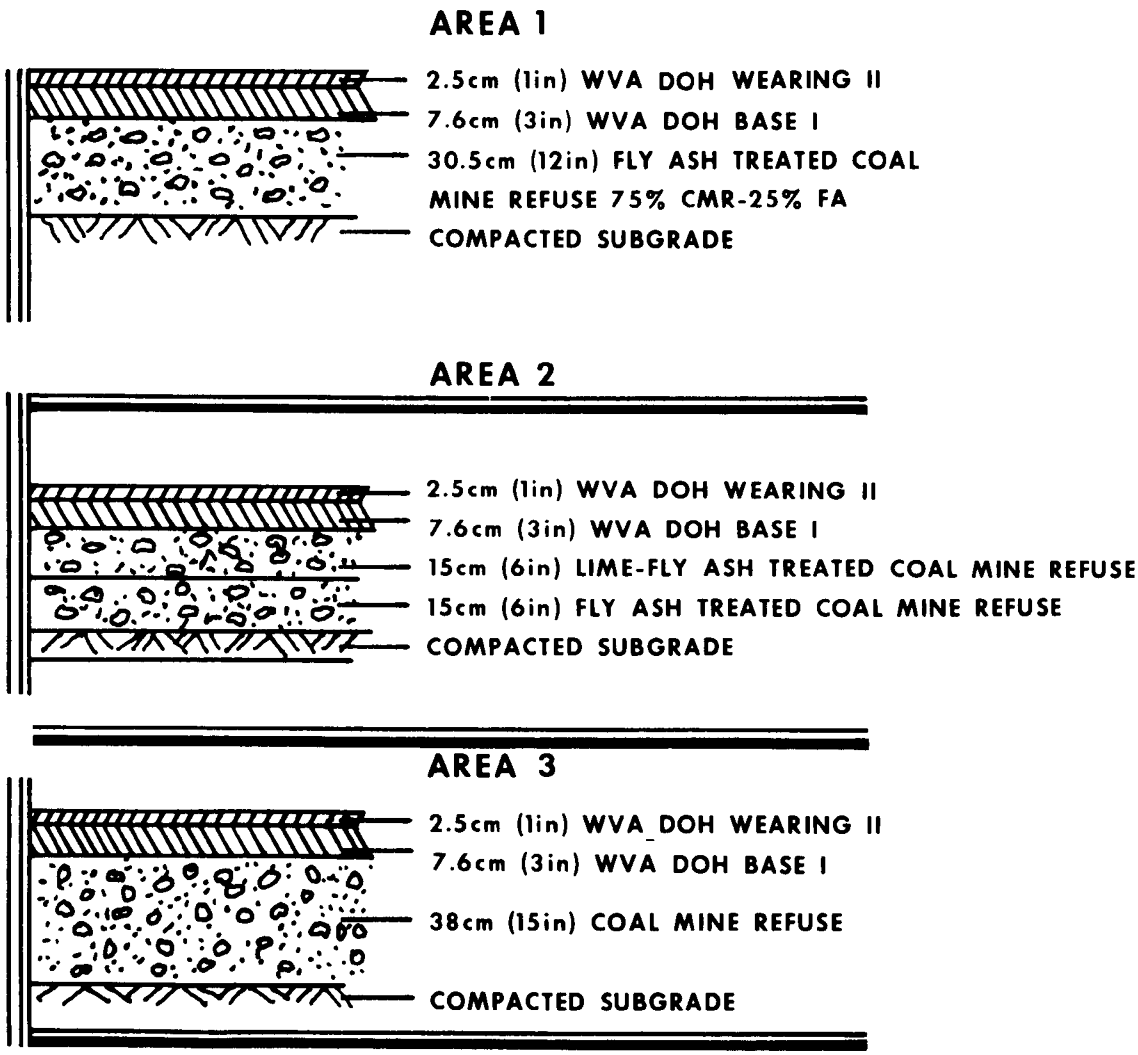

FIGURE 3. Typical cross-sections of the three road bases (as built).

asphalt and 2.5 cm (1 in) of wearing course asphalt. The asphalt complied with West Virginia Department of Highways Standard Specifications for Roads and Bridges outlined in Section 401 for Base 1 and Wearing 2 Courses.

A pictorial history of construction of Area 2 is presented in Figures 4 through 11.

COST

In Table 1, the cost of the construction is detailed. (1) The fly ash and refuse were provided to the contractor at no charge; thus, the only expense to the contractor was transportation from the source to the site. The cost of each treated area was not determined. Average cost of the pavement was $10.92 per sq m ($9.13 per sq yd). These costs are not necessarily representative of costs that would be obtained for a large project where more sophisticated mixing equipment would be necessary and where the efficiency of the operation could be greatly improved.

TABLE 1. CONSTRUCTION COSTS (1973)

Payroll and taxes	$3957
Materials	2986
Equipment charges (includes moves)	4968
Miscellaneous charges	499
	$12,416

NOTE: The above figures do not include any company overhead or profit.

Figure 4. Excavation of existing ground to subgrade level (Area 2).

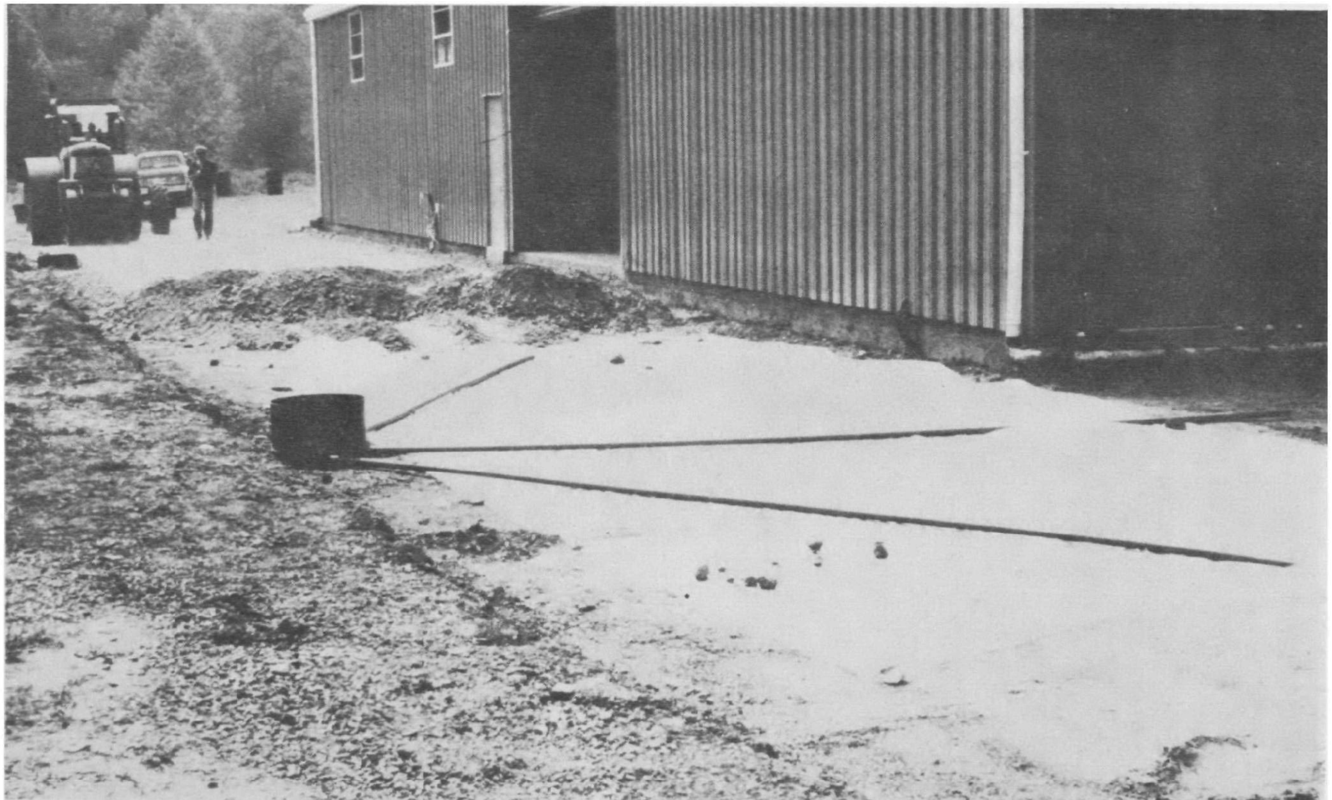

Figure 5. Placement of polyethylene sheeting and perforated - PVC piping on subgrade for water sampling purposes (Area 2).

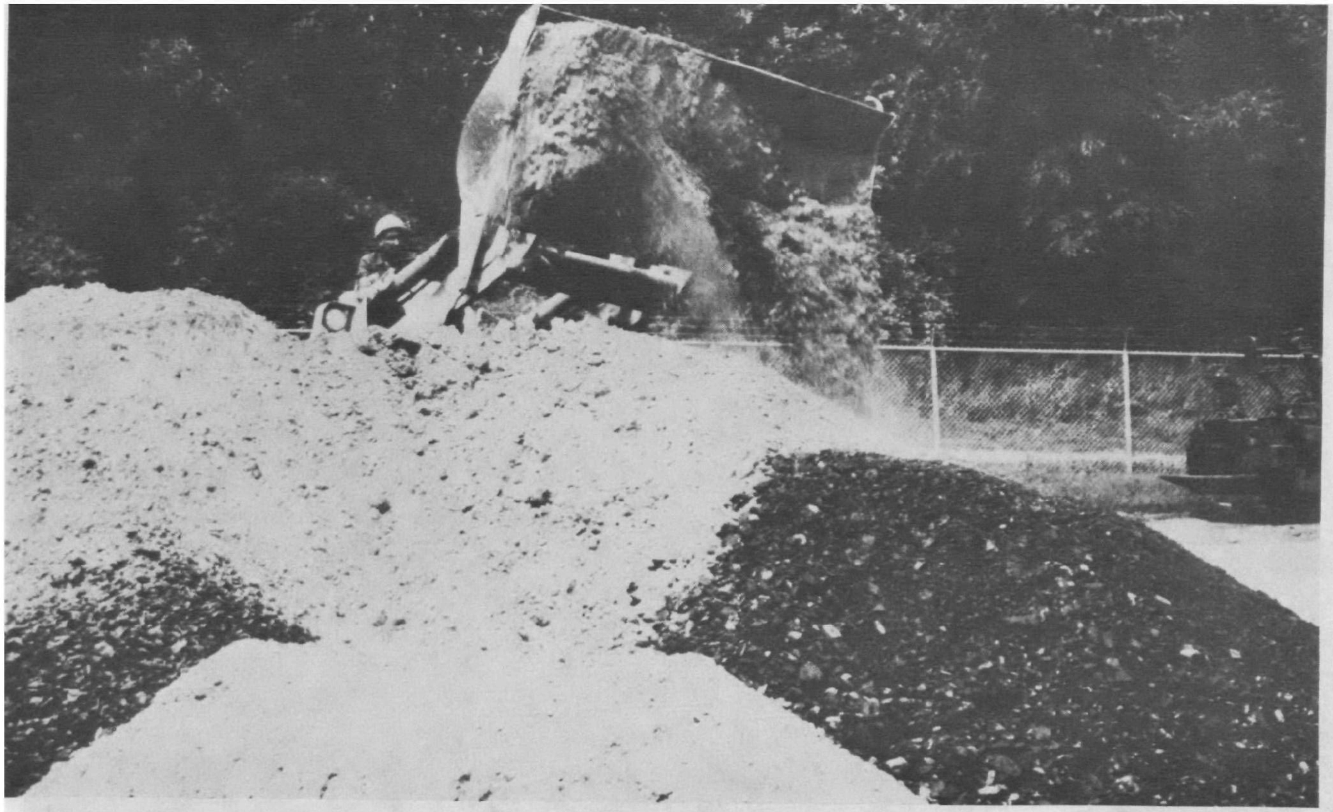

Figure 6. Mixing the refuse and fly ash with an endloader (Area 2).

Figure 7. Placing the refuse-fly ash mixture base material (Area 2).

Figure 8. Grading the base material (Area 2).

Figure 9. The prepared base material after lime was added to the top 6 in (15.2 cm) (Area 2).

Figure 10. Placement of the base-course asphalt (Area 2).

Figure 11. The finished project. Area 1 extends from the extreme right side of the picture to the near side of the building (where cars are parked). Area 2 extends from the left-front corner of the building to the left rear corner. Area 3 covers the area from the right-front corner of the building to the right-rear corner (past storage silos).

SECTION 2

CONCLUSIONS

AREA ONE (COAL MINE REFUSE/FLY ASH)

Chemical Characteristics

The excellent compaction and particle interlock of the base material minimized the flow of subsurface water, particularly through the center of the area.

Chemistry data collected at Point C were biased by its physical location along the edge of the pavement and by lime spilled or carried over from Area 2. Intermittent spikes of boron, acidity, iron, aluminum, and other metals were noted.

Physical Characteristics

The permeability of the subbase and the moisture gradient in the fly ash/refuse mixture indicates a tendency for the fly ash in the mixture to retain water.

Physical appearance of the subbase material removed during the plate bearing tests in Area 1 indicated that the material was well compacted with excellent particle interlock and could only be removed with considerable chiseling and prying. There was no evidence of slaking or other degradation.

AREA TWO (COAL MINE REFUSE/FLY ASH/LIME)

Chemical Characteristics

Spikes of boron concentrations of 30 to 40 mg/l occurred during successive winter months (1974-76).

Physical Characteristics

During plate bearing tests in Area 2, it was necessary to use an air chisel to remove the portion of material mixed with lime. It is estimated that the compressive strength of the material was at least 3.5 N/sq mm (500 psi). Mixing of the lime in the upper 15 cm (6 in) of Area 2 was less than adequate.

AREA THREE (ALL COAL MINE REFUSE)

Chemical Characteristics

Chemical data collected at the discharge of this area continued to show increasing concentrations of environmentally unacceptable chemical constituents in the effluent; therefore, the use of coal mine refuse without fly ash and/or lime would not be considered an acceptable road base material.

Physical Characteristics

Loss-on-ignition test performed on a small cross-section of the road base material in all-refuse Area 3 showed an ignition loss of 72 percent indicating it to be predominately coal with little rock.

GENERAL OBSERVATIONS

Chemical Characteristics

Because the test areas were in a parking lot, the base materials were poorly drained. Even so, the volume of effluent collected from each sampling pipe was surprisingly small (on the order of one liter per month). Though the intermittent discharge of pollutants from Area 2 and the intermediate area between Areas 1 and 2 were disturbing in terms of concentration, they represented almost negligible pollutant loads because of the small volume of discharge.

Physical Characteristics

Results obtained from the plate bearing tests were indicative of low-quality granular materials suitable as a subbase but of questionable value as a base coarse directly under asphaltic concrete designed to carry heavy loads.

Coarse material that was removed from test holes and allowed to sit overnight in the rain with subsequent drying the following day resulted in slaking of the large particles. Confinement under the pavement surface effectively stopped physical degradation of both the plain coal refuse and the coal refuse-fly ash mixtures.

SECTION 3

RECOMMENDATIONS

It is recommended that additional research is needed to determine the long-term effects of service (frost, moisture, traffic loading, etc.) on the properties of coal mine refuse and to determine optimal materials and mixtures for the stabilization of different sources of refuse.

Additional research on the use of coal mine refuse in civil engineering construction is needed. Emphasis should be placed on use in areas with excellent drainage so that both water contact time and the tendency for water retention by the base materials would be reduced.

SECTION 4

PROCEDURES

A drainage monitoring system was installed between the base course and the subgrade (Figure 12). The drainage monitors were 6.4-m (21-ft) joints of 3.8-cm (1½-in) perforated PVC pipe laid on 6-mil polyethylene plastic sheeting. The base course was carefully placed over the pipes. Discharges from the pipes drained into catch basins and were collected in plastic containers. Samples were generally collected on a weekly basis during the early part of the study and generally on a monthly basis during the later phases.

The following methods were employed for chemical analyses: conductivity and pH were determined potentiometrically; suspended solids, boron and alkalinity were determined by EPA methods; (2) total iron, aluminum, magnesium, manganese, sodium, cadmium, nickel, lead, zinc, and copper were measured by atomic absorption spectroscopy; (2) sulfate was measured indirectly by atomic absorption (adding barium chloride to the sulfate aliquot, then analyzing for residual barium); (3) acidity was measured by the Salotto acidity method (4) adding hydrogen peroxide to oxidize the metals, then titrating the cold sample to pH 7.3; and, rainfall was recorded by a Belfort Universal-type rain gage. Density of the base material was determined by the ASTM D-1556-64 sand-core method. (5)

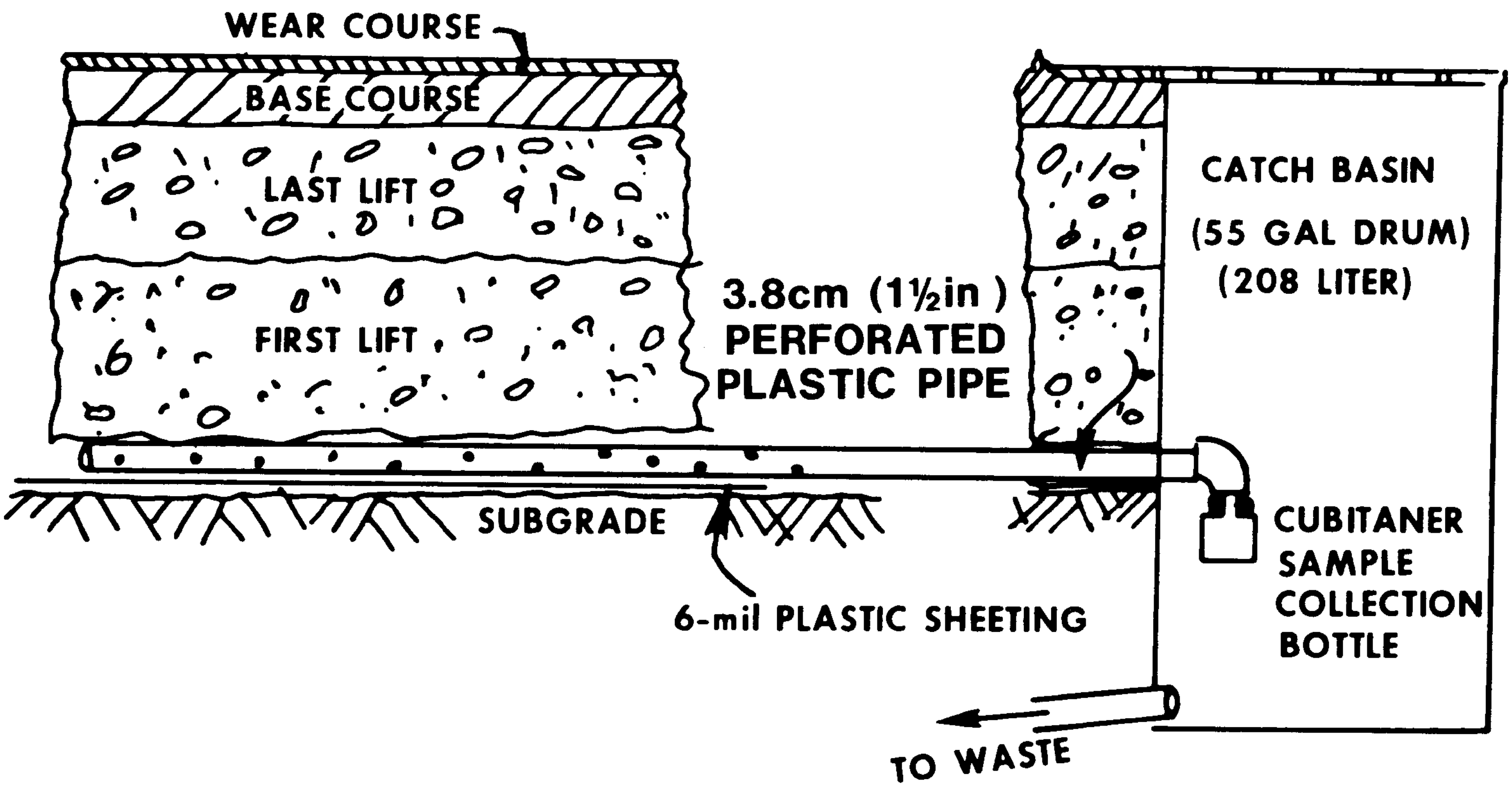

FIGURE 12. Drainage monitoring system for road base study.

SECTION 5

RESULTS

PHYSICAL CHARACTERISTICS

Field compaction of the base materials was satisfactory; the density of the in-place materials exceeded the laboratory design values (Table 2). A more complete discussion of the physical capabilities of the base material has been presented by Moulton, et al (6) and Anderson. (7)

Compaction and physical characteristics of coal mine refuse were evaluated by Dr. David Anderson (7) under a consulting service contract. Dr. Anderson reported:

> "Field and laboratory moisture-density data taken at the time of construction are given in Table 2. In Areas 1 and 2, the field densities were higher than those obtained in the laboratory. This may be due to the omission of the plus 3/4-inch (1.9-cm) material in the laboratory tests or, more likely, may be due to the difference in the nature of field compaction versus laboratory compaction. This point needs to be investigated with respect to coal mine refuse and its potential for degradation (and subsequent densification) under compaction, both in the laboratory and in the field. As expected, the lime treated material was consistently lower in density than the untreated fly ash/refuse blend.
>
> Gradation curves for the 75-25 refuse/fly ash blend before and after field compaction are given in Figure 13. The before and after gradation curves show very little evidence of degradation. This is in keeping with visual observations made during actual field compaction. The change in gradation between the blend and the plain refuse is due to the addition of fly ash. The increase in minus 100-mesh material from 3 percent to 24 percent indicates about 21-percent fly ash in the refuse/fly ash blend, slightly less than the 25-percent specified.
>
> In July of 1974, approximately one year after the initial construction, a ten-inch (25.4-cm) or twelve-inch (30.5-cm) diameter section of pavement was removed in Areas 1, 2, and 3. A plate bearing test was run on the surface of each base section as well as on the material directly underlying each base section. Moisture-density and gradation determinations were made on the in situ material following each plate bearing test. The results of the moisture-density tests are given in Table 3. The data are in

TABLE 2. MOISTURE-DENSITY DATA FROM CROWN PARKING LOT AT TIME OF CONSTRUCTION

Test area	Treatment of refuse	Test condition	Dry density, pcf	Dry density, kg/cu m	Moisture, percent
1	75% Refuse -	Laboratory[1]	110.4	1770	7.0
	25% Fly ash	Field,[2] during construction	123.4	1980	4.4
2	75% Refuse	Laboratory[1]	102.0	1630	4.0
	25% Fly Ash with 5 % lime, by weight	Field,[2] during construction	107.4	1720	4.7
3	Plain refuse	Laboratory[1]	96.9	1550	5.6
		Field,[2] during construction	69.6	1110	10.1

[1]ASTM D698-70, Method C, 4-in mold and minus 3/4-in material

[2]ASTM D 1556-64

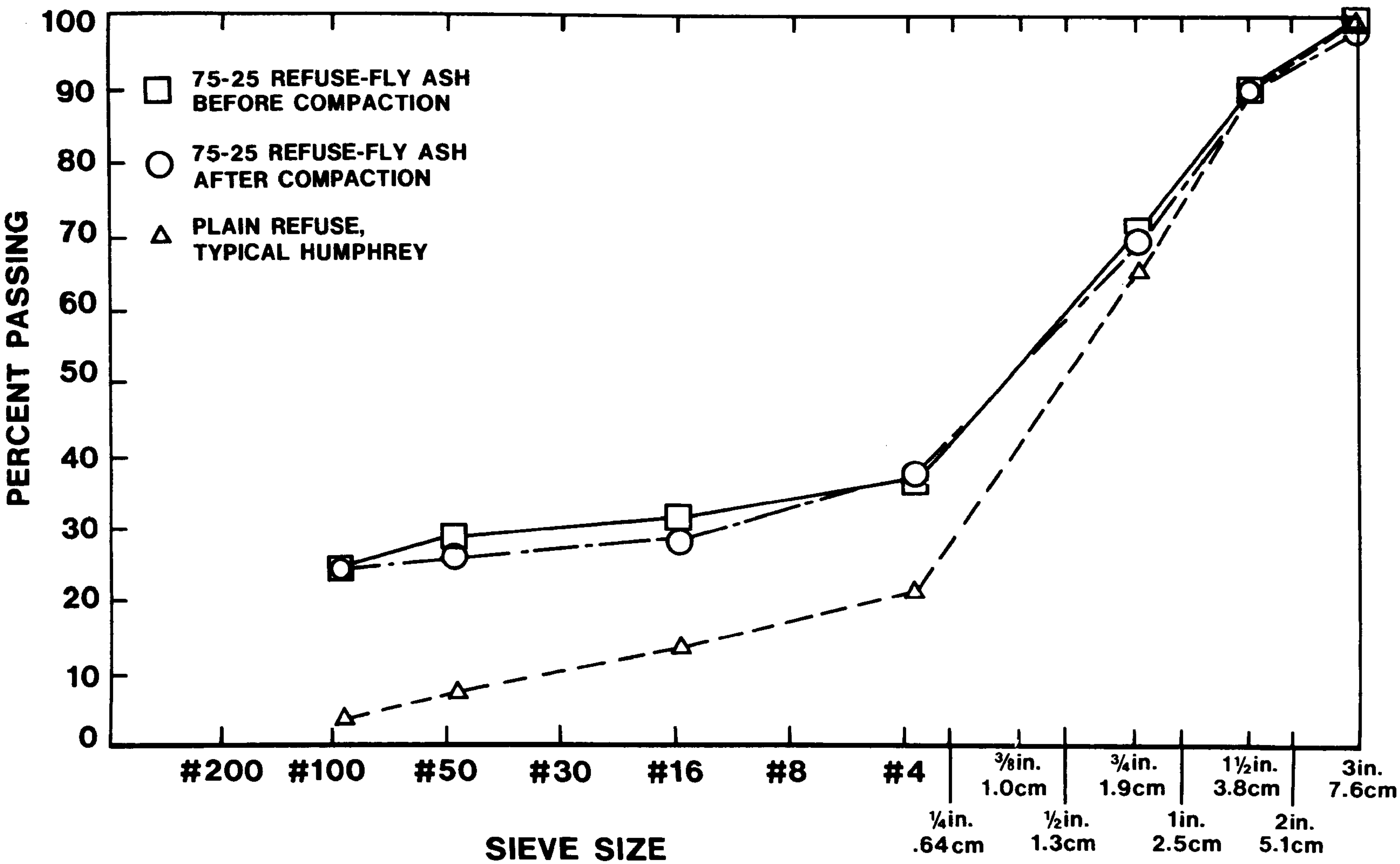

FIGURE 13. Gradation curves for Humphrey refuse and refuse-fly ash blends. (7)

TABLE 3. MOISTURE-DENSITY RESULTS ASSOCIATED WITH PLATE BEARING TESTING(7)

Depth,* inches	Depth,* cm	Moisture, percent	Dry density, lb/cu ft	Dry density, kg/cu m
		AREA 1 - 75%-25% REFUSE - FLY ASH		
0-6	0-15	8.1	110.0	1760
10-12	25-30	11.0	-	-
12-16	30-40	11.4	111.8	1790
		AREA 2 - 75%-25% REFUSE - FLY ASH WITH 5% LIME		
0-1½	0-4	10.6	-	-
0-4	0-10	14.5	103.0	1650
1½-3	4-8	16.2	-	-
3-7	4-18	16.6	-	-
10	25	20.5	-	-
12-16	30-40	15.1	99.4	1590
		AREA 3 - 100% REFUSE		
0-6	0-15	13.5	70.7	1330
10-12	25-20	15.4	-	-

*Measured in base section alone, excluding asphaltic concrete.

reasonable agreement with the data obtained at the time of construction (Table 2). The discrepancies between the two data sets are attributed to testing variability rather than to any significant change in material properties during the one year of service.

The coal mine refuse in Area 3 is considered typical of the Humphrey coal mine refuse. As sampled during the plate bearing testing, the refuse appeared to be predominately coal with little rock. During the construction, the contractor encountered some Humphrey refuse that was exceedingly high in coal content. This accounts for the anomalous density and appearance of the material in Area 3 (Tables 2 and 3). To substantiate the suspected high coal content of the material from Area 3, loss-on-ignition tests were performed on material from each of the base sections sampled during the plate bearing testing. The results are as follows:

Area 1, 16-percent loss
Area 2, 16-percent loss
Area 3, 72-percent loss.

Gradation curves for representative material removed during the plate bearing testing are given in Figure 14. The curves for the material from Areas 1 and 2 are similar to those in Figure 13, indicating little or no change in gradation during the one year of service. The gradation curve for the material from Area 3 is significantly different than the typical Humphrey refuse shown in Figure 13. This reflects the physical appearance and the open and porous nature of the material as it was removed during the plate bearing testing. (8) These factors could account for the quality of the water collected from Area 3. Because of its atypical nature (density, gradation appearance and loss on ignition) the portion of Area 3 that was sampled probably does not represent typical behavior for the unstabilized coal mine refuse.

The change in moisture content with depth of the ash-refuse mixture in Area 2 is of particular interest. Just under the asphaltic pavement, the base was noticeably drier than at depth. The material directly under the base is old weathered coal mine refuse that is reasonably permeable. This permeability was confirmed by the rapidity with which rain water drained from the test hole after a sudden downpour after the completion of testing. The permeability of the subbase and the moisture gradient in the fly ash/refuse mixture indicates a tendency for the fly ash in the mixture to retain water. At 20.5-percent moisture, the fly ash in the base mixture is sufficiently wet such that water can be squeezed from it. In both Area 1 and 3, just below the asphaltic concrete, the base mixture was significantly wetter than when placed, again indicating a tendency for the fly ash to take up and hold moisture. Still, in spite of the saturated condition of the fly ash in these areas, there was no apparent slaking of the coal mine refuse as might have been expected.

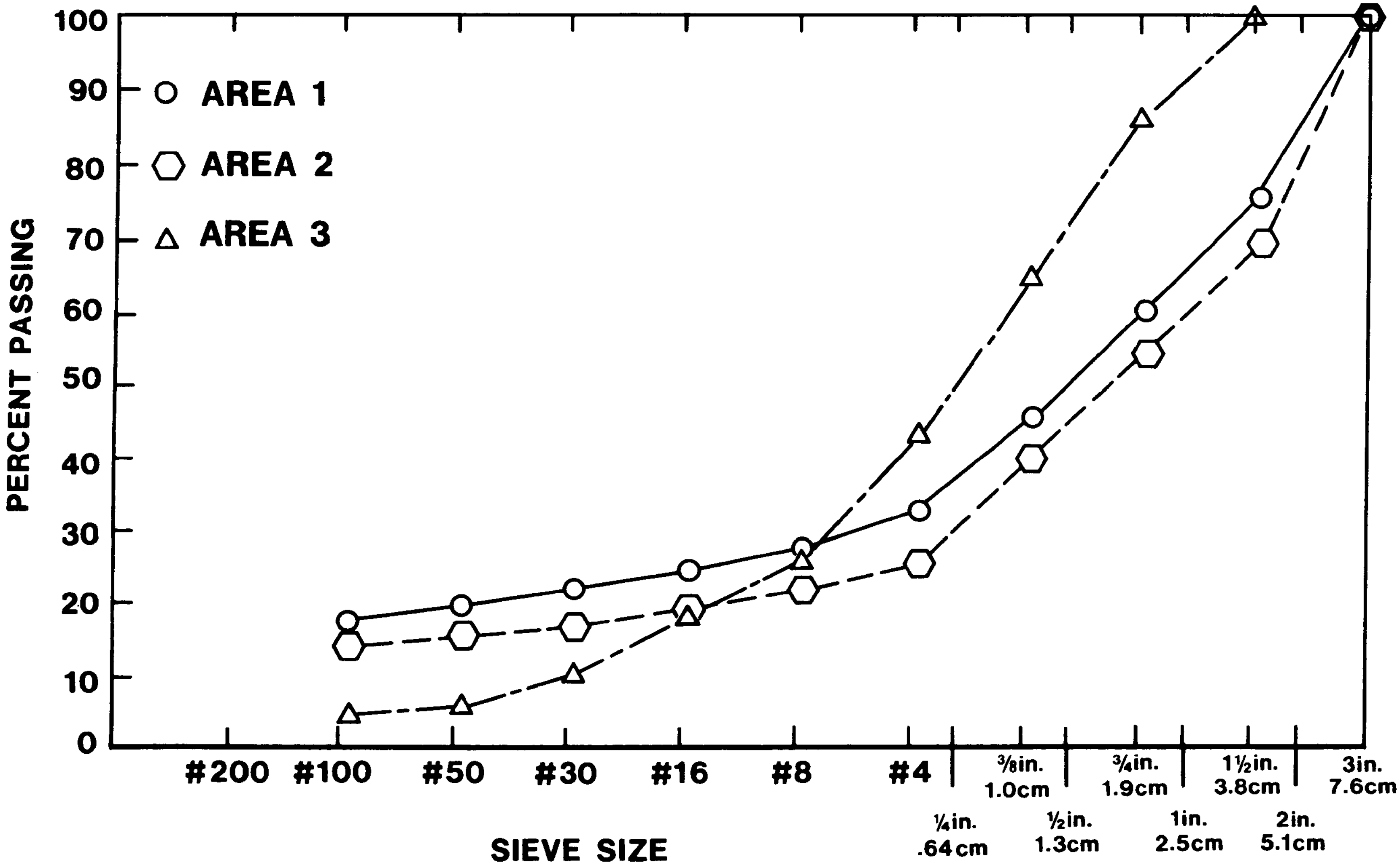

FIGURE 14. Gradation of material removed from base sections during plate bearing tests.

The physical appearance of the coal mine refuse as it was removed from the Area 1 and 2 test holes during the plate bearing testing was of particular interest. The base material was well compacted with excellent particle interlock and could be removed only with considerable chiseling and prying. There was no evidence of slaking or other degradation of the refuse itself. Some very minor staining was observed in three or four of the coarse particles from each test hole. Some of the coarse material that was removed from the hole was allowed to sit overnight in the rain. With subsequent drying the next day, many of the large particles had slaked to the point that they easily crumbled when worked between one's fingers. The differing behavior of well compacted refuse is in distinct contrast to refuse open to the weather in a loose, poorly compacted state.

Area 2 was to be stabilized with lime in the upper 6 in (15 cm) of the section. As this material was removed from the test hole, it was quite apparent that the mixing of the lime was less than adequate. The upper 1½ inches (3.8 cm) were not cemented at all. The next 4½ inches (11.4 cm) contained isolated pockets that obviously had not received lime. The effectiveness of the lime was quite dramatic, however. It was necessary to use an air chisel to remove the portions of the refuse mixture that contained lime. It is estimated that the unconfined compressive strength of this material was at least 500 psi (3.5 N/sq mm). There was no evidence of any chemical reaction with pyritic portions of the refuse. The effective layer of lime-stabilized material was estimated to be 2 to 3 in (5 to 8 cm) in the area sampled.

Plate Bearing Tests

The results of the plate bearing tests that were performed on the base and subbase sections are tabulated in Table 4. The plate bearing tests were performed according to ASTM Standard Method D-1195-64, Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements. The tests were run confined on plates of either 10-in (25.4-cm) or 12-in (30.5-cm) diameter, as noted in Table 4. Under test load, the coal mine refuse behaved essentially as a granular material. The deflections under applied loads became stabilized after only a few minutes, even at the higher loads. Complete rebound upon release of the applied loads was obtained in a few minutes. Load-deflection curves for Area 1 are shown in Figures 15 and 16. These are considered typical of the various results.

The results given in Table 4 are based on load-deflection curves after 10 cycles of repeated load. Values for the modulus of subgrade reaction, k, are based on plate pressure, p, of 10 psi (0.069 N/sq mm) where

TABLE 4. RESULTS OF PLATE BEARING TESTS(7)

		Top of base	Bottom of base
Area 1	k, pci[1]	769	385
	P, psi[2]	94	42
	E, psi[3]	2440	736
	plate diam, in	12	12
	depth of test, in[4]	4	16
Area 2	k	588	541
	P	81	87
	E	1546	1400
	plate diam, in	10	10
	depth of test, in	4	16
Area 3	k	476	500
	P	75	71
	E	1086	1118
	plate diam, in	10	10
	depth of test, in	4	19

Note: ASTM procedure D-1195-64 was used for these tests.

[1]Based on plate pressure of 10 psi.

[2]At 0.2-inches deflection.

[3]Tangent modulus at 20 psi corrected for surcharge (2).

[4]Includes thickness of asphaltic section.

To convert pci to kg/cu m, multiply by 27680; to convert psi to N/sq m, multiply by 7143; to convert in to cm, multiply by 2.54.

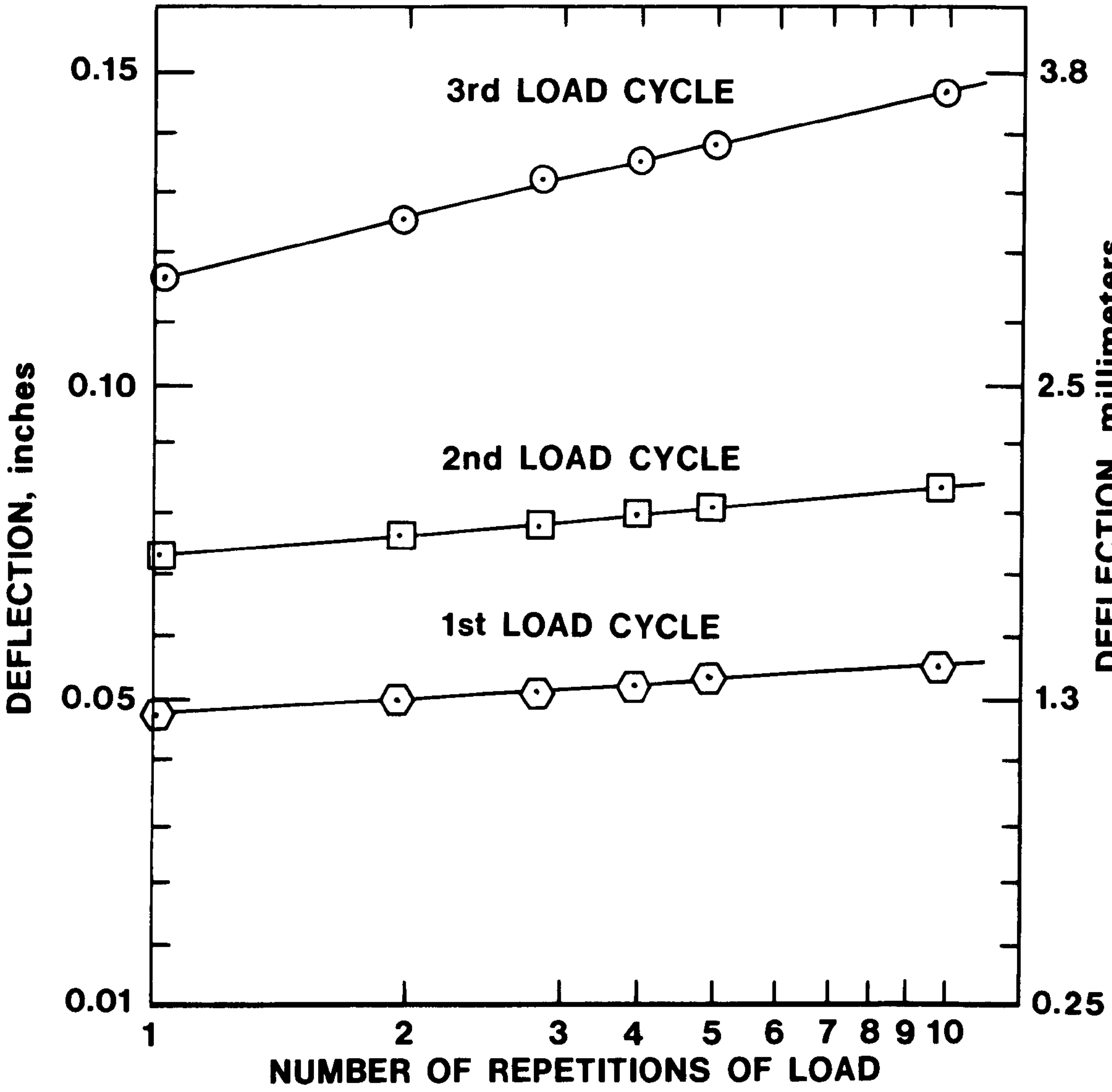

FIGURE 15. Deflections for repeated load applications, Area 1, top of base.

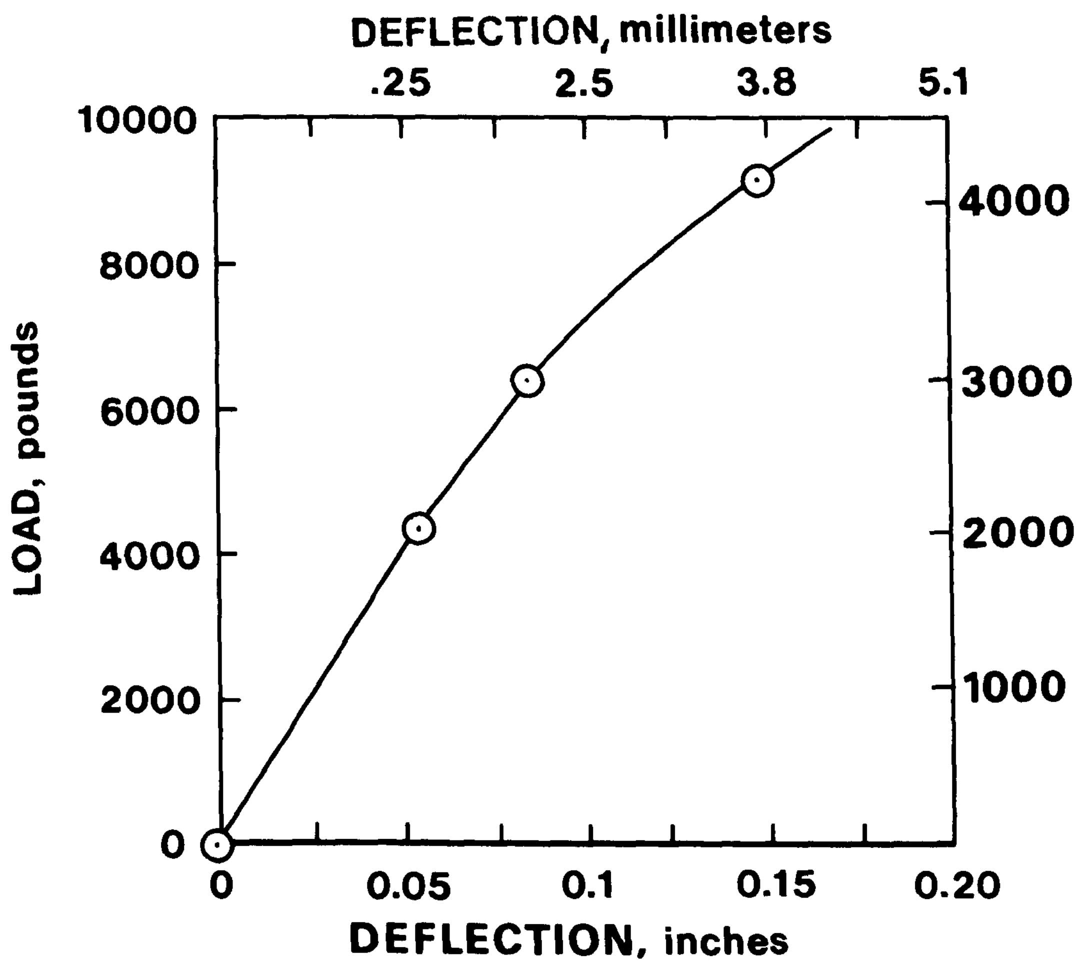

FIGURE 16. Load deflection curve for Area 1, top of base.

$$k = \frac{p}{\delta}$$

and δ is the deflection in inches. The bearing value, P, is the plate pressure required to give a deflection of 0.2 in (0.5 cm). The modulus of elasticity, E, is based on Boussinesq theory with a correction for the effect of the surcharge. (9) These data are indicative of a low-quality granular material suitable as a subbase but of questionable value as a base course under asphaltic concrete."

CHEMICAL CHARACTERISTICS

The chemical data resulting from this study are presented graphically in two formats: first, the relationships of each specific site with respect to pH, acidity, aluminum, boron, iron, sulfate, and suspended solids are illustrated in Figures 17-23; second, the chemical parameters for Area 3 (all-refuse) can be compared in Figures 24-27. Rainfall data for the study period are shown in Figure 28.

Area 1

Water samples collected at points A and B were averaged and used to chemically characterize the effluent from Area 1. The excellent compaction and particle interlock of the base material minimized subsurface water flows particularly through the center of the area at collection points A and B. This was evidenced by minimal water volumes collected from these sample points.

On December 15, 1973, an acid mine drainage (AMD) pipeline which was buried beneath the pavement in the vicinity of the Area 1 and 2 sampling stations ruptured. This break appeared to affect primarily the boron levels of Area 2 and the sulfate levels of both Areas 1 and 2. The influx of AMD appeared to have no residual effects on Area 2. The effluents collected from Area 1 appeared generally inoffensive throughout the study period. The effluents were characteristically neutral or slightly alkaline and contained minimal concentrations of aluminum, boron, iron, and sulfate.

Chemistry data collected at point C (Table 5) were not representative of water quality of Area 1 for the following reasons: This small area was biased by lime that was spilled or carried over from Area 2 during construction. Also, sample point C was located near the edge of the pavement and was subject to lateral infiltration of surface water that normally flooded a grassy area adjacent to the pavement during precipitation events. This was further evidenced by overflowing of the water collection container at point C during flooding. Chemistry data analyzed at this site for the period of September 1973 to July 1975 showed the effluents to be characteristically neutral or slightly alkaline. On September 10, 1975, the effluent became suddenly acid with acidity readings of 910 mg/l and pH of 2.7; however, water samples collected and analyzed in February 1976 show zero concentrations of acidity and an increase of pH to 7.1 (see Table 5). Iron and aluminum concentrations were less than 3.5 mg/l. A similar incident occurred October 13, 1976. The

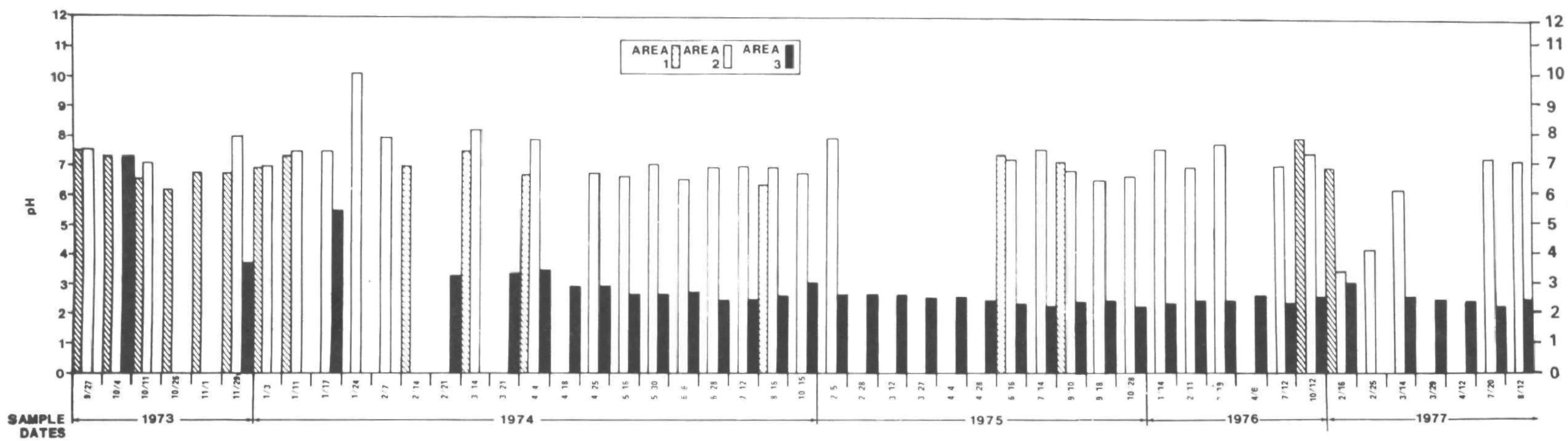

FIGURE 17. Comparison of effluent pH from each tested area.

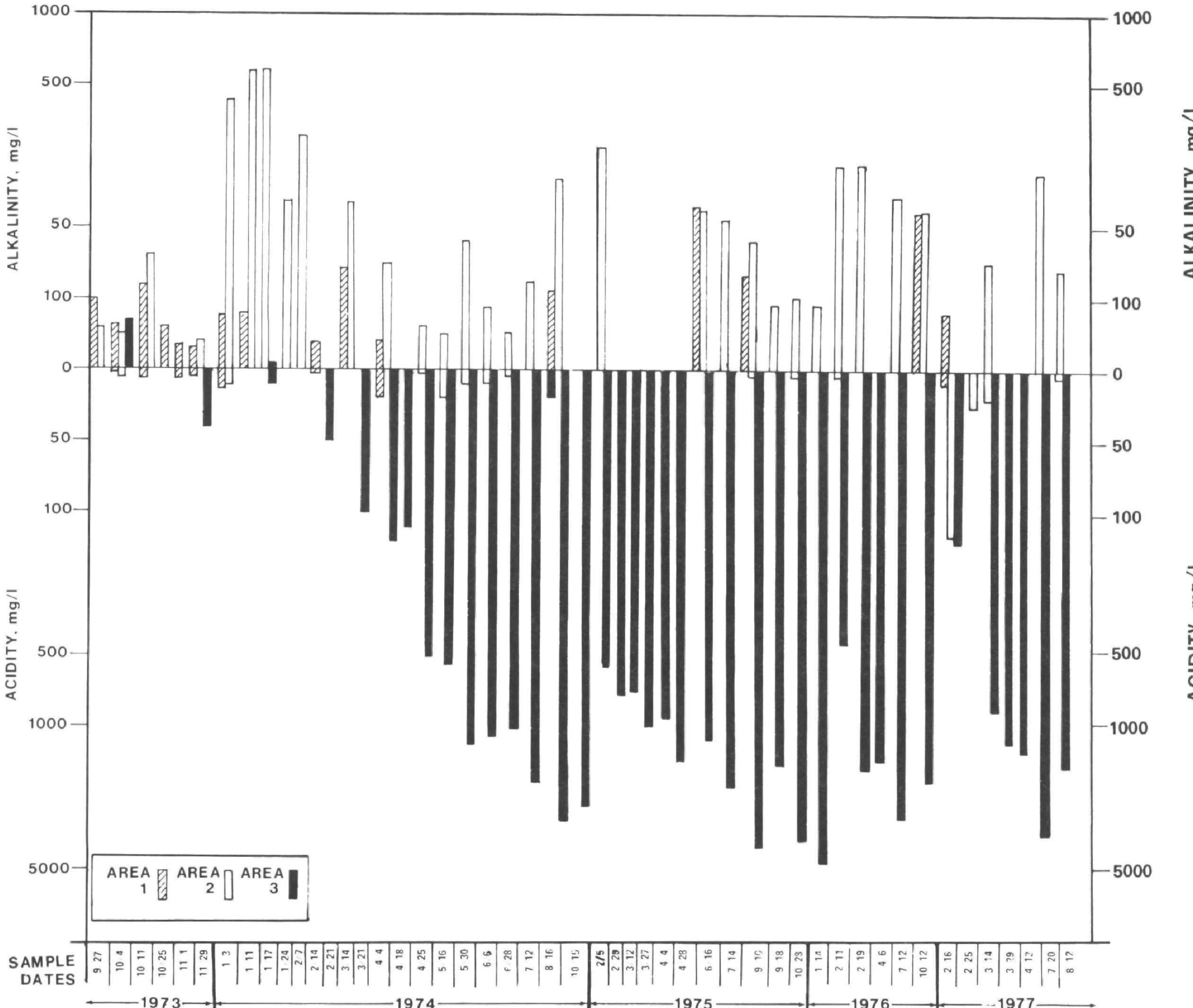

FIGURE 18. Comparison of acidity/alkalinity in the effluents from each test area.

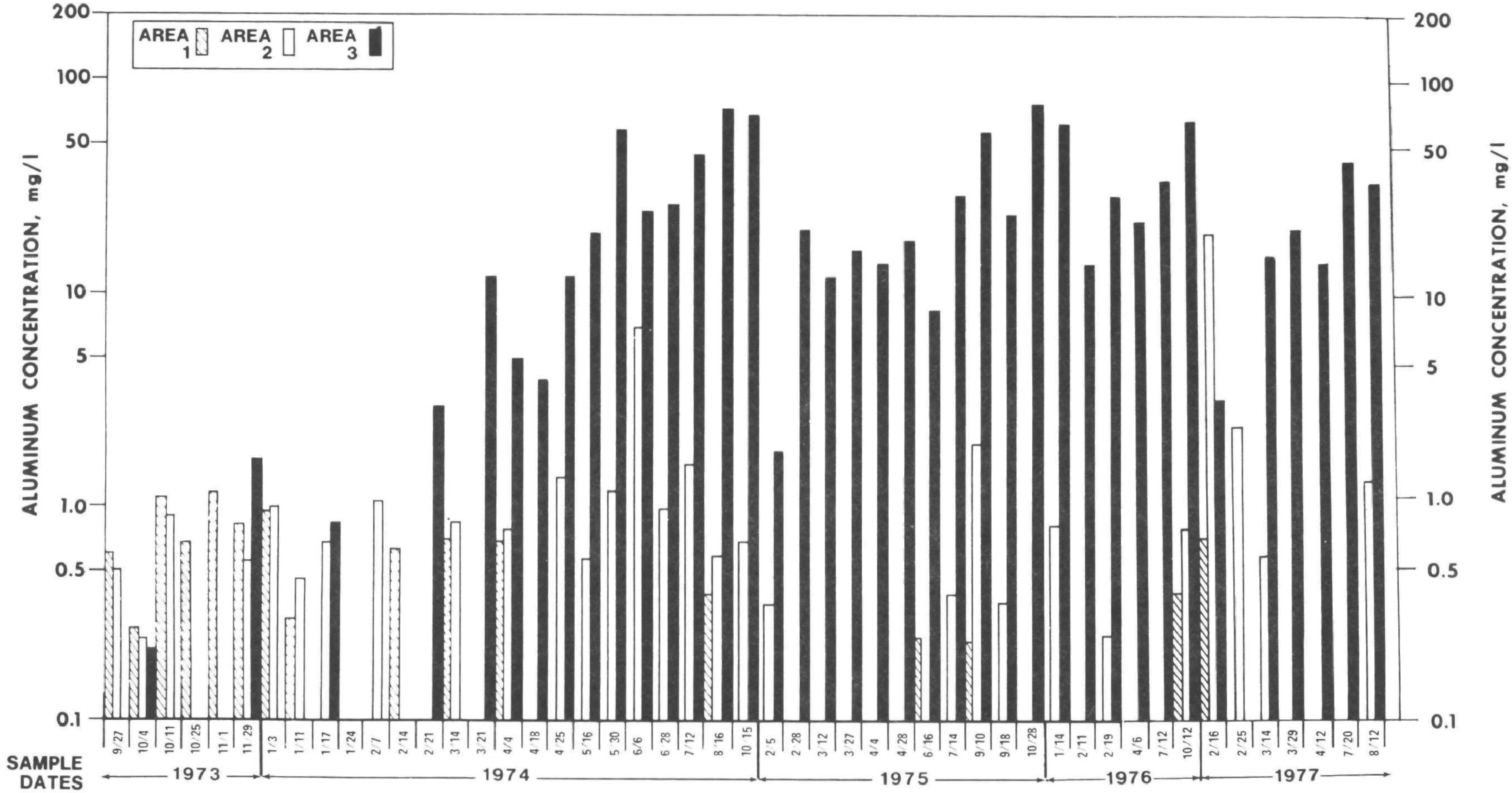

FIGURE 19. Comparison of aluminum concentrations in the effluents from each test area.

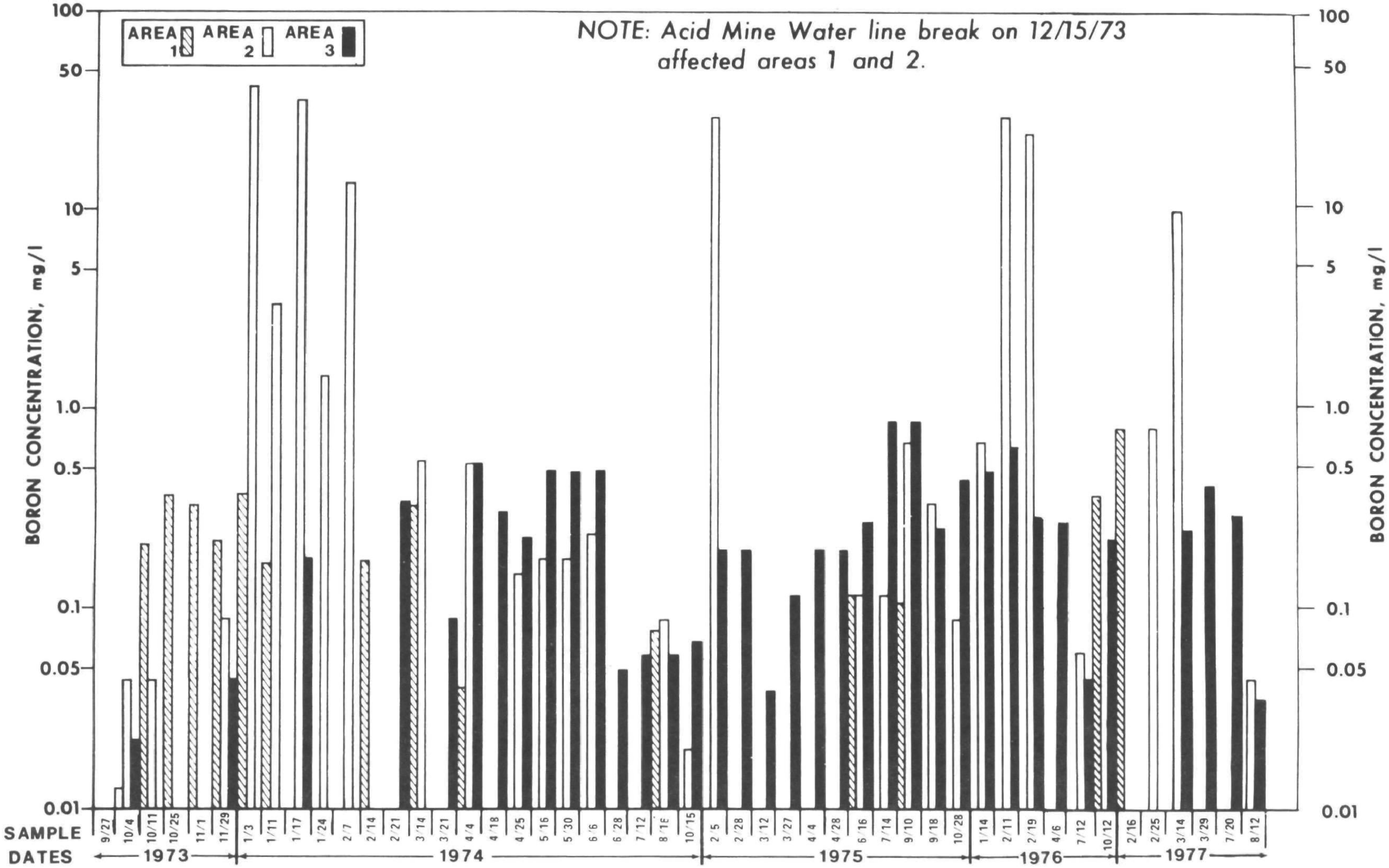

FIGURE 20. Comparison of boron concentration in the effluents from each test area.

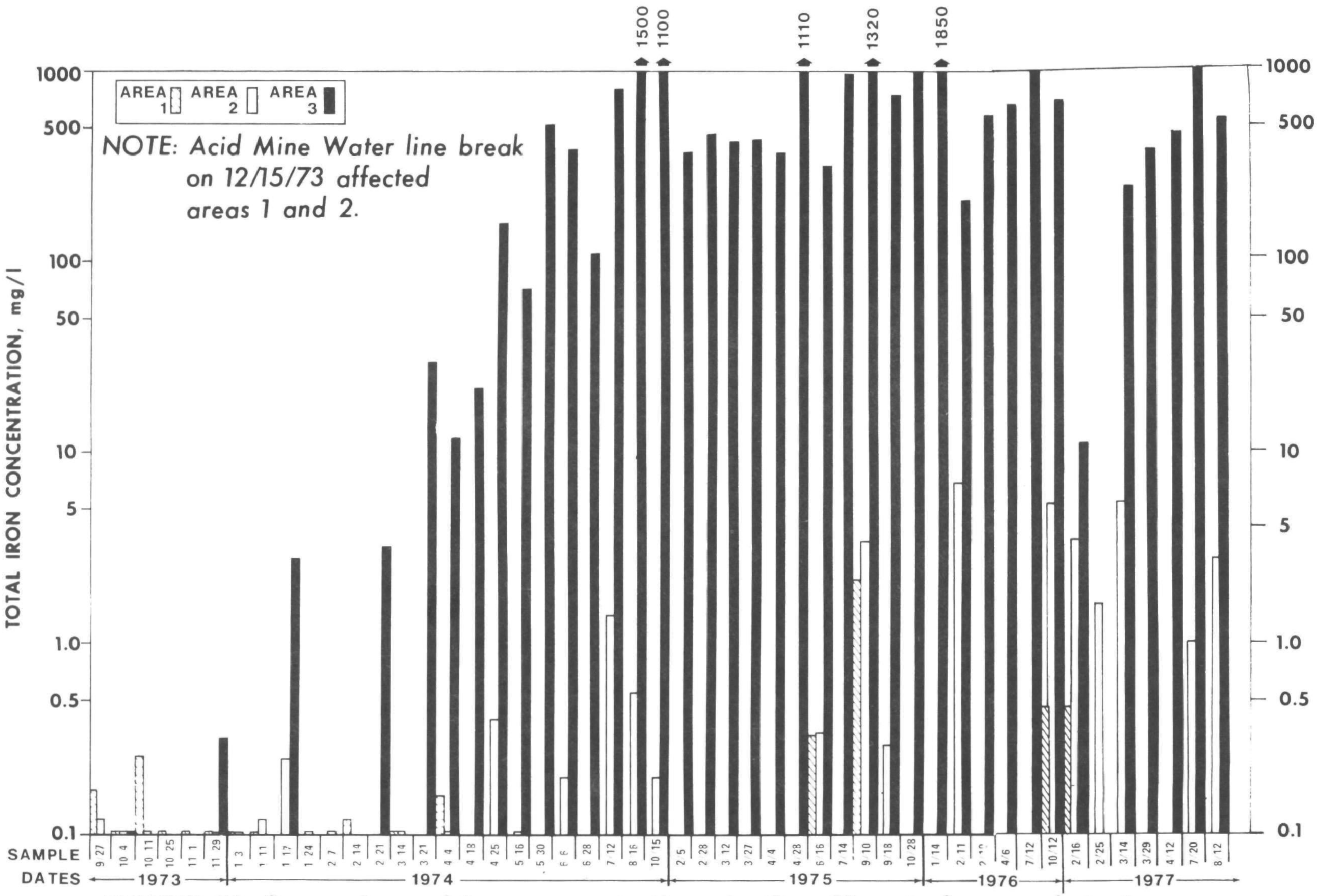

FIGURE 21. Comparison of iron concentrations in the effluents from each test area.

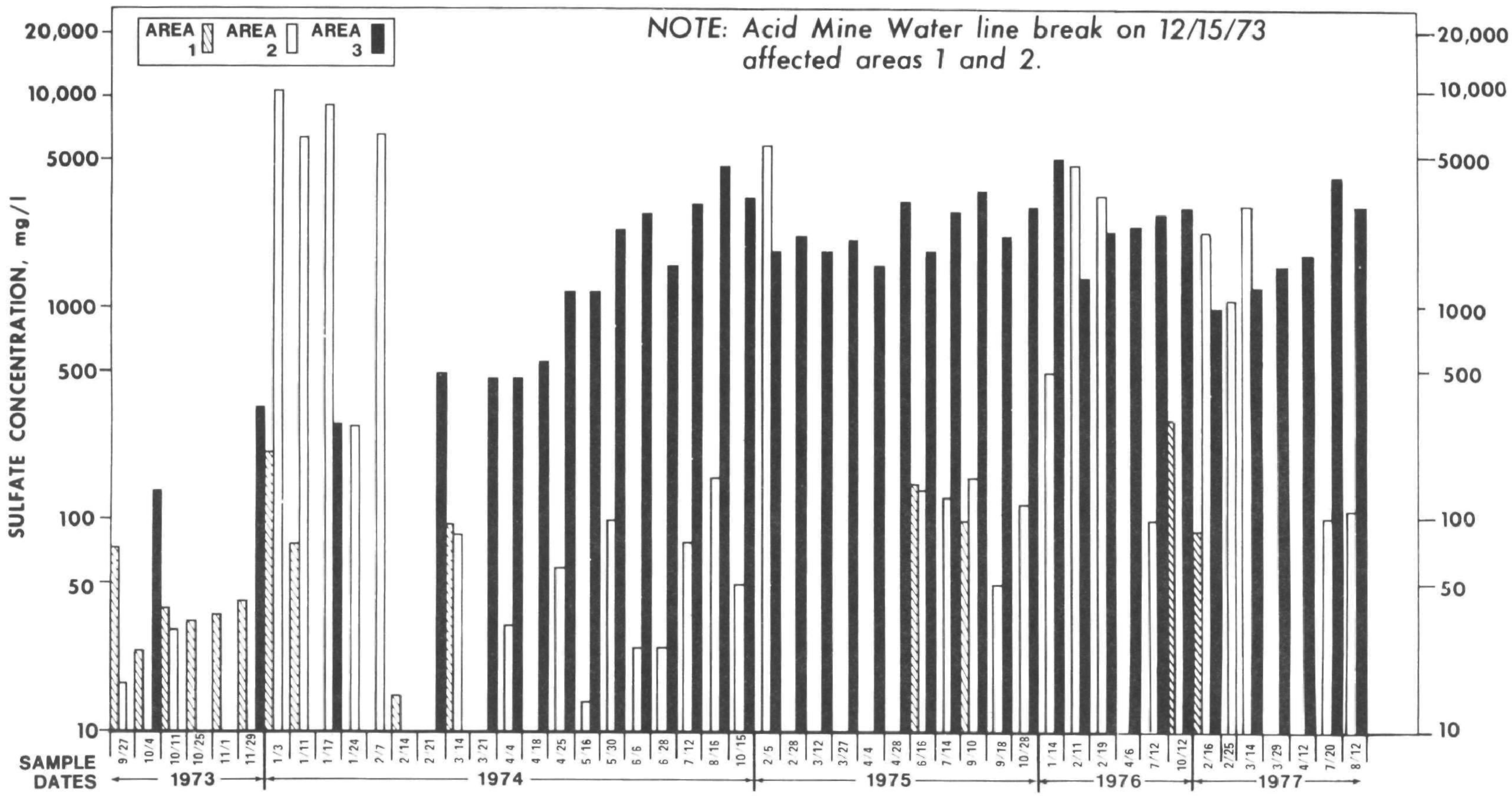

FIGURE 22. Comparison of sulfate concentrations in the effluents from each test area.

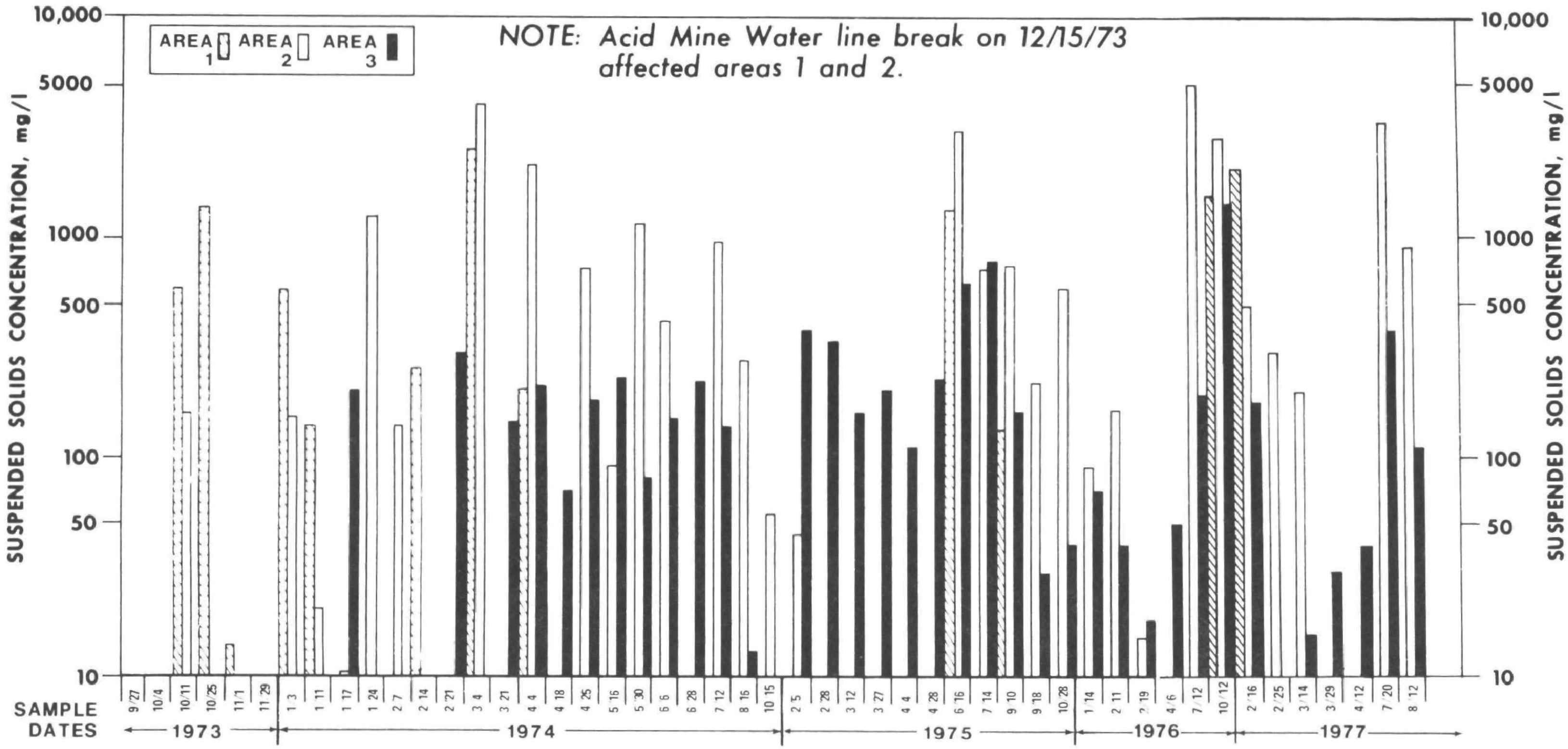

FIGURE 23. Comparison of suspended solids in the effluents from each test area.

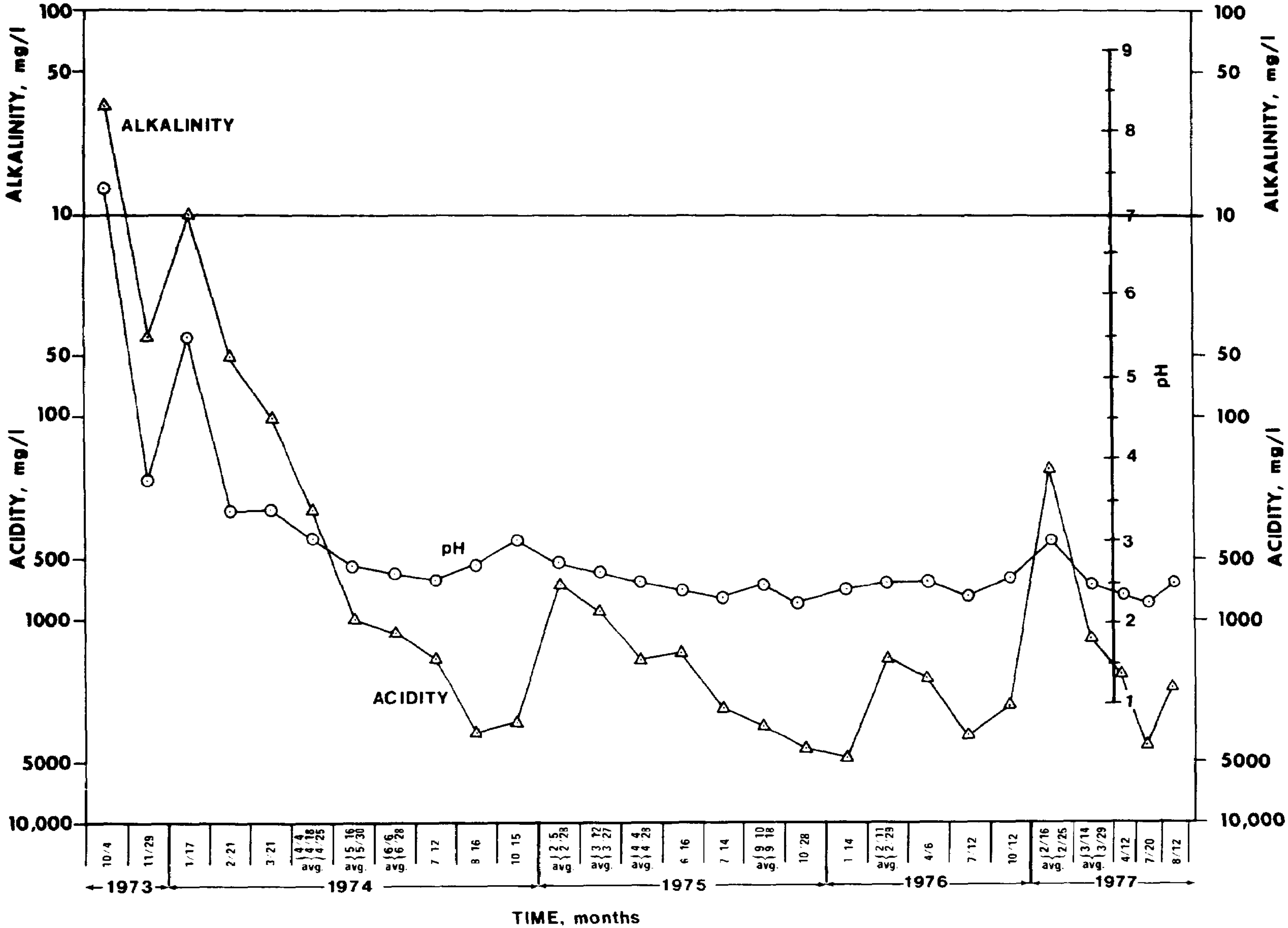

FIGURE 24. Acidity/Alkalinity and pH trends from Area 3 (all-refuse).

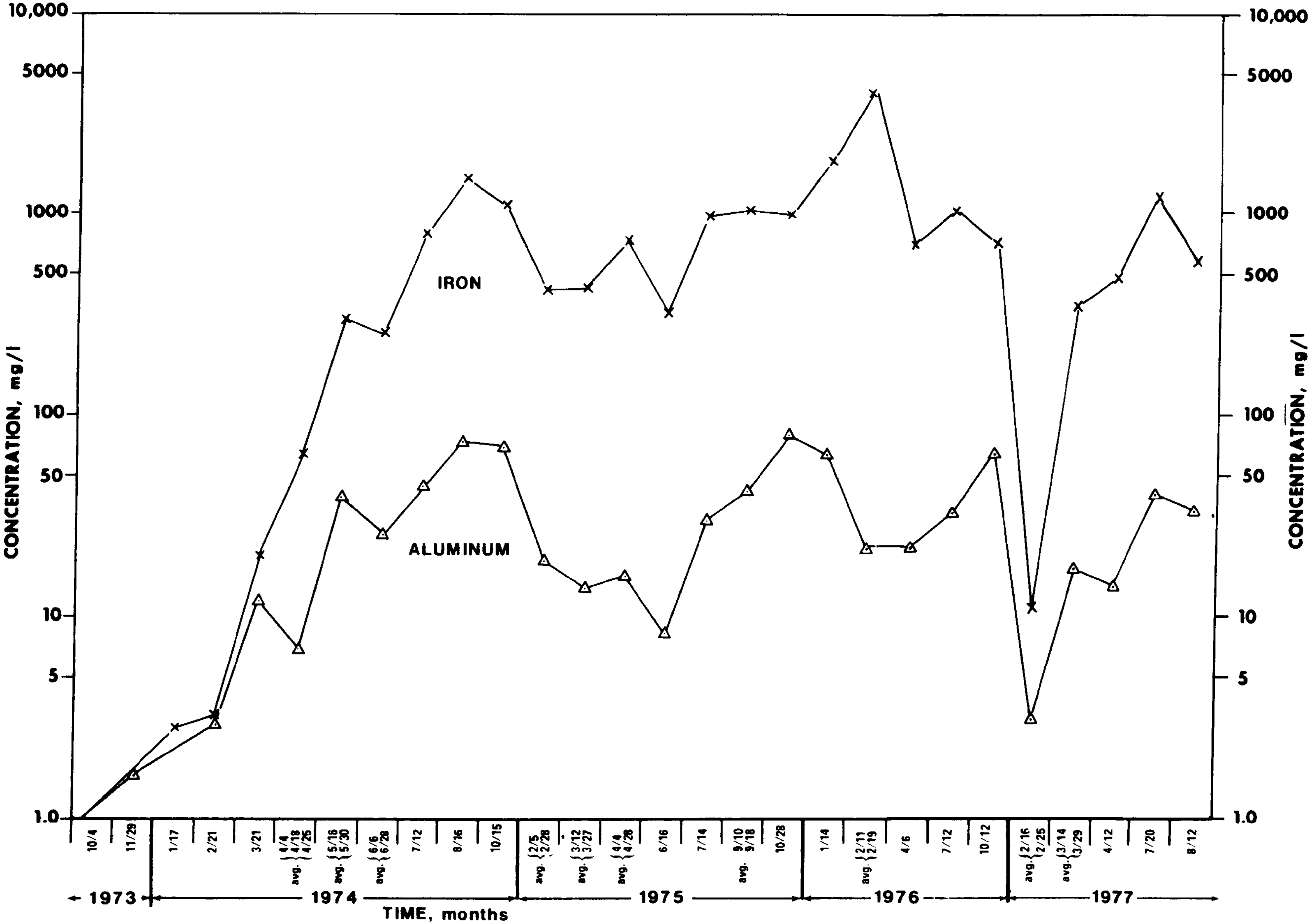

FIGURE 25. Aluminum and iron trends from Area 3 (all-refuse).

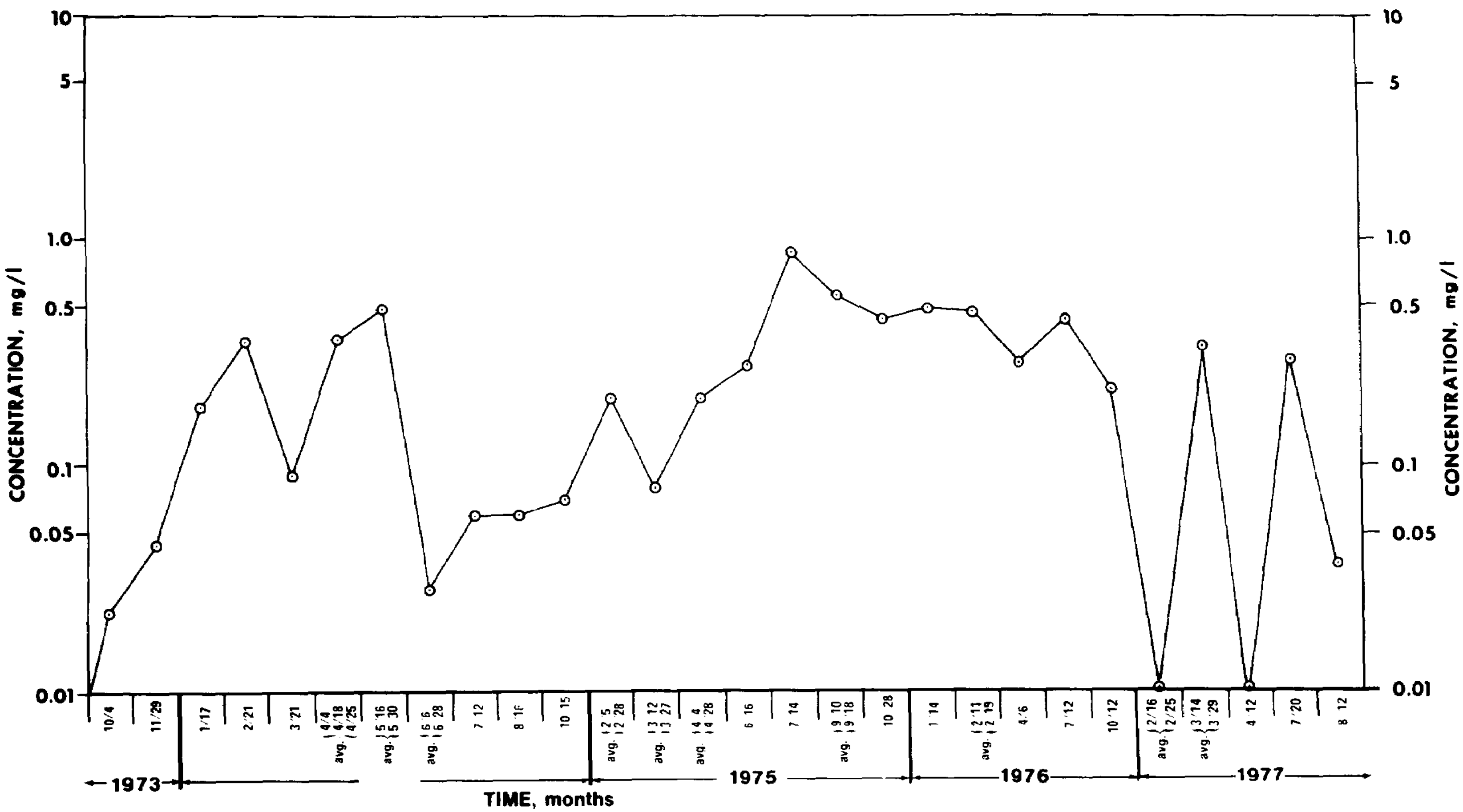

FIGURE 26. Boron trends from Area 3 (all-refuse).

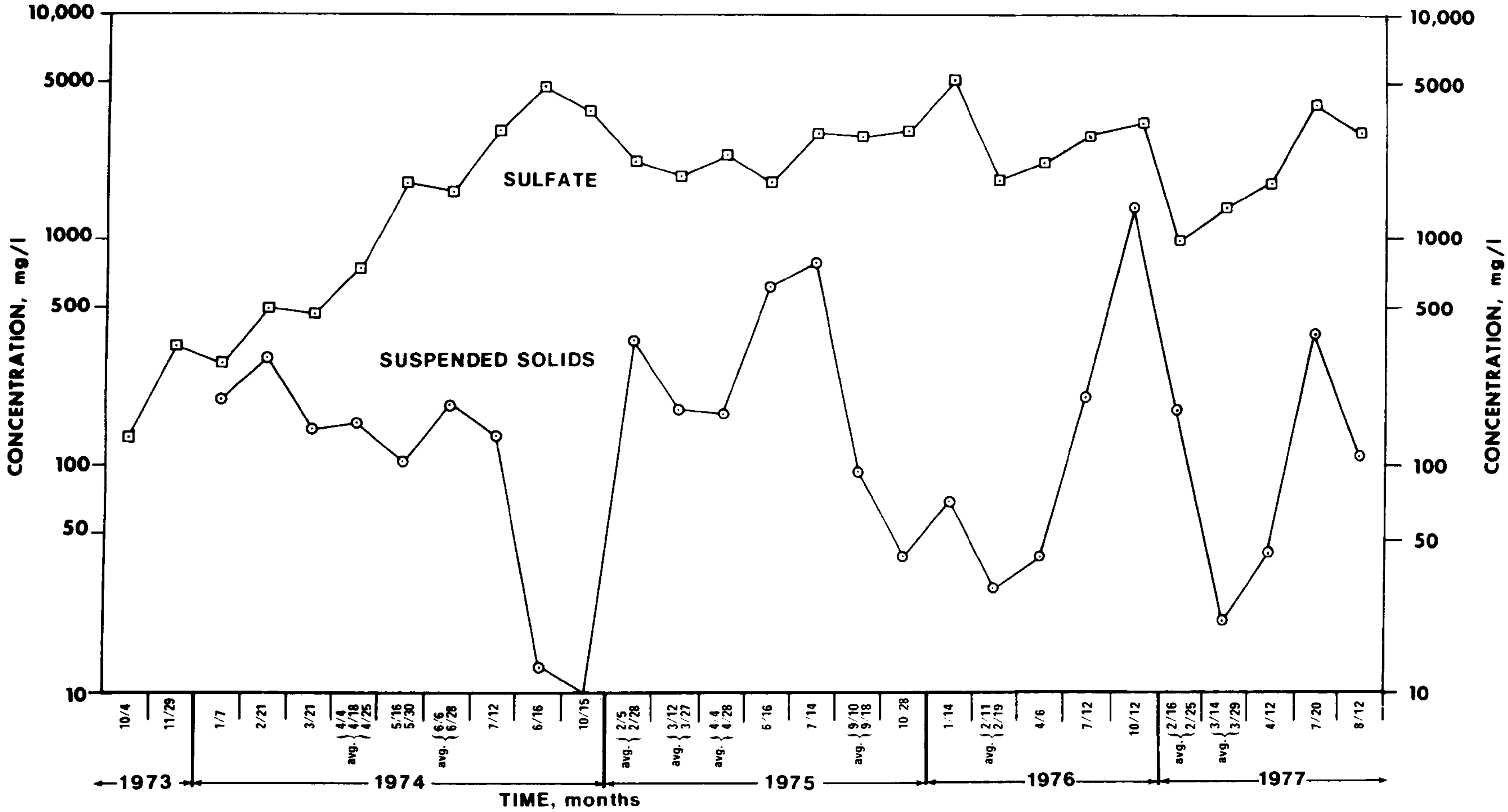

FIGURE 27. Sulfate and suspended solids trends for Area 3 (all-refuse).

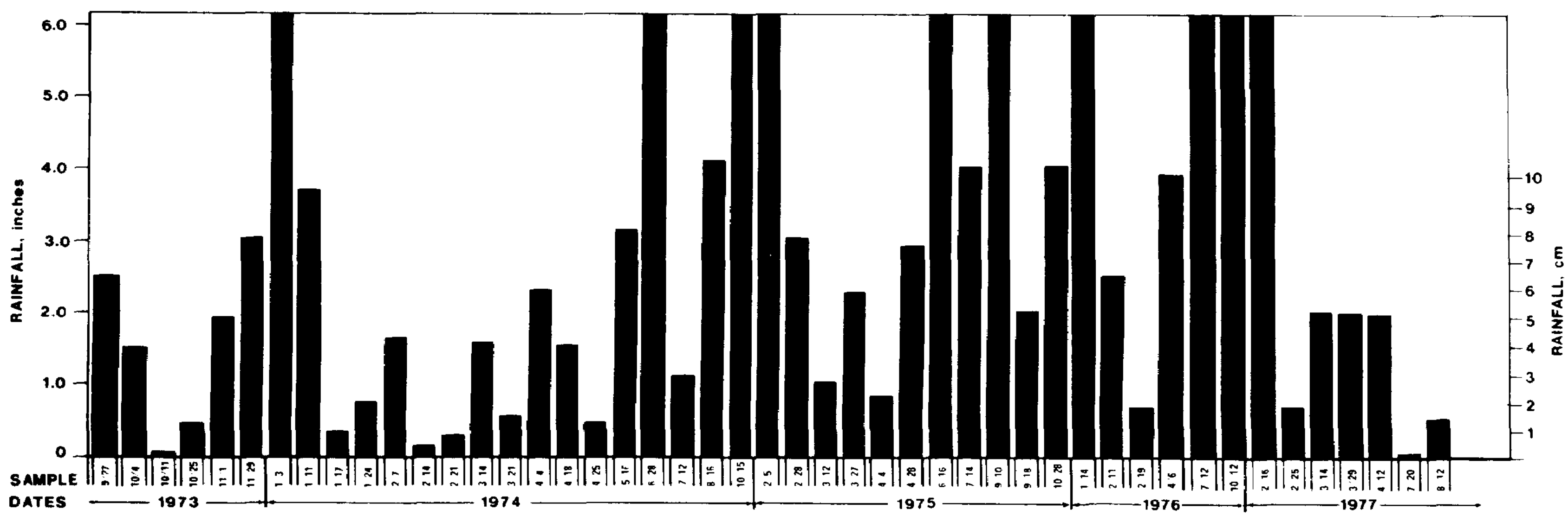

FIGURE 28. Rainfall for each sample date reported as total precipitation from one sample date to the next.

TABLE 5. CHEMISTRY ANALYSES OF WATER SAMPLES FOR SITE C (AREA 1)

Date	pH	Cond.	Acid	Alk	Ca	Mg	Fe^{+3}	Al	Mn	Na	Boron	Cd	Ni	Pb	Zn	Cu	SO_4	JTU	SS
9/27/73	10.75	670	0	70	66	.4	.08	.60	<.01	124	-	-	.10	<.01	.07	-	315	-	-
10/4/73	10.66	258	0	45	16	.2	<.01	.60	<.01	15	.06	-	-	-	<.01	-	32	125	-
10/11/73	7.93	167	0	130	24	.7	<.01	.90	<.01	13	.29	-	-	-	.02	-	42	30	140
11/1/73	10.65	320	0	90	26	1.9	<.01	1.50	<.01	32	.86	-	-	-	<.01	<.01	90	63	22
11/29/73	10.85	440	0	165	40	1.0	<.01	.92	<.01	50	.31	<.01	<.01	<.01	<.01	.05	18	260	-
12/6/73	10.85	165	0	88	32	.4	<.01	.52	<.01	9	.12	-	-	-	-	.03	19	170	220
1/3/74	8.3	650	0	850	60	12	<.01	1.0	.03	135	1.0	-	-	-	.05	-	435	425	1220
1/11/74	7.74	2250	0	500	300	40	.60	1.8	.25	450	3.1	-	.10	.12	.12	.04	1500	120	140
1/17/74	8.25	1750	0	190	200	35	.40	.80	.14	400	3.0	-	.02	.08	.08	.05	1350	75	20
1/24/74	9.37	400	0	175	62	5.6	<.01	<.01	<.01	100	1.5	-	-	<.01	<.01	<.01	281	500	1220
1/31/74	11.0	300	0	180	45	.68	<.01	1.0	.02	22	.40	<.03	<.01	<.01	.04	.03	75	80	143
2/7/74	10.6	420	0	70	55	4.0	<.01	1.2	<.01	50	.50	<.01	<.01	<.01	.06	<.01	188	50	100
2/28/74	8.34	340	0	240	65	5.0	.04	.62	.02	56	.60	<.01	.10	<.01	<.01	.11	54	150	420
3/7/74	8.4	300	0	190	45	3.2	.30	.80	.02	55	.32	<.01	.15	<.01	.08	<.01	75	120	220
3/21/74	9.2	480	0	95	75	3.6	.72	1.6	.06	28	.64	-	.18	-	.12	-	321	80	170

(continued)

TABLE 5. (continued)

Date	pH	Cond.	Acid	Alk	Ca	Mg	Fe^{+3}	Al	Mn	Na	Boron	Cd	Ni	Pb	Zn	Cu	SO_4	JTU	SS
4/4/74	8.3	550	0	100	70	4.3	<.01	.80	.03	35	1.0	<.01	<.01	<.01	.06	<.01	100	275	770
4/18/74	8.1	420	0	50	100	4.4	<.01	.32	.10	45	.85	.02	<.01	<.01	.05	<.01	350	30	90
4/25/74	10.3	185	0	65	32	1.0	.06	2	.08	30	.31	-	-	-	.06	-	84	55	160
5/16/74	7.3	980	0	60	200	8.84	.33	.32	.01	24	1.4	-	.45	.09	.04	-	500	60	300
5/30/74	7.2	1210	6	100	230	14	.10	.9	.16	80	1.7	-	-	-	.05	.03	800	70	870
6/6/74	7.3	1300	0	88	240	12	1.10	.60	.04	26	1.7	-	-	-	-	-	750	35	150
6/28/74	7.4	1480	0	72	250	13	.75	1.2	<.01	25	1.5	-	-	-	.13	-	650	20	90
7/12/74	7.0	530	4	100	90	5	.40	1	<.01	12	.05	-	-	.50	-	-	190	170	604
8/16/74	7.3	350	0	350	45	3.3	.14	.52	<.01	7.6	.12	<.01	<.01	.35	.06	<.01	45	750	304
10/15/74	7.1	300	0	84	64	6.1	5	1.0	.07	3.3	.08	-	-	.40	.14	-	140	80	42
2/5/75	7.9	2700	0	167	450	45	.17	.82	.21	380	5.6	-	.28	-	.02	<.01	2100	4	40
2/28/75	7.6	1260	0	88	465	2.6	4.0	.30	.08	5	.16	-	.20	-	.23	<.01	1100	360	1440
3/12/75	7.6	1140	0	48	412	1.8	1.1	.28	.11	10	.20	-	.39	-	.06	<.01	1000	10	16
4/28/75	7.0	1700	10	44	507	10	12	.28	.38	11	.60	-	.64	-	.46	.01	1350	80	220
6/16/75	7.3	350	0	88	60	28	.21	.40	.10	1.4	.12	<.01	.44	-	.18	.10	170	250	980

(continued)

TABLE 5. (continued)

Date	pH	Cond.	Acid	Alk	Ca	Mg	Fe^{+3}	Al	Mn	Na	Boron	Cd	Ni	Pb	Zn	Cu	SO_4	JTU	SS
7/14/75	8.0	300	0	114	42	1.5	<.10	.40	.10	8.6	.12	-	-	.16	.30	0	130	65	620
9/10/75	2.67	3400	910	0	470	75	80	36	4.9	12	1.2	.04	.44	.33	2.6	.50	1950	650	1120
9/18/75	2.9	2150	450	0	230	50	28	26	2.6	6.5	1.2	.05	-	.34	1.45	.30	1000	160	250
10/28/75	4.46	900	40	0	180	22	<.10	4.8	.72	2.8	.44	.05	12	.30	.45	.06	600	90	220
1/14/76	6.0	1280	20	4	265	17	.20	.56	.36	20	.45	.04	<.01	-	.50	.04	780	40	151
2/11/76	7.1	2500	5	154	340	60	3.5	1.0	.41	400	6.8	.07	.22	.45	.48	.02	1900	170	116
3/23/76	6.2	2000	10	30	700	42	2.5	4.8	.70	350	.52	.10	.40	.60	.70	.01	2700	40	46
7/12/76	7.0	310	0	161	42	3.2	.42	.16	<.05	6.5	-	<.01	.45	<.01	<.01	<.01	30	860	50
10/13/76	3.5	1775	273	0	440	60	.70	11	3.3	20	-	<.01	.97	<.01	1.2	<.01	1425	125	3300
2/16/77	5.3	1220	20	10	200	17	<.05	1.5	.73	60	-	<.01	.39	.67	.57	.06	690	20	500
3/14/77	6.4	4200	10	92	600	75	.50	.28	1.8	400	-	<.05	.46	.44	.42	.07	2675	61	268
4/12/77	7.3	860	0	365	175	25	.10	1.0	<.05	23	-	<.05	-	<.05	.07	<.05	220	>1000	6332
7/20/77	6.9	250	10	90	50	1.8	.12	.40	<.05	2	-	<.05	<.05	<.05	.06	<.05	60	>1000	2628
8/12/77	6.9	168	6	77	110	7.1	6.2	4.8	1.45	2	-	.09	.21	1.4	2.6	.25	103	>1000	3584

All units are expressed as mg/l except for pH and conductivity (micromhos/cm).
Potassium was less than 12 mg/l.
Strontium content generally less than one mg/l.

effluent became suddenly acid with an acidity reading of 273 mg/l and a pH of 3.5. Samples collected in March 1977, showed acidity to be 10 mg/l; pH was 6.4; and iron and aluminum were less than 0.5 mg/l. Similarly, these periods of high concentration of mine drainage occurred after periods of major precipitation. The cause of this spike of acidity in water quality is not really known. It is possible that lateral permeation of surface water through the subbase material could have influenced the momentary degradation of water quality in this particular sample site. If the water were permeating laterally, it might not come in contact with the lime that was placed on the upper portion of the base material. The permeation paths of the water through the voids in the base material were probably in a constant state of flux as ferric hydroxide flocs were formed during contact of the acid water with fresh lime surfaces. This in turn impeded the path of water permeation; therefore, surface water could flow to other areas in the base material and flush out acid water that had been formed previously by pyrite oxidation.

Area 2

The cause of the spike of boron concentrations ranging from 10 to 40 mg/l during successive winter months (1974-77) is not known. It has been reported (10) that a boron concentration above 4 mg/l in irrigation water was generally unsatisfactory for most crops. Experimental evidence concerning the toxicity of boron to livestock water demonstrated that an upper limit of 5.0 mg/l would be acceptable. The recommended maximum concentrations for semi-tolerant and tolerant plants are be 1 and 2 mg/l. (10)

Suspended solids and sulfates ranged as high as 4000 mg/l and 10,000 mg/l, respectively. These high concentrations were not typical of the values for the period of record. (See Figures 22 and 23).

Because of the intermittent slugs of boron, it is felt that the effluent quality from this area would be of questionable acceptability. Generally, the effluents were characteristically neutral or slightly alkaline and had minimal concentrations (less than 7.0 mg/l) of aluminum and iron and less than 1.0 mg/l of boron.

Area 3

The quality of the effluent from Area 3, where the base material was entirely coal mine refuse, continually decreased (Figures 24-27). The pH value of the effluent dropped from pH 7 to near 2.5 and the acidity increased to nearly 5000 mg/l. The aluminum and iron fluctuated from 3 to 50 mg/l and 3 to 5000 mg/l respectively; boron values were less than 1.0 mg/l; and sulfate concentration ranged to 5000 mg/l; therefore, effluent quality from this area would make this area environmentally unacceptable.

Comment

It must be emphasized, however, that the volume of water eminating from these test areas was surprisingly small in all cases. For example, approximately one liter was collected from each sample pipe over a one-month period. In view of the small quantities involved, consideration should be given to applications with better drainage than parking areas.

SECTION 6

DISCUSSION

CONCENTRATION AND LOADS

The sample collection system accumulated a maximum of approximately one liter of water per month per sampling pipe. Each sample pipe collected water from approximately a 39-sq m (420-sq ft) area. This amounts to 0.026 liter/month/sq m.

The base material in this study was poorly drained. The finished grade of the parking lot was even with the existing ground requiring excavation for all material placement. In contrast to this construction, a road would be well ditched and crowned in the center to encourage rapid removal of surface water. In terms of water retention, this parking lot application was probably an extreme-case illustration.

If we use the 0.026 liter/month/sq m drainage rate and apply an extreme-case water quality from Table 5 (i.e., 700 mg/l calcium, 75 mg/l magnesium, 80 mg/l iron, 36 mg/l aluminum, 5 mg/l manganese, 400 mg/l sodium, a total of 10 mg/l of boron, cadmium, nickel, lead, zinc, and copper, and 2000 mg/l sulfate, for a total of 3400 mg/l total dissolved solids, it is possible to calculate the increase in pollutant concentration in a resultant stream from a hypothetical use of fly ash/lime stabilized coal mine refuse as a road base material.

Assuming a 10-km (6.2-mi) road were constructed using lime/fly ash stabilized coal mine refuse as a base material, and further assuming a width of 7 m (23 ft), the total surface area would be 70,000 sq m (753,500 sq ft). If the monthly rainfall were 100 mm (4 in), a total of 7000 cu m (1,850,000 gal) of water would be applied to the road area. At the 0.026 liter/month/sq m percolation rate, 1820 liters (480 gal) of water would result as effluent from the road base material. Assuming the concentration of total dissolved solids in the road base effluent to be 3400 mg/l, the 1820 liters of effluent would discharge 6190 grams of dissolved solids into the 7000 cu m resulting in an approximate hypothetical total dissolved solids concentration of 0.9 mg/l. As previously stated, this is by far an extreme-case illustration.

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16. ABSTRACT

The U. S. Environmental Protection Agency conducted a four-year study to determine the feasibility of using fly ash and coal mine refuse as a road base in a parking lot. The lot was divided into three areas each receiving the same surface treatment but with different ratios of fly ash to refuse. Area 1 was composed of 75-percent coal mine refuse and 25-percent fly ash; Area 2 was composed of the same material as Area 1 with the addition of 5 percent by weight of lime; and, Area 3 consisted solely of coal mine refuse. All areas were periodically monitored and with the exception of Area 3 were found to be environmentally acceptable. Physical structural characteristics of the road base material indicated that these waste products can be successfully used as a base or subbase road material when properly compacted and/or stabilized.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Fly ash Drainage, mines Roadbeds Lime Neutralizing	Coal refuse Road base	13B 50A 50B 68A 91A 91B

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