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FLY ASH UTILIZATION

Proceedings: Edison Electric Institute-National Coal Association-Bureau of Mines Symposium, Pittsburgh, Pennsylvania, March 14-16, 1967

Compiled by John H. Faber, John P. Capp, and John D. Spencer

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
1967

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UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Walter R. Hibbard, Jr., Director

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FLY ASH UTILIZATION

Proceedings: Edison Electric Institute-National Coal Association-Bureau of Mines Symposium, Pittsburgh, Pennsylvania, March 14-16, 1967

Compiled by

John H. Faber,[1] John P. Capp,[2] and John D. Spencer[3]

INTRODUCTION

Over 500 industrial, academic, and government representatives from Europe, Canada, and the United States attended the first large symposium ever held in this country on fly ash utilization and technology, March 14-16, 1967, at Pittsburgh, Pa. Sponsored by the Edison Electric Institute, the National Coal Association, and the Bureau of Mines, the symposium featured 27 formal presentations by leading experts from the United States and Europe on all major phases of fly ash production, utilization, and research. Representing the three sponsoring organizations were Edison Electric Institute, James D. Williamson, The Dayton Power and Light Co.; National Coal Association, James R. Garvey, Bituminous Coal Research, Inc.; and Bureau of Mines, Harry Perry. Symposium chairman was John H. Faber of the Bureau of Mines.

Gerard C. Gambs, Consolidation Coal Co., addressed the opening session. Moderated by Mr. Garvey, President and Director of Research of Bituminous Coal Research, Inc., the opening session was devoted to a discussion of the nature of the fly ash problem, including availability, specifications, and limitations on its use. Subsequent sessions covered fly ash marketing, fly ash utilization in concrete and masonry products, specialized uses, and recent developments in basic fly ash research. Others serving as session chairmen were Oscar E. Manz, Associate Professor of Civil Engineering, University of North Dakota; Mrs. Katharine Mather, Chief, Petrography and X-ray Section, Concrete Division, U.S. Army Engineers Waterways Experiment Station; Mr. Williamson, and Mr. Perry.

During the week of the symposium a group of Fly Ash Experts representing the Economic Commission for Europe (ECE), under the sponsorship of the United Nations, participated in official meetings of the Commission and highlighted one of the symposium sessions. At this session, four members of the Fly Ash Experts group described the ECE's work in fly ash utilization, and current

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[1] Supervisory chemical research engineer.
[2] Chemical research engineer.
[3] Chemical engineer.
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practices in several European countries. Presenting these papers were Z. Falecki, Coal Committee Secretariat, ECE, Geneva, Switzerland; Henry W. G. Dedman, Central Electricity Generating Board, London, England; Adolphe Jarrige, Consulting Engineer (retired), Paris, France; Hermann Erythropel, Chief, Research and Development Department, Steinkohlen-Electrizät AG, Essen, Germany; Antoni Paprocki, Assistant Professor, Institute of Building Technics, Warsaw, Poland; and Dr. Vladimir V. Stolnikov, Chief of the Concrete Laboratory, All-Union Research Institute of Hydrotechnics, Leningrad, U.S.S.R.

Luncheon speakers were Joseph Pursglove, Jr., Vice President-Chemicals, Consolidation Coal Co., Inc., and Harry A. Fisher, Materials Handling Engineer, American Electric Power Service. The latter substituted for John A. Tillinghast, Vice President and Chief Engineer, American Electric Power Service Corp., who was unable to attend because of illness. The Honorable Kenneth Holum, Assistant Secretary of the Interior for Water and Power Development, who was scheduled to address the assemblage at the symposium banquet, was also unable to attend. His remarks were delivered by Robert M. Paul, Water and Power Development, U.S. Department of the Interior.

Sidney Katell, Bureau of Mines, U.S. Department of the Interior, served as toastmaster.

The proceedings of the symposium are given in this report, following the abstracts of all the papers.

Trade names appearing in these papers are solely for purposes of identification and to facilitate understanding. Endorsement by the Bureau of Mines is not implied.

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AVAILABILITY, QUALITY, AND PRESENT UTILIZATION OF FLY ASH

by

C. E. Brackett[1]

In opening a meeting of this nature, I feel that it is well to start out by first trying to define fly ash, which after all is the subject we are about to explore in this symposium.

Fly ash can be defined as a product of combustion, chiefly the product of burning pulverized coal, and to some extent the burning of residual oils in large industrial or power boilers. As pulverized coal is burned, fly ash is formed from the incombustible components in the coal and those particles of coal that are not burned, due to incomplete combustion within the furnace proper. When it is examined microscopically, collected fly ash may be observed to consist of particles varying in shape and size. The average size varies from less than 1 micron to approximately 80 microns and most of the smaller particles are minute, hollow, translucent spheres. In shape, the carbon or carbonaceous particles of the ash vary from slivers to spongy or lacelike entities that can range in size from approximately 10 microns to, in extreme cases, more than 300 microns. These lacelike carbonaceous particles are usually large in size and low in density. Chemically speaking, more than 85 percent of most fly ashes consist of alumina, silica, iron oxide, lime, and magnesia, with the percentage of any one constituent varying over a wide range of values, depending upon the character of the particular ash being analyzed. As the ash particles leave the furnace, they are suspended in the flue gas and, as such, form what can be considered as an industrial aerosol. Figure 1 illustrates how the particle size of fly compares with other familiar industrial aerosols. After the fly ash has been separated from the flue gases, we find that in the bulk state the ash can and will vary greatly, having a wide range of particle sizes and a considerable variation in chemical content. Usually the ash is light gray in color; however, the color can vary from light tan, through the various shades of gray, to that of being nearly black. The tan color is usually associated with the presence of iron oxide, while the darker colors are associated with carbon or, in some cases, with the presence of magnetic iron oxide or magnetite.

As you can see from the above definition, the product we are about to discuss is widely diverse in its physical and chemical properties. This diversity in makeup and the resulting differences in properties have led to many of

[1] Operating manager, Southern Electric Generating Co., Birmingham, Ala.

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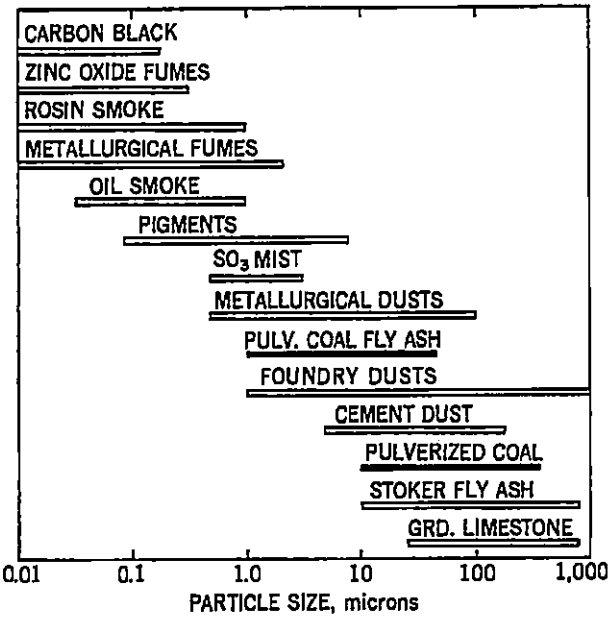

FIGURE 1. - Industrial Aerosols. (From Munger, H. P. and L. C. McCabe (eds.). The Spectrum of Particle Size and Its Relation to Air Pollution. McGraw-Hill Book Co., Inc., New York, 1952, 160 pp.)

the misunderstandings that have placed rather severe limitations on its present commercial use. I feel that, as this seminar proceeds, you will reach the same conclusion that I have held for several years; namely, that we are having to face up to the fact that we are sadly lacing in basic knowledge relating to a product that each of us is dealing with every day. In reality, we have a tiger by the tail in that we have a product that is readily available in many sections of the country and has a great potential, but, in spite of the fact that we have been dealing with this product on a commercial basis for well over 25 years, we are still not able to explain exactly why one ash performs satisfactorily in a particular application while another ash, which is apparently similar, performs differently or on extreme occasions is actually detrimental to the product or process in which it is being used. Even more essential, as far as the coal-burning industries are concerned, is the fact that there are many unanswered questions of a basic nature about why certain ashes seem to be either almost impossible or at best, very difficult, to collect in the electrostatic precipitators, which now must be used to eliminate the particulate matter emanating from our stacks.

Of this we can be sure in 1967 the electric utility industry in the United States is by itself going to produce between 21 and 22 million tons of fly ash and the generation of ash over the coming years will continue to increase until, by 1980 it is estimated that the electric utilities in the United States will produce between 39 and 40 million tons of ash. This amounts to almost twice as much as we are producing today.

The past, present, and projected consumption of coal by the electric utilities in the United States is shown in figure 2. This graph, prepared from data supplied by the National Coal Association, sets forth the coal used by the electric utility industry since 1950 and estimates its continued usage by the utilities until 1980. These figures take into account the lates estimates of the Atomic Energy Commission and various other agencies as to the growing amount of power expected to be produced by atomic powerplants and the possible increase in consumption of lower quality coals necessitated by the increased consumption during the period under study. As far as we can determine, these

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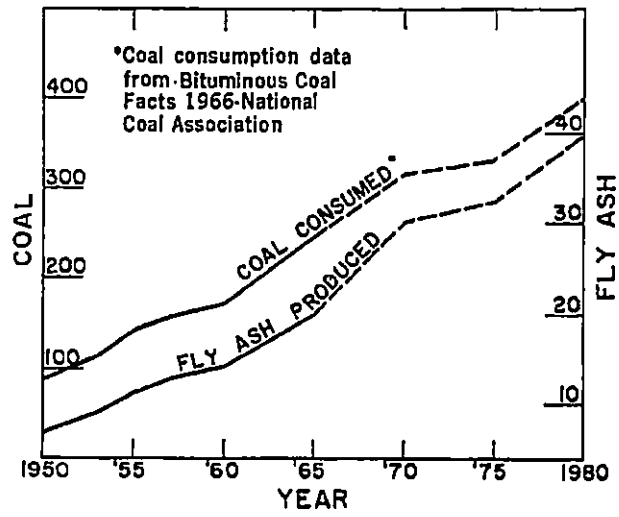

FIGURE 2. - Fly Ash Production by U. S. Electric Utilities.

are the most accurate coal consumption data we have to work with today. We have superimposed on this graph a curve indicating the estimated production of fly ash by the electric utility industry for the same period.

The costs presently associated with the disposal of fly ash at the current production rate of 20 million tons per year are high and, in some rare cases, exceed $2 per ton. When you consider that in 1962 the electric utility industry alone dumped over 8,500,00 tons of fly ash because markets for the ash were unavailable[2], you begin to get some idea of the magnitude of the problem we are facing, particularly in the light of our presently scheduled expansion program. These disposal costs are continuing to rise at an alarming rate, particularly in the large urban or metropolitan areas, and by 1980, they could rise to the point where they will be one of the dominant items of what is rapidly becoming a long list of factors weighing againt the future use of coal as a primary fuel for the generation of electrical power.

In making these predictions of future ash production, I have purposely limited my remarks to the electric utility industry for several reasons:

1. The latest coal consumption figures, which are for 1965, indicate that the electric utility industry consumed 53 percent of the coal burned in the United States, with only 22 percent going to all other industrial installations which might be able to produce relatively small amounts of fly ash. The remaining 25 percent of the coal consumed went into the production of coke and minor uses which had little or no commercial value as far as the production of fly ash is concerned.[3] The above percentages of coal usage have remained fairly constant for the last 6 years, and it is expected that they will remain so for the coming years.

2. The expansion figures for the electric utility industry through the coming years are firmly charted and accurate estimates of coal consumption and resulting ash production can be made.

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[2] Fuel and Ash Handling Subcommittee of the Prime Movers Committee, Edison Electric Institute. Fly Ash Utilization, 1962. EEI Pub. 63-70, 1962, p. 15.
[3] National Coal Association. Bituminous Coal Facts 1966. 1966, 80 pp.

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3. The United States, as shown in table 1[4], is with one exception doing the worst job of all the major producers in the world as far as the utilization of fly ash is concerned.

TABLE 1. - World utilization of fly ash

Country	Production of fly ash in 1965, million tons	Estimated utilization of fly ash in 1965, million tons	Percentage of production
France ---------	9	3.5	40
Germany, West --	4	2.0	50
United Kingdom -	10	2.7	27
United States --	20	°.5	3
U.S.S.R. -------	20	1.3	6

[5] Estimate.

Thus it would appear that the problem to be solved is here in the United States and while we can and should use the tremendous amount of knowledge concerning fly ash utilization that our European friends can impart to us the basic problem of disposal and utilization is ours and must be solved in our own way.

As I stated in the definition of fly ash, it is a product of combustion that is the residue left over from the burning of pulverized coal and, as such, the marketing of it presents many special problems. Essentially, fly ash is, except in a very few specialized cases, either in direct competition with or used as an add-mix or component of many highly competitive bulk products which are basically low in unit price. As such, the price of fly ash or fly ash products, f.o.b. the sites at which they are to be used, must be kept low enough to insure that they are competitive; and in this respect, freight rates play an important part. As a result of present rather high freight rates on fly ash, it is uncommon to find bulk fly ash being shipped over 500 to 600 miles from its point of origin or collection to its point of use. One of the rare exceptions to this statement can be found in our own case where the company which processes and markets our ash is shipping relatively large quantities of bagged ash to South America where it is used in various grouting operations.

From the foregoing discussion, it is apparent that the limitations on the distances which fly ash can economically be shipped is going to affect its availability and that the availability is going to be greatest in those

[4] Gambs, Gerard C. Report on Fly Ash in England, Europe and Soviet Union. Consolidation Coal Co., Res. Div., Library, Pa., July 1, 1966, p. 1.

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large urban or metropolitan areas that are served by electric utilities using fossil fuels to generate power. Table 2 indicates those general areas where the largest coal-burning utilities are located and, as a result of this, where the greatest amounts of fly ash are available. As might be expected, the Middle Atlantic area, which covers the States of New York, New Jersey, and Pennsylvania, and the East North Central area, covering the States of Illinois, Indiana, Michigan, Ohio, and Wisconsin, consume the largest amounts of coal in the generation of electrical energy. These are followed by the South Atlantic, East South Central, West North Central, New England, and Mountain areas, in that order.

TABLE 2. - Coal burned by U.S. utilities, geographical distribution[1]

Geographical area	Net generation		Coal burned, thousand tons	Generation by coal, pct
	Million kwhr	Percent of total		
New England ---------	30,841.9	3.9	8,207	63
Middle Atlantic -----	126,036.7	15.9	40,553	77
East North Central --	196,548.6	24.7	83,570	96
West North Central --	50,045.8	6.3	13,749	50
South Atlantic ------	126,505.3	16.0	39,502	79
East South Central --	88,575.9	11.1	33,902	92
West South Central --	87,483.4	11.0	10	Negligible
Mountain ----------	24,808.2	3.1	6,644	45
Pacific ----------	63,799.0	8.0	None	0
Total ----------	794,644.8	100.0	226,137	65

[1] Geographical areas are as follows:
New England: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut.
Middle Atlantic: New York, New Jersey, Pennsylvania.
East North Central: Ohio, Indiana, Illinois, Michigan, Wisconsin.
West North Central: Minnesota, Iowa, Missouri, Kansas, Nebraska, South Dakota, North Dakota.
South Atlantic: Maryland, Delaware, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida.
East South Central: Mississippi, Alabama, Tennessee, Kentucky.
West South Central: Louisiana, Arkansas, Texas, Oklahoma.
Mountain: New Mexico, Arizona, Nevada, Colorado, Utah, Wyoming, Montana, Idaho.
Pacific: California, Oregon, Washington.

There are several interesting facets concerning the distribution of fly ash, some of which are readily apparent upon studying table 2 and others which are a little more obscure. As stated above, a great proportion of the coal burned in the United States by the electric utilities is consumed in the Middle Atlantic and East North Central areas. Distances between the large utilities are

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relatively short in these areas and, as a result of this, bulk shipments of fly ash can be made available on an economical basis in all sections of these states. In the New England area we find that the total block of power generated is small and that only 63 percent of it is produced by coal-burning utilities; however, the distances are so short that ash from the Middle Atlantic States can be brought into this area and compete favorably with that produced locally. The South Atlantic area is interesting in that, in spite of the fact that large quantities of coal are burned in the generation of power, there are large areas, particularly in the southern peninsula of Florida, where fly ash is totally unavailable and for that matter is an almost unheard-of commodity. However, with the startup of large coal-burning powerplants presently being built on the west coast of Florida, fly ash should start flowing into this high-potential market at an early date. The East South Central States have a number of large utilities that are almost wholly dependent upon coal; the distances are relatively short, thus fly ash is readily available in all parts of this area. The West North Central and Mountain areas are interesting in that the utilities burning coal are relatively few and the distances are great. As a result of this, the availability of fly ash is largely centered in a few widely separated localities. The West South Central and Pacific areas present real challenges to the coal producers and fly ash salesmen due to the fact that practically no power is produced in these areas by coal-burning utilities and fly ash is an extremely scarce commodity that is in demand.

In essence, I feel that this map holds a key for those of us marketing fly ash in the East, and that is this: As we eventually fulfill the needs of the available markets in our surrounding areas with salable fly ash, we are going to have to find economic ways to ship our product into those Western market areas where it is now unavailable and can be used in large quantities. Remembering that we are now utilizing only 6 percent of our total fly ash production, I feel that Horace Greeley's phrase, "Go West Young Man, Go West," not only applied to the young man of his day, but also points the way for today's fly ash marketing experts.

Leaving the subject of fly ash availability and moving to the subject of quality, we find that we are entering one of the most controversial areas surrounding this topic. As stated in the definition of fly ash, the particle size, particle shape, density, color, and chemical properties can and do vary over a wide spectrum of values. Sad but true, the properties that seemingly vary the widest are the very properties which determine the overall commercial quality of fly ash. To compound this problem, we find that the quality of fly ash collected at any one source can and does change from time to time, as conditions within the producing plant change. It has been this past inconsistency in the quality of ash from source to source or from time to time at the same source, coupled with a lack of basic knowledge about fly ash in particular, that has created some of the misconceptions in this country concerning the actual effects the addition of fly ash has on any basic product. In many instances, this lack of basic knowledge concerning our product and our inability to accurately predict its performance have damaged marketing possibilities in certain areas to the point where it has taken years to repair, and, in some particular instances, may never be overcome.

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With these thoughts in mind, what can we say are some of the basic conditions that can and do play a large part in determining the quality of fly ash?

1. The first and most basic ingredient in the formation of any fly ash is the coal that is used as a fuel in the producing boiler. Obviously, the overall chemical content in the total amount of ash produced in any one boiler is going to approximate the overall chemical content of the incombustible in the coal plus a percentage of unburned carbon which is left in the ash owing to the inefficiencies in the furnace itself. The crystalline and/or chemical forms of the incombustible constituents found in the coal and those found in the ash can be and in many cases are, nowhere near the same; however, there is no basic chemical loss of incombustibles in the combustion process. Speaking as a coal producer, I would like to point out that there are really two types of incombustibles or ash found in any raw or processed coal delivered to a consumer:

a. The first of these incombustible particles is generally defined as surface ash and can be divided into two groups:

(1) Those formed by silts laid down at the time the coal was formed which have remained in a definite stratum and are not microscopically associated with the coal particles.

(2) Those that are introduced by the mining process itself, such as pieces of rock that form the mine roof and/or bottom, rock dust, and other extraneous matter loaded concurrently with the coal.

If this type of material is producing a problem for a consumer, a producer can install a well-designed preparation plant that will remove virtually all of it. There is obviously an economic point below which the coal cannot be cleaned before the reject ratio becomes excessively high; however, this type of ash or impurtiy can usually be economically cleaned to the point where only 2 to 3 percent of it remains in the final product.

b. The second type of ash found in coal is called "inherent" or "fixed" ash and is defined as the ash content of the coal that is structurally part of the coal itself and cannot be separated from it by mechanical means. There is nothing the coal producer can do to eliminate this inherent ash because it is unaffected by normal coal preparation processes. The sum of the surface ash plus the inherent ash in a sample of coal is the ash that you see appearing in the normal laboratory proximate analysis.

An example of coal having both surface and inherent ash is the coal mined from our SEGCO No. 1 mine. This mine is producing approximately 1,500,000 tons of coal annually in the Marylee seam of the Warrior Coal field and is located in Walker County, Ala. As found in its natural

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state, the seam varies from 28 to 72 inches in thickness and lays between a shale or sandstone roof and a clay bottom which is primarily kaolin. In addition, the seam has a middleman or parting of rock in various places. As mined, the coal is dirty and must be passed through a washer which rejects 20 to 25 percent of the raw coal as it is cleaned. In this process we reduce the external impurities to a total of approximately 2 percent. However, the catch to this problem is that this coal has an inherent ash content of approximately 12 percent which we can do nothing about. As a result of this, we have not only rejected 25 percent of the material we mined in passing it through the cleaning process, but we still end up with a product having a total ash content of approximately 14 percent.

To compound an already bad situation, a small percentage of the inherent ash is made up of halloysite, which is a form of kaolin. Halloysite is a very efficient insulator and in passing through the combustion process, it changes form but not its properties; and as it leaves the boiler proper and starts to cool, it commences to pick up moisture which in turn causes it to plate out in a thick coat that completely covers and insulates the electrical components of our electrostatic precipitators. This insulating coating makes it a very difficult ash to collect electrostatically.

2. At least two things can be done after the coal has been received at the powerplant to change the overall quality of the resulting fly ash:

a. In preparing the coal for burning, it has generally been conceded that the finer the coal is crushed or pulverized before it is consumed the finer will be the resulting fly ash. There is obviously an economical limit to the fineness that can be obtained with any modern high-capacity pulverizer; however, most pulverizers are designed and guaranteed to produce a pulverized coal product 80 to 85 percent of which will pass a 200-mesh screen and 98 percent of which will pass a 50-mesh screen. Practically and economically we cannot appreciably raise the percentage passing a 200-mesh screen; however, we have found that if pulverizer performance falls much below the guarantee point our ash becomes so coarse that it will fail to pass Government specifications and the percentage of unburned carbon in the ash begins to rise to the point where it becomes excessive. This again becomes uneconomic and, as a result of this, the prudent operator will always try to keep his pulverizers operating at or near the guarantee point, as far as fineness is concerned.

b. The amount of excess air used in the combustion process can be varied. Assuming the fineness of the coal is to remain constant, the ash particles will tend to be smaller and there will be less unburned carbon in the ash if high excess air, 20 to 25 percent, is used. Basically, this is caused by the fact that the actual furnace is somewhat cooler, owing to the larger amounts of gas moving through it, and the small particles of ash, generally speaking, will not remain in the fluid or plastic state long enough to collide with each other and agglomerate into large particles. However, high excess air passing through a boiler can present other problems

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such as excessive power required to operate the fans and excessive fly ash erosion on the various parts of the boiler exposed to the gas stream. This type of operation can also cause an imbalance in furnace temperatures due to the cooler-than-design gas temperatures in the combustion chamber and the resulting movement of high-temperature gases back into the convection passes of the boiler which have not been designed for this type of service. Higher-than-design velocities in the electrostatic precipitators, caused by high excess air, can and will present serious collection problems. As a result of this, the prudent operator will be cautious about using too much excess air and will generally use it only to control a troublesome slagging problem in the furnace.

3. The type of ash collectors used is a significant factor having to do with the quality of fly ash collected. Several years ago the only type of collectors available to the industry were mechanical collectors. These are basically a cyclone or centrifugal type of device that produces a spinning motion in the gas and depends upon the centrifugal force developed to throw the ash particles to the outside of the stream where they can be skimmed off. Obviously, devices of this nature are much more sensitive to the collection of ashes having a high percentage of large dust particles, or only succeed in removing the large and medium-sized particles in a gas stream having an ash content with a distribution of particles ranging from fine to coarse. Basically, mechanical collectors have been developed to the point where guaranteed collection efficiencies will range from 85 to 90 percent on an ash having a high percentage of coarse or medium-sized high-density particles to a low of 50 to 60 percent on ashes having a high percentage of fine particles.

Many years ago it became apparent that mechanical collectors were not efficient enough to allow large high-capacity powerplants to be built in and around large urban areas without becoming at the least a nuisance and at the worst a definite hazard to the surrounding populace because of the ash fallout from the stacks. As a result of this, development was started on electrostatic precipitators, and this type of collector has been refined to the point where it is generally in use on most large powerplants being constructed today. In an electrostatic precipitator the dust-laden gas is passed through a high-voltage dc field and the dust particles take on an electrical charge. The charged particles are then attracted to large collecting plates which carry an electrical charge opposite to that the particles are carrying. In essence, the plates act as large electromagnets. Electrostatic precipitators have several advantages over mechanical collectors in that guaranteed efficiencies of 99+ percent on medium resistivity ash can be obtained. In addition, the draft loss across a mechanical precipitator is in the order of 2 inches of water, whereas the draft loss across an electrostatic precipitator rarely exceeds 1/2 inch, thus greatly reducing the power required to operate the forced and induced draft fans; however, some of this gain is offset by the power requirements of the electrostatic precipitators themselves. Here again the industry is faced with many blank spots or voids in our knowledge of fly ash: Some individual ashes will take an electrostatic charge easily and collect readily, while other ashes, seemingly identical to the first, act as an insulator, refuse to take a charge, and, as a result of this, cannot be

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collected readily. In addition, still other ashes require excessive amounts of precipitator power to obtain the desired collection; these are called "power hogs." While the leaders of the precipitator industry would have us believe otherwise, those of us who are buying precipitators are inclined to believe that the design of electrostatic precipitators is still somewhat of an art, rather than a science, and until such time as we know exactly why the various particles of ash varying as they do from coal to coal react as they do in an electrical field, the industry will continue to have more of the unexplained precipitator failures that have plagued it in the past.

As the utilities have become more and more aware of their roles in the community and with further emphasis being placed on clean air, much money has been and is being expended trying to make our stack effluents "so clean that the Angels will fight to fly through them." In trying to accomplish this, we have tried various combinations of mechanical and electrostatic precipitators in series, superlong and superhigh or double-decked electrostatic precipitators, and now experiments are being performed on pilot precipitators which are using fabric bags as the collection medium rather than electrically charged plates. In a bag type of percipitator the dust-laden gas is drawn through a fabric bag, in much the same process that occurs in your vacuum cleaner. While the draft loss in this process is as high or higher than that experienced in the old mechanical type of collector, I personally feel that the bag type of precipitator presently seems to offer those of us dealing with an ash that is difficult to precipitate a possible means of obtaining 98+ percent precipitation efficiencies.

For those of us using combination mechanical and electrostatic collection, a satisfactory product can be obtained, if careful quality control is observed, by blending the coarse ash obtained from mechanical collectors in proper proportions to the fine ash collected in the electrostatic precipitators.

4. Last but by far not the least, a quality product can be obtained from coarse and inferior ash by mechanical means. In this respect, there are basically two methods at our disposal. One is that of grinding an originally coarse ash until the particles are fine enough to pass the accepted tests; the second is the mechanical separation of the coarse and fine particles.

As far as we are concerned, the mechanical separation process, as applied to fly ash in the preparation of a salable product, holds great promise, and one of the few mechanical ash separation plants in the world is presently in operation at our Ernest C. Gaston Steam Plant located near Wilsonville, Ala. Basically, we burn the fuel and collect the ash. Midway between the collection hoppers and a disposal tank the dry ash is intercepted by equipment belonging to the Southern Fly Ash Co.

Southern Fly Ash Co. is a completely independent company which is in no way connected with the Southern Electric Generating Co. or the Southern Co. System, of which we are a part. As such, Southern Fly Ash Co. has engineered and owns, operates, and maintains all of the fly ash processing equipment, which includes warehousing facilities, a bulk plant equipped to load either covered hopper bottom railroad cars or trucks, a bagging plant, and the mechanical separating facility described below.

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Owing to the difficulties with our ash, that have been described briefly in earlier portions of this paper, the ash is very difficult to collect and, when compared to Corps of Engineers specifications, is of marginal quality when delivered to Southern Fly Ash. By this I mean that only 80 to 85 percent will pass a 325-mesh screen. To correct this problem, Southern Fly Ash has installed a large mechanical separator, shown in figure 3, the basic process

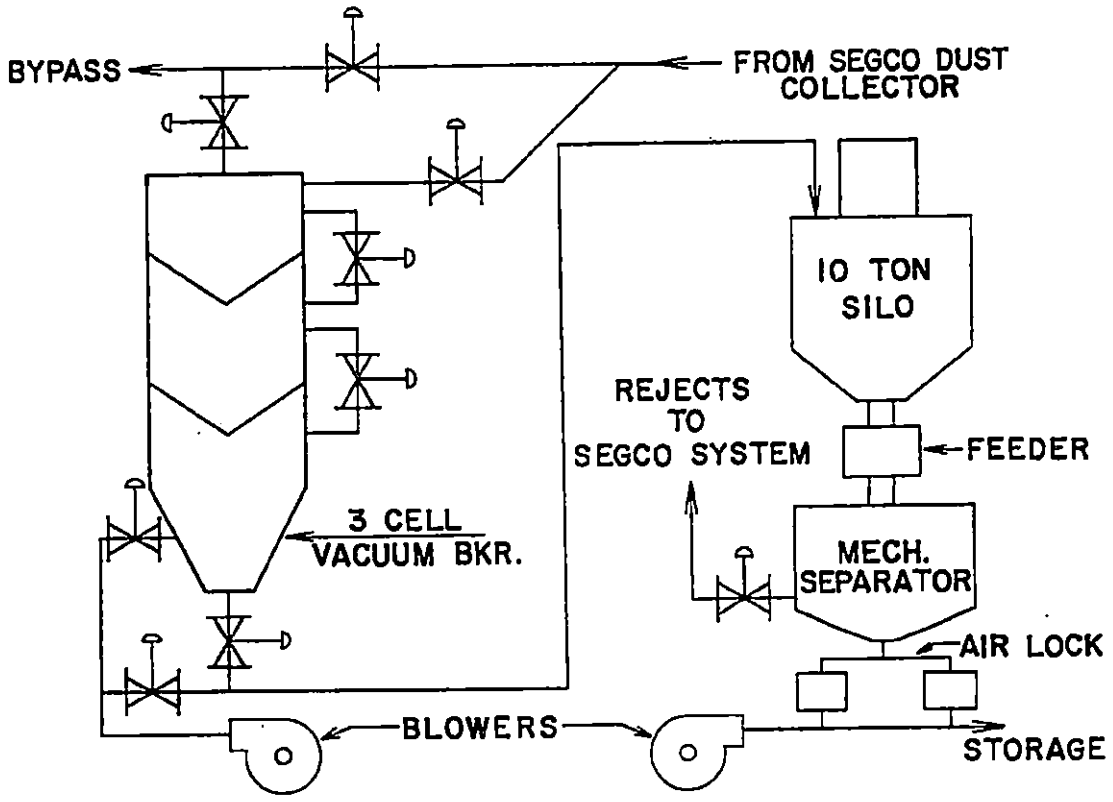

FIGURE 3. - Fly Ash Collecting System.

is shown on the flowsheet, figure 4. In essence, the dry ash is taken from our system under vacuum, raised from a negative to a positive pressure in a three-cell vacuum breaker, blown into a 10-ton holding silo and then fed through a rotary feeder into the mechanical separator. In the separator the ash is passed through sets of whirling and stationary blades, both of which are adjustable, and is picked up on a stream of air. The air velocities inside the separator can be adjusted so that the fine particles are removed and sent to Southern Fly Ash's storage bins and the coarse particles are returned to our system for ultimate disposal. By properly adjusting the mechanical separator, a product can be produced in which 99 percent of the particles will pass a 325-mesh screen. At present Southern Fly Ash is receiving, as stated, an ash of which 80 to 85 percent will pass a 325-mesh screen, and are producing a product for shipment of which 91 to 93 percent will pass a 325-mesh screen. The reject ratio is currently running at between

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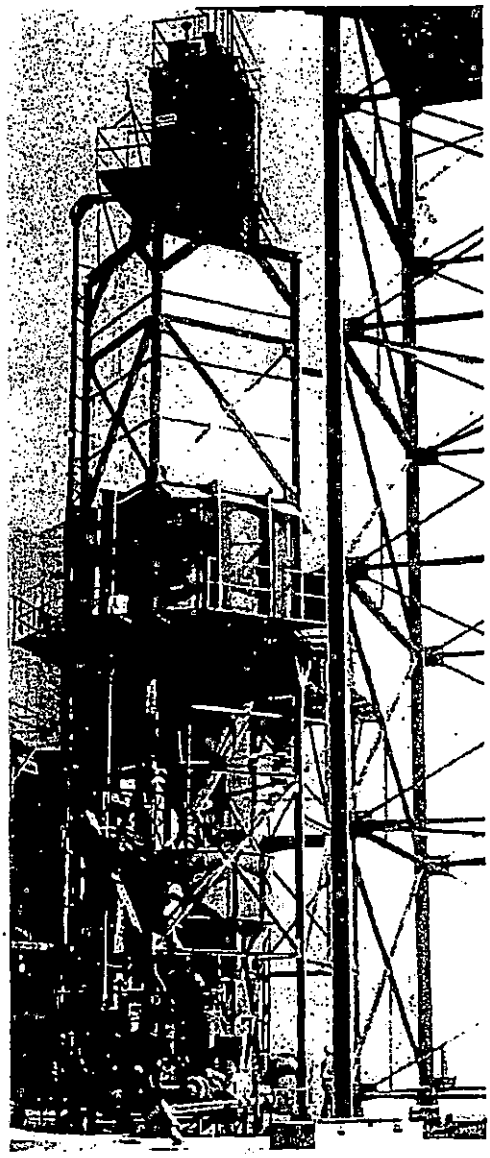

FIGURE 4. - Mechanical Separator Manufactured by Combustion Engineering Co., Owned and Operated by the Southern Fly Ash Co., Wilsonville, Ala., and Used To Produce Large Quantities of High Quality Fly Ash From Ash Originally Having a High Percentage of Coarse Particles.

15 to 16 percent of the material received. In our opinion, the outstanding feature of this type of equipment is that it makes a separation by size without destroying the spherical particle shape which we consider to be most important, particularly when the ash is to be used as an add-mix in concrete.

At present fly ash is used in many and various ways. Many of these uses are highly specialized and are somewhat dependent upon the location in which the ash is produced and sold. A specific example of this would be the production of lightweight aggregate from fly ash. In the large urban or metropolitan centers, such as New York, Philadelphia, Pittsburgh, Detroit, Chicago, etc., where large numbers of high rise structures are under construction, lightweight aggregate is in demand and presents a market having tremendous potential and calling for the use of large quantities of fly ash. However, in our particular area, with its somewhat rural atomosphere, the sale of lightweight aggregate would not result in the use of appreciable quantities of fly ash.

At present the following are the major uses for fly ash in this country.[5]

1. For use as a constituent in concrete. Inasmuch as fly as is a pozzolan, it can and is used to not only replace cement in the mix, but as an add-mix to help or aid in the workability of the concrete mixtures.

By using fly ash as a constituent in concrete, I am also referring to its use when added in the cement making process before the clinker is formed and ground, its use in the manufacturing of concrete blocks, and its use in various types of grouting operations, etc.

2. As an ingredient, not only in the stabilization of the soil used as the base

[5] Fuel and Ash Handling Subcommittee of the Prime Movers Committee, Edison Electric Institute. Fly Ash Utilization. February 1958, 90 pp.

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for roads or highways, but in the strengthening of the base immediately under the paving through the use of mixes such as "Poz-O-Pac."

3. As a filler in asphalt paving.

4. In the production of lightweight aggregate.

There are several small-scale uses for fly ash which have been tried and found successful, such as--

1. An additive for core sand used in foundries.

2. An additive in masonry mortar.

3. A blasting compound. Because of its predominantly spherical shape, fly ash does not cut rapidly when used as a blasting compound, particularly when it is used to clean metal surfaces. Conversely, it does not unduly erode metal surfaces. As a result of this, it can be mixed with sand or other sharp blasting compounds used to clean metal surfaces and a mixture obtained that will clean a surface quickly, yet not damage it due to excessive erosion.

4. For the manufacture of acoustical blocks.

5. As a constituent in heat-insulating cement.

6. As a soil amender; that is, to supply trace elements and act as a soil conditioner.

7. As a filler for several products such as roofing, fertilizer, soap, paper, rubber, asphalt tile, etc.

In addition, several very interesting projects are in progress such as one currently being conducted by West Virginia University's School of Mines in which they are studying the problems associated with making common building bricks of fly ash. In this project they have made satisfactory bricks which consisted of approximately 75 percent fly ash.[6]

In England large quantities of fly ash are being used in structural fills. These structural fills are found on highways, embankments, airport runways, and other mass applications where a stable base is required. When used in a structural fill, water is added to the fly ash in the amount of 18 to 25 percent and the mixture placed in layers 8 to 10 inches thick which are compacted with rollers. To date the highest embankment using fly ash as a structural fill is 80 feet high and this process has been found to be particularly effective when used as a fill near bridge abutments because there is absolutely no sinking of the base.[7]

---

[6] Shafer, H. E., Jr., C. F. Cockrell, and J. W. Leonard. Fly Ash Brick. School of Mines, West Virginia Univ., Coal Res. Bureau Rept. No. 26, Sept. 14, 1966, 14 pp.

[7] Page 4 of work cited in footnote 4.

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In regard to fly ash usage, I have included in this paper figures 5 through 14 which illustrate a few of the many projects in our area which have used fly ash in their construction, supplied by Southern Fly Ash Co. and produced at our Ernest C. Gaston Steam Plant. With few exceptions, I feel that the titles are self-explanatory; however, we are particularly proud of the large quantities of fly ash being used on the various interstate highway projects in the State of Alabama. All contractors working on these projects are using fly ash in all road and bridge construction, as required by Alabama state highway specifications and as approved by the Federal Bureau of Public Roads. We would also like to call your attention to figure 14, which, as indicated, is a picture of Jordan Dam located near Wetumpka, Ala. This is one of the few structures of its kind in which 50 wt percent of the cement has been displaced by fly ash.

In conclusion, I would like to state that this paper was not prepared with the thought in mind of solving all of the problems presently confronting the fly ash industry, but rather to present basic data on the present availability, quality, and use of fly ash. I have also tried to acquaint you with some of the problems which not only face you in the fly ash processing and distributing business, but also those of us in the electric utility or fly ash producing industry, and I have pointed out a few of the alternatives open to us in the solution of some of our problems. Finally, I have tried to emphasize our lack of truly basic knowledge concerning fly ash and the absolute necessity of obtaining these much-needed data before we can continue our progress in the making of scientific determinations of possible new and important uses for fly ash. This basic knowledge will also help us strengthen our position in markets or applications in which we are presently participating. Until such time as we can produce and sell a product which is uniform in quality and predictability, you as fly ash processors and distributors cannot hope to grow to the point where you can dispose of the tremendous amounts of ash that we as fly ash producers will be able to deliver. This ash must, of necessity, be disposed of in a way that is not only efficient but also makes the maximum possible use of a byproduct that has commercial value and is, in reality, a national asset that we cannot afford to waste.

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THE PUBLIC CONCERN FOR ENVIRONMENTAL IMPROVEMENT

by

Kenneth Holum[1]

A few weeks ago, this country passed an historical milestone when President Johnson sent a message to Congress entitled simply: "The Pollution of Our Air." And with this message--which should be completely familiar to all of you--air pollution control moved from the smoke-filled rooms of technical symposiums to stage center in the arena of public discussion, taking its place alongside of water pollution control, scenic preservation and the other major environmental issues in the forefront of our time.

One need only take a quick glance at the newspapers around this country to realize the measure of growing public concern over the question of air pollution. The front page of every newspaper reminds us almost daily that the improvement of our atmospheric environment has become a top-priority national goal.

This change in public attitudes toward the control of pollution has happened so dramatically that many of you may be still asking, "Why have people gotten so concerned lately when we have really done a pretty good job of building waste treatment facilities?"

Actually, this concern about air and water pollution is just one of the manifestations of the public's dissatisfaction with the condition of our present overall environment, and their real fears of what will happen in the future if we do not change our ways. There is no question that we have learned it is no longer enough to just try and save what we have now, and that we must start a greatly expanded effort to avoid condemning future generations to a dreary existence unleavened even by personal memories of clean water, clean air, open space, and the beauty of our natural pastoral landscape.

No parts of the healthy environment we need for survival and growth are more crucial than clean water and clean air. Today's pollution is one of the unwanted legacies of America's growth and prosperity. It is a product in part of early necessity, in part of false notions. One of the false notions was that pollution, if anyone

[1] Assistant Secretary of the Interior for Water and Power Development.

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stopped to think about it, was an unavoidable byproduct of our national growth and prosperity.

In part, this was true. We have had wars to fight, schools to build, food to produce, a whole host of problems to cope with--a host of aspirations to fulfill. Waste treatment meant a lot of money and little glamour. And, besides, there were so few of us, it did not really make much difference if any one stream was polluted or a hillside was denuded by sulfurous fumes.

But now we are meeting ourselves coming back. Now we find the next stream is already being used by someone else. The air over some cities is so befouled at times it causes sickness and threatens our health. Our trash pile has suddenly turned into someone else's living space.

At this point--two-thirds through the 20th century when we know our population will double in the next 33 years, we must ask ourselves again and again--

> What can we do that we are not doing now to protect the areas not yet spoiled by pollution? What can we do that we are not doing now for those that are?

In short, are we thinking big enough about all forms of pollution control? Are we making our decisions on a "can do" basis or are we making those decisions, as has happened all too often in the past, on a "can't do" basis?

At the outset, I believe strongly that we can be confident that air and water pollution control is a goal that we can achieve. And it is no longer an academic or merely desirable goal. Events have made it an imperative goal. Water pollution can be controlled with the knowledge and techniques now available. New knowledge and new techniques are being developed, which will make the job easier in the years ahead.

This realization that pollution can be controlled is the key to our whole effort. The tragic condition of many of the waters of this country is a result of the economic fallacy that we cannot afford to control pollution. Today, there is a wide and growing realization that we cannot afford not to control pollution because the effects of pollution are far more costly than its control.

This widespread public awareness that pollution is more costly than its control has been triggered in an endless number of ways: Perhaps when an industry could not locate where it (or the city trying to broaden its tax base) would have liked to be, simply because there was not enough water of suitable quality; or when a popular beach had to be suddenly closed in the middle of summer, to protect the recreation-seeking public from water-borne disease; or when the people of a great city once richly endowed with clean water were given one too many rationing orders; or when air pollution alarms were sounded, like in New York over the Thanksgiving weekend.

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In any case, I hope that by now none of you have any doubts about the public's desire to improve the conditions under which we must live. Recently one of the most astute political scholars pointed out that "Being prowater and antipollution is today's political equivalent of being for mother and against sin." The American public wants and expects to have pollution stopped and, given the facts, they will get behind any practicable means of doing so. This public understanding that pollution can be controlled will result in far more than just negative or punitive action. Instead, it has already been transformed into positive action on unprecedented scale--support for bond issues, acceptance of individual responsibility for better waste disposal, and, perhaps most important of all, respect and good will toward individual companies and industries that insist on sound pollution control programs.

How is industry responding to this challenge? Inevitably some are doing nothing but hoping the problem will go away or be solved by someone else.

And perhaps just as inevitably, there are a few philosophical descendants of William Vanderbilt who are still saying (but not very loud) "The public be damned."

But the great majority of the leaders of industry have read the signs of the times just as clearly as the political leaders. There was a major speech given a few weeks ago which included this quote:

> Today, we still have the freedom to make a reasoned and resolute response to the problem; tomorrow our actions may be tightly controlled by Government regulations.
>
> If our efforts in this area are made mandatory, not only will we be forced to take more costly and less efficient action, but we will also forfeit our claim to being a responsible segment of society.
>
> To those who say they cannot afford to take effective antipollution measures, I can only respond that they can't afford not to.

Now, if I were to ask you whether this was said by Secretary Stewart Udall, or the President of the U.S. Chamber of Commerce, those who would say Secretary Udall would be wrong. And I'm glad that Mr. Wright, who is also the Board Chairman of Humble Oil, is so clearly charting the right course for enlightened private industry.

Pittsburgh is a particularly appropriate area to consider the costs of cleaning up--and the costs of not cleaning up. No other city has had as much experience with both sides of the equation. If we took a poll of people walking outside this building, I doubt if we could find anyone who would not agree that the money spent to improve the environment around the Golden Triangle was the best investment this area has made--not only in control of air and water pollution, but in the outstanding "land pollution" cleanup at the junction of your rivers.

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This mention of land pollution brings us back to fly ash--the subject of your conference. The spoil banks left by strip mining create a strikingly ugly blot on the landscape that is all out of proportion to the percent of land stripped. Earliest possible revegetation is a prime requirement, and a great deal of planting has been done; but there are serious gaps in reclamation that need more attention, particularly along streams, roads, and highways. As a result, we are extremely interested in your report that raw fly ash can be used as an admix with acid spoils and acid soils to produce better and faster plant growth.

And to demonstrate again that all pollution problems are interrelated, any discussion of coal mining and fly ash should encompass power generation and its problems of air pollution and the pollution of water by wasted heat.

The generation of electric power is responsible for a third of the 130 million tons of contaminants that are released to the atmosphere from the combustion of coal, petroleum, and natural gas.

The generation of power with coal currently represents about one-half of the total coal production and is the most rapidly growing market that the coal industry can point to. But effective air pollution controls will have to be developed if the coal industry is going to capture its share of the sixfold increase in power generation that we will need by the end of the century. And you cannot wait much longer.

In many localities, new or proposed regulations for air pollution control will place limitations on the chemical analysis of the fuels that can be used. Last December the Department of Health, Education, and Welfare served notice of its intent to issue standards for sulfur oxide emissions to be applied to fuels used at Federal installations in New York, Chicago, and Philadelphia, to be effective by October 1968.

If coal is to continue to supply its present portion of these markets, some method must be used to reduce the sulfur content either before the coal is burned or from the products of combustion. Scientists are working hard to conquer this problem. At the moment, I am told our brightest hope for a breakthrough in sulfur control lies in removing the oxides from stack gases at temperatures close to those at which the waste products of combustion are discharged into the atmosphere. So far no process has been proved on an industrial scale. However, some processes show promise. The alkalized alumina process developed by the Bureau of Mines and now being pilot tested is designed to produce elemental sulfur from the oxides in stack gases; and if it is proven successful, we should have an additional source of sulfur, which is in short supply.

The utility industry is only beginning to realize the magnitude of the water conservation and thermal pollution problems it will have to solve soon. Although cooling towers use only 1 percent of the water needed for one-pass circulation and contribute

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little to thermal pollution, they are not yet considered "standard equipment." But the time is coming--perhaps sooner than we now realize--when the cost of cooling powerplant discharges will be just as much part of the costs of doing business as providing transformers and transmission lines.

Technology already has reduced thermal pollution and promises to reduce it further. We are using far less heat per unit of electrical production today than 25 or 30 years ago--about 10,000 Btu per kwhr on the average today compared with 16,500 Btu per kwhr in 1938, and the FPC suggests that average heat rates of 8,500 Btu per kwhr are likely by 1980. This will reduce potential thermal pollution by almost 20 percent. Air cooling and, ultimately, new methods of power generation may eliminate thermal pollution. But future hopes are no substitute for eliminating critical heat pollution problems at existing plants and for better planning and location of new generating facilities so that heat pollution problems can be anticipated and avoided.

One last problem should be stressed--the growing demand that scenic and esthetic values be taken into account in planning power facilities--both in the design of powerplants and the routing of power lines. The President has already recommended that Congress appropriate funds to enable the Interior Department to conduct a program of research and development in underground transmission. We also have Project Badger, a research program looking into faster and cheaper methods of tunneling for a variety of purposes, not the least important of which is placing transmission lines underground--although Project Badger and our underground transmission research programs are separate programs.

In conclusion, I want to assure you that the Department of the Interior, like the other Federal and State agencies that are playing essential roles in the fight against pollution, is fully committed to this battle. We are convinced that sulfur and other pollutants will ultimately be controlled and that their control will be achieved without adverse effects on our energy economy. We believe that this can be accomplished to a large degree by advancing technology, supported by an adequate research effort and through the efforts of the industries that have already demonstrated a willingness to meet their public responsibilities. We are confident that, working together, Government and industry can come up with answers to our pollution problems--answers that are urgently needed, so that we can meet our responsibilities--not only to the American public today, but most importantly to our children and to the generations who will follow them.

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Georg O. Bergemann

Georg O. Bergemann, a native of Richmond, Va., enrolled at Virginia Tech at Blacksburg and graduated in 1963 with a degree in Building Construction. During college, Bergemann was associated with Allis Chalmers, Southern Railway, and several consulting firms. Shortly after graduation, he joined Intrusion Prepakt as a field engineer and is presently assigned to the Cleveland Regional Office as District Engineer.

Charles E. Brackett

Charles E. Brackett, Operating Manager, Southern Electric Generating Company, obtained his B.S. degree in Mechanical Engineering from Iowa State College and studied advance mathematics at Texas Tech, Lubbock, Texas, and Cambridge University, Cambridge, England. Mr. Brackett has a distinguished record of service during World War II in the United States, Canadian, and British Air Forces. His professional experience includes employment at Babcock & Wilcox Company and Link Belt Company as design engineer, engineer on the staff of the Georgia Power Company, and nuclear powerplant test engineer, plant testing engineer, and since 1965, Operating Manager, Southern Electric Generating Company. He is a Registered Professional Engineer in Alabama, Georgia, and Michigan; a member of the ASME, AIME, Engineering and Operating Section and Production Committee of the Southeastern Electric Exchange, and Chairman of its Clean Air and Water Task Force Committee; Prime Movers Committee of the Edison Electric Institute; Vice-Chairman of the Fuel and Ash Handling Sub-committee; Chairman of the Southern Company Production and Engineering Committee; and member of the Southern Company System Committee on Water Control.

John P. Capp

John P. Capp graduated from St. Vincents College with a B.S. degree in Chemistry in 1943. He served with the U.S. Army 8th Air Force during World War II, after which he returned to civilian life as Chemist with the U.S. Bureau of Mines. He has been associated with various Bureau programs, including underground gasification of coal; synthesis of abestiform minerals; development of analytical methods for tantalum, niobium, and titanium; and fly ash utilization.

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James R. Garvey

James R. Garvey, President and Director of Research, Bituminous Coal Research, Inc., received a Bachelor of Engineering degree in Mining from the Ohio State University in 1941. He joined Bituminous Coal Research, Inc., in 1946 as Development Engineer, rising to Director of Research in 1958 and President in 1963. Mr. Garvey is a member of the American Institute of Mining, Metallurgical and Petroleum Engineers; and American Society of Mechanical Engineers. He is a past chairman of the AIME Utilization, Combustion, and Session Program Committees; Vice Chairman of the ASME Committee on Bulk Solids Flow; and member of the American Mining Congress Committee on Coal Preparation. Mr. Garvey holds several patents on coal-combustion equipment, is the author of many professional papers covering research and engineering applications in these fields, and the recipient of awards for outstanding work in his field.

Joseph A. Hester

Joseph A. Hester has been with the Alabama State Highway Department for more than 30 years. He has served the Department as Chief Chemist, Research Engineer, and Assistant Testing Engineer and has been closely associated with the Department's program to incorporate fly ash in highway construction throughout the State of Alabama. Mr. Hester is a graduate of Auburn University with a B.S. degree in Chemical Engineering. He is author of several papers on the use of fly ash in highway construction.

Kenneth Holum

Kenneth Holum, Assistant Secretary, Water and Power Development, U.S. Department of the Interior, attended public schools in South Dakota and holds a Bachelor of Arts degree from Augustana College, Sioux Falls, S. Dak. He served the South Dakota Legislature from 1949 through 1953, was a candidate for the United States Senate in 1954 and 1956, and was a member of the Missouri Basin Survey Commission, appointed by President Truman, in 1951-52. The Honorable Mr. Holum also served as President, Mid-West Electric Consumers Association, January to July 1957; Executive Director, July 1957 through Jan. 15, 1961; and Chairman, Western States Water and Power Consumers Conference, 1956 through Jan. 15, 1961. He has served at his current position since January 1961.

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ENVIRONMENTAL CONTROL IMPLICATIONS OF GENERATING ELECTRIC POWER FROM COAL

TECHNOLOGY STATUS REPORT

VOLUME I

ENVIRONMENTAL CONTROL-
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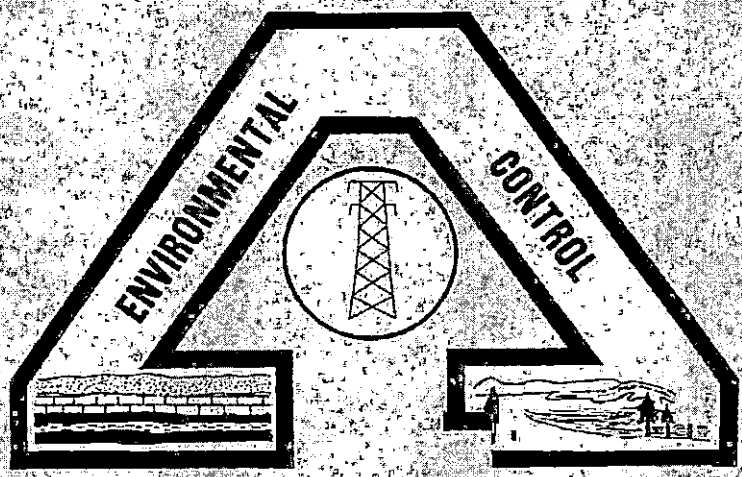

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ENVIRONMENTAL CONTROL IMPLICATIONS OF GENERATING ELECTRIC POWER FROM COAL

TECHNOLOGY STATUS REPORT

Volume I

December 1976

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FOREWORD

A continuing assessment of "Environmental Control Implications of Generating Electric Power from Coal" is being carried out for the Division of Environmental Control Technology in the ERDA Office of Environment and Safety by Argonne National Laboratory and a number of subcontractor companies. This report is the first in a series of reports to be issued under the program and represents efforts from inception of the program in March, 1976 through December, 1976. The primary emphasis in this initial report is on the characterization and evaluation of existing and near-term technologies for coal utilization. Environmental regulations and the health effects of pollutants are also reviewed.

Volume I of the report is a condensation of the technology descriptions and evaluations. It also includes recommendations for research and development activities identified by the study thus far, and an executive summary. Reference citations have been omitted from this volume in the interest of brevity and readibility.

Volume II of the report contains much more extensive and detailed technology descriptions and evaluations. The appropriate reference citations are included to identify source materials, with a list of references presented at the end of each major topic.

N. F. Sather, the Program Manager, and K. E. Wilzbach had overall responsibility for preparation of the report. Other participants in the work were:

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EXECUTIVE SUMMARY

The continued and expanded use of coal for the generation of electricity in the United States is generally accepted as a certainty. This is due in large part to the oil and natural gas shortages experienced in recent years coupled with the existence of vast U.S. coal reserves. However, if this coal utilization is to take place without significant social, environmental and public health impacts, effective control technologies for power plants must be developed and implemented in order to achieve acceptable levels of airborne, waterborne, and solid waste effluents. This is the first in a series of reports evaluating such control technologies from an in-depth engineering and cost point of view. The evaluations take into account both the direct and indirect environmental and economic impacts of coal utilization, as well as other relevant factors such as reliability, the time frame for development, and the availability of required resources. Primary emphasis is placed on currently available technologies, but those expected to achieve commercial status in the near future are also analyzed. The report was prepared by the Environmental Control Technology Program at Argonne National Laboratory for the Division of Environmental Control Technology of the U.S. Energy Research and Development Administration.

Motivation for the control of power plant effluents is provided largely by deleterious health effects due to many of those substances, particularly those which are airborne. Although this is an area of intense and continuing study, the precise nature or extent of the effects has not yet been determined in most cases. There are many difficulties related to heterogeneities in the exposed populations, quantification of received doses, measurement of biological response, and transference of animal experiment results to humans. However, enough is known for the following conclusions regarding the primary air pollutants to be made:

- Sulfur dioxide (SO_2) is an irritant for sensitive tissues, but the effect is mild for realistic dose ranges. Co-irritant effects have been noted. Carcinogenic effects may be caused by SO_2 alone or through interactions with other agents. Lung clearance mechanisms may be affected.
- Nitrogen dioxide (NO_2) is the most important of the nitrogen oxides (NO_x). It is a strong irritant and is also capable of inhibiting lung clearance mechanisms. Carcinogenic effects may arise from NO_2 alone or through interactions with other substances.

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- Particulates cause damage through deposition in the respiratory tract. Their effects may be magnified by the actions of adsorbed irritants, such as SO_2, and toxic trace elements from coal.
- Other pollutants of concern include carbon monoxide, ozone, and various hydrocarbons.

Regulations have been promulgated at various levels of government for the purpose of controlling air pollution. Some of the most important are included in the State Implementation Plans (SIPs) aimed at attainment of the National Ambient Air Quality Standards (NAAQSs) set by the EPA. Most of the SIPs rely upon emissions limitations, but other methods such as fuel sulfur content limits and ambient air measurements are also used. A number of states specify more stringent standards than the NAAQSs, and some have regional variations.

All new power plants must also conform to the federal New Source Performance Standards (NSPSs), which are based on the use of the best available control technology. These represent the most stringent regulations in many areas of the country. At this time, there are NSPSs for particulates, SO_2, and NO_x, all expressed in terms of pounds of pollutant per million Btu of heat input.

Compliance with the applicable regulations has generally been achieved for airborne particulates and NO_x. However, SO_2 control has been more difficult to attain, with about 43% of the coal burned for the generation of electricity in 1975 not meeting emission regulations.

Wastewater effluents from power plants are presently regulated by numerous mechanisms. Additionally, new standards corresponding to the best practicable control technology currently available (BPCTCA) and the best available technology economically achievable (BATEA) must be met by July 1, 1977 and July 1, 1983 respectively.

In view of the compliance situation, SO_2 control technology is obviously of high priority. A number of techniques are available for use, either singly or in combination. The most desirable mix will depend upon the applicable regulations, fuel availabilities, power plant type, and a number of site-specific factors.

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Many utilities have been switching to low sulfur coal, most of which is found in the western states. This coal has different characteristics from eastern and midwestern coals. Some of the salient factors are:

- Existing boilers may have to be derated for use with low sulfur coal due to its lower calorific value, higher moisture content, greater hardness, and incomplete combustion problems.
- Greater volumes of coal must be transported, stockpiled, and handled in-plant. Ash disposal systems must be enlarged.
- Particulates collection is affected since electrostatic precipitator efficiencies are lowered.

Low sulfur coal delivered costs for 1985 have been estimated for both eastern and western sources. The market boundary between coals from the two regions was found to be along a line running from Mississippi northeast through Ohio and into upper New York. Costs along that boundary were on the order of 125 cents per million Btu.

For coal higher in sulfur, there are various physical cleaning processes which can remove some of the pyritic sulfur as well as a large part of the ash. This not only lowers the sulfur content, but produces a more uniform fuel, reduces handling and transportation costs, improves combustion efficiency, and lowers ash disposal costs. Current cleaning techniques may be grouped into five levels, with the higher levels generally processing finer coal fractions and achieving greater sulfur removal with correspondingly higher costs. Constraints on sulfur reduction include the organic sulfur component (not removed by cleaning) and technical difficulties in processing ultrafine particles.

Costs for coal cleaning to meet emissions standards were recently estimated to range from 0.5 to 2 mills/kWh. For comparison, the incremental costs for lime/limestone (L/LS) flue gas desulfurization (FGD) were estimated at 4-6 mills/kWh. However, under some circumstances the optimum choice may be a combination of cleaning and FGD.

The feasibility of achieving efficient SO_2 removal with both high and low sulfur coals through FGD has been demonstrated at a commercial (>100 MWe) scale, but concerns still exist regarding reliability, costs, and waste disposal problems of the systems. By far the most emphasis in the U.S. has been

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on wet, throwaway processes using lime or limestone. The major problems have been plugging of components due to deposition of solids and corrosion or erosion of pumps and linings. Thus far, only two large-scale systems (>100 MWe) have achieved operating reliabilities of 80% or more for a year, although some new systems have reported high reliability.

Regenerable systems producing sulfur or sulfuric acid for sale are under development, but none have been operated satisfactorily in the U.S. The double alkali process avoids some of the operating problems of L/LS scrubbing, but the regeneration step produces the same undesirable sludges.

Current FGD cost information is as follows:

- Capital costs for LS scrubbing on a new 500 MWe plant using 3.5% sulfur coal range from $70 to 100/kW. At a 0.80 load factor, incremental power costs are 4-6 mills/kWh.
- Estimates for regenerable FGD range ±25% from those for L/LS scrubbing.
- Annualized costs for retrofitted systems are increased due to the decreased plant lifetime remaining. Low sulfur or cleaned coal may be a better choice in such a case.
- Critical cost factors include system size, fuel sulfur content, required redundancy, process energy use, and new versus retrofit installation.

Deployment of FGD is lagging behind the EPA estimates of scrubbers needed by 1980 (90,000 MWe). Only 17,358 MWe of capacity will be served by FGD in the East by 1980, whereas 93% of the noncomplying utility coal was burned there in 1975.

The control of airborne particulates has not been a major problem in most cases. Primarily through electrostatic precipitation (ESP), more than 90% of the fly ash produced is now collected. ESP installations have generally performed well, and impose only a modest energy penalty on operation (~0.3% of plant capacity for 99% collection efficiency). Total costs (based on a 68% capacity factor) are estimated to be ~1 mill/kWh.

However, the use of low sulfur coal produces high resistivity fly ash that is more difficult to collect than that from high sulfur coal. Larger ESP units are required, and the costs may be approximately twice those of units for high sulfur coal. Also, there is a possibility that new regulations

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may be placed on fine particulates (<1 μm in diameter) which fall in the range of minimum operating efficiency for ESP.

To cope with these problems, fabric filters (baghouses) have been receiving attention. They are higher in maintenance costs than ESP and impose a greater energy penalty. However, they have achieved overall collection efficiencies greater than 99.8%, independent of ash resistivity and largely independent of particle size.

Wet scrubbers do not appear promising for particulates removal, except perhaps for combined installations, removing both SO_2 and particulates.

Nitrogen oxides (NO_x) are another class of pollutants formed during combustion. They are formed by fixation of molecular nitrogen in the air at high temperatures (thermal NO_x), and by oxidation of chemically bound nitrogen in the fuel (fuel NO_x). Control of NO_x has been achieved through combustion condition modifications. Current methods include:

- Low excess air (LEA) firing. NO_x reductions of 20% are possible with excess air reductions of 10%. There are negligible operating cost penalties and retrofit capital costs of $.55/kWe.
- Staged combustion uses both low oxygen concentrations and low flame temperatures. Reductions in NO_x of up to 45% are possible at costs comparable to those for LEA firing.
- Flue gas recirculation also lowers temperatures and available oxygen but is less effective than the previous two methods and more expensive.
- New burner designs have shown potential for major NO_x reductions and will probably be the preferred approach for new units.

A number of flue gas treatment processes are under investigation for additional NO_x control if it is needed. These fall into four classes, characterized by chemical absorption, physical adsorption, catalytic processes, and noncatalytic processes such as selective reduction. Costs are expected to be a least a factor of 10 higher than costs for combustion modifications.

Many of the preceding techniques for flue gas cleaning exacerbate yet another problem -- solid waste disposal. The disposal of ash alone involves potential problems of surface and subsurface water pollution, primarily through the leaching of toxic chemical elements from the ash. Control methods include prevention or diversion of surface and subsurface water flows, proper

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drainage, and development of vegetative cover. However, ash does not readily support plant growth. In general, the problem can be managed by careful monitoring and employment of available technology.

The wastes from L/LS scrubbing, often combined with fly ash, present a more difficult problem. A new 1000-MWe plant with LS scrubber and using coal with 3% sulfur and 12% ash will produce enough waste in its first 10 years to cover one square mile to a depth of 12 feet. Also, the presence of calcium sulfite hemihydrate makes it impossible to physically dewater the sludge to the extent required to support weight. Thus ponding of the sludge is objectionable both because of potential leaching problems and because the land is permanently withdrawn from use. Chemical fixation of sludges using a variety of additives has achieved some success, and has produced material suitable for landfill. This extra step adds further to operating costs, although the extent is not yet well defined.

Two areas of advanced technology have also been investigated for this report. These are fluidized-bed combustion (FBC) and advanced coal preparation. FBC is of interest because it has the potential for good pollution control, regardless of coal type, combined with high energy efficiency. Some of the more important features include:

- As much as 90% of the SO_2 formed is absorbed in the bed by limestone or dolomite, forming a dry, solid waste product.
- Low combustion temperatures (1500-1700°F) produce NO_x levels in the flue gas well below present limits.
- Particulates control can likely be achieved through the use of cyclones and baghouses.
- Trace element and hydrocarbon emission levels are still under investigation and are still highly uncertain.
- The solid discharge of ash and spent sorbent may be disposed of by landfill, although the potentially high pH of any leachate makes site-specific studies essential. Commercial uses and regeneration are being studied.

Commercial availability of large atmospheric-pressure FBC plants is expected by the mid-1980s, while pressurized FBC is projected for the mid-1990s.

Advanced coal preparation techniques may be important for the economic utilization of high sulfur coal in conventional boilers and conversion processes. New physical processes for pyrite particle removal include several based on gravity, magnetic separation, flotation, flocculation or

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agglomeration. Several advanced moisture control techniques are also under development. A number of chemically-based processes are also being investigated. Among them, the oxygen leaching, Battelle hydrothermal, and nitrogen oxides processes have the potential for both organic and pyritic sulfur removal.

During the coming year, the scope of this program will be expanded to include solvent refined coal and low Btu gasification with combined cycle combustion. The topics covered in this report will continue to be followed, and some of them will be treated in more depth than has as yet been possible.

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ENVIRONMENTAL CONTROL IMPLICATIONS OF GENERATING ELECTRIC POWER FROM COAL

ABSTRACT

This is the first in a series of reports evaluating environmental control technologies applicable to the coal-to-electricity process. The technologies are described and evaluated from an engineering and cost perspective based upon the best available information obtained from utility experience and development work in progress. Environmental control regulations and the health effects of pollutants are also reviewed.

Emphasis is placed primarily upon technologies that are now in use. For SO_2 control, these include the use of low sulfur coal, cleaned coal, or flue-gas desulfurization systems. Electrostatic precipitators and fabric filters used for the control of particulate matter are analyzed, and combustion modifications for NO_x control are described. In each area, advanced technologies still in the development stage are described briefly and evaluated on the basis of current knowledge.

Fluidized bed-combustion (FBC) is a near-term technology that is discussed extensively in the report. The potential for control of SO_2 and NO_x emissions by use of FBC is analyzed, as are the resulting solid waste disposal problems, cost estimates, and its potential applicability to electric utility systems.

The report is divided into two volumes. Volume II presents the detailed technology analyses complete with reference citations. This same material is given in condensed form in Volume I, although the references are omitted. A brief executive summary is also given in Volume I.

1 INTRODUCTION

The realities of the world's limited energy resources have been brought home forcibly to most Americans through shortages and rising prices. As one result, it has become increasingly clear that the United States must make more use of its vast coal resources, particularly for the generation of electricity. At the same time, it is obvious that exploitation of these resources can result in significant social, environmental, and health impacts if not properly controlled. Thus, the subject of this report, *Environmental Control Implications of Generating Electric Power from Coal*, has been receiving

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increased emphasis in many quarters. Most of this attention has been centered on the reduction of airborne particulate and sulfur oxide levels, but nitrogen oxide, trace element, and wastewater controls are becoming increasingly important.

A number of pollution control techniques for coal combustion are already available to the utility industry. These include the use of low sulfur coal, coal cleaning, and flue gas scrubbing for sulfur dioxide (SO_2) control; modification of combustion conditions for nitrogen oxides (NO_x) control; and electrostatic precipitators and fabric filters for particulates control. Other promising technologies that are still under development include advanced coal preparation, solvent refining of coal, fluidized-bed combustion, and coal gasification with combined cycle combustion.

As a leading agency in the identification, support, and direction of research and development efforts, the Energy Research and Development Administration (ERDA) has a responsibility to review the status of environmental control technologies and to develop independent positions on their technical and economic feasibilities. To provide assistance in that task, ERDA's Division of Environmental Control Technology has sponsored a technology evaluation program at Argonne National Laboratory (ANL) since March, 1976. This program will produce a series of reports, of which this is the first, concentrating on evaluating control technologies for coal-to-electricity processes from an in-depth engineering and cost point of view.

The purpose of this report is to provide an assessment of the status of available and near-term technologies, and a preliminary evaluation of their potential for meeting environmental protection requirements in a cost-effective manner. The available information on all of the environmental control issues associated with each technology is discussed and areas where information is lacking are identified. However, the intention is not to present a detailed description of each technology nor comprehensive analyses of their relative strengths and weaknesses.

Extensive comparative evaluations of the control technologies are planned for future reports in the series. It is intended that these evaluations be based on information obtained from all relevant technology work in progress, and that they be kept current as new information becomes available. Such comparative assessments can be expected to be of considerable value in

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planning development and demonstration programs, and in the selection of control systems for new power plants. Also there is apparently no other program that provides for a continuing effort to maintain a current file of information on control technologies for coal-to-electricity processes, as this program does. Because of this, it should be possible to follow progress in technology development work and trends in overall performance of control systems, and to anticipate more readily the effects of changes in emission regulations on control technology requirements.

The performance evaluations of control system options are to take into account both direct and indirect environmental and economic impacts of coal utilization. Direct impacts include emission of atmospheric pollutants, such as particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and the trace elements in coal; pollutants in process wastewater, including polyaromatic hydrocarbons and trace metals; groundwater contamination by infiltration of pollutants from landfill burial of waste ash, coal fines, and scrubber sludge; and the use of resources, including both land and water. Indirect impacts include pollutant emissions from the production of process materials, such as limestone used in scrubbers and fluidized-bed combustion units, and from the production of steam, electricity, and other utilities used to operate the process or its control systems. The evaluations are to be made in the context of existing and anticipated emissions regulations for coal-fired power plants, and thus regulatory developments are being monitored. Proposed regulations will be appraised in the light of the cost penalties that they impose on the electric utility sector, combined with information about the health and ecological effects produced by environmental disturbances from power plants. Thus, the program also includes monitoring of investigations into health and ecological effects for all pollutants from each technology.

In addition to environmental impacts, the evaluations will involve a number of other factors affecting the potential for utilization of the technologies. These factors include the time frame for availability of demonstrated technology, capital and operating costs, overall energy efficiency, operating reliability, adaptability of existing facilities for retrofit or modifications, and potential for improved control efficiency. Consideration is also to be given to the availability of needed hardware, manpower, materials, and transportation facilities.

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Evaluations of the kind to be undertaken in this program will necessarily generate large amounts of information. Hence, a significant part of the program effort must be devoted to developing a systematic methodology for organizing the information and reducing it to a manageable form for making overall comparative assessments. This effort has already begun; the methodology that results will be described in detail in subsequent reports.

The following sections summarize the information compiled in the project up to the present time. In order to provide perspective for the technology discussions, a section on pollutant health effects and the regulations promulgated to mitigate those effects is given first. Next, currently available fuel, combustion, and post-combustion control options are described, followed by material on certain advanced techniques expected to become commercially available in the near future. Finally, expansions of the program scope in the coming year are described, and the more important research and development needs identified thus far are given.

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separation will be at as low a level as 1.3 g/cm^3 in a plant circuit achieving maximum liberation, resulting in a practical elimination of the coarse-coal circuit. The process will produce a premium quality clean coal (<0.8% sulfur) with yields of less than 30%, and can only be justified economically if a usable middling product (2.2% sulfur) is developed.

Figure 3.2 is a flow diagram of a modern closed-circuit coal preparation plant utilizing Level Four processing. The plants based on this concept typically use heavy media vessels or Baum jigs to treat coarse coal (Level Two). Heavy media cyclones for fine coals may be added to achieve Level Three, and froth flotation for slime recovery is typically used for Level Four. Thermal driers are sometimes added to reduce the water content of products from fine and ultra-fine coal processing circuits. Wastewater is generally treated and recirculated.

Table 3.3 indicates some of the changes in coal quality that can be realized at two cleaning levels as compared to run-of-mine coal. In addition to the reduced sulfur contents, there are dramatic reductions in ash levels. This is the source of the reduced transportation requirements noted previously, and has the additional effect of shifting much of the solid waste disposal burden from the power station to the coal processing plant.

3.2.6 Preparation Constraints and Costs

Although coal preparation is a very promising approach for the achievement of environmental standards, there are indeed certain constraints on its use. These can be generally grouped into technical, environmental control, and economic categories.

In the technical area, there are several coal characteristics that can limit the effectiveness of coal cleaning operations. These include the coal component particle sizes, the difficulty of component liberation, and the relative amounts of near-gravity material. Furthermore, sulfur occurs in both organically-bound and pyrite forms, with the organic sulfur generally considered to be inaccessible to mechanical cleaning methods. The organic sulfur thus constitutes a lower limit for sulfur removal by physical preparation. This limit is quite variable, since the ratio of organic to pyritic sulfur can vary greatly from seam to seam, as well as within a single seam. The actual removal achieved also depends on the pyritic sulfur reduction

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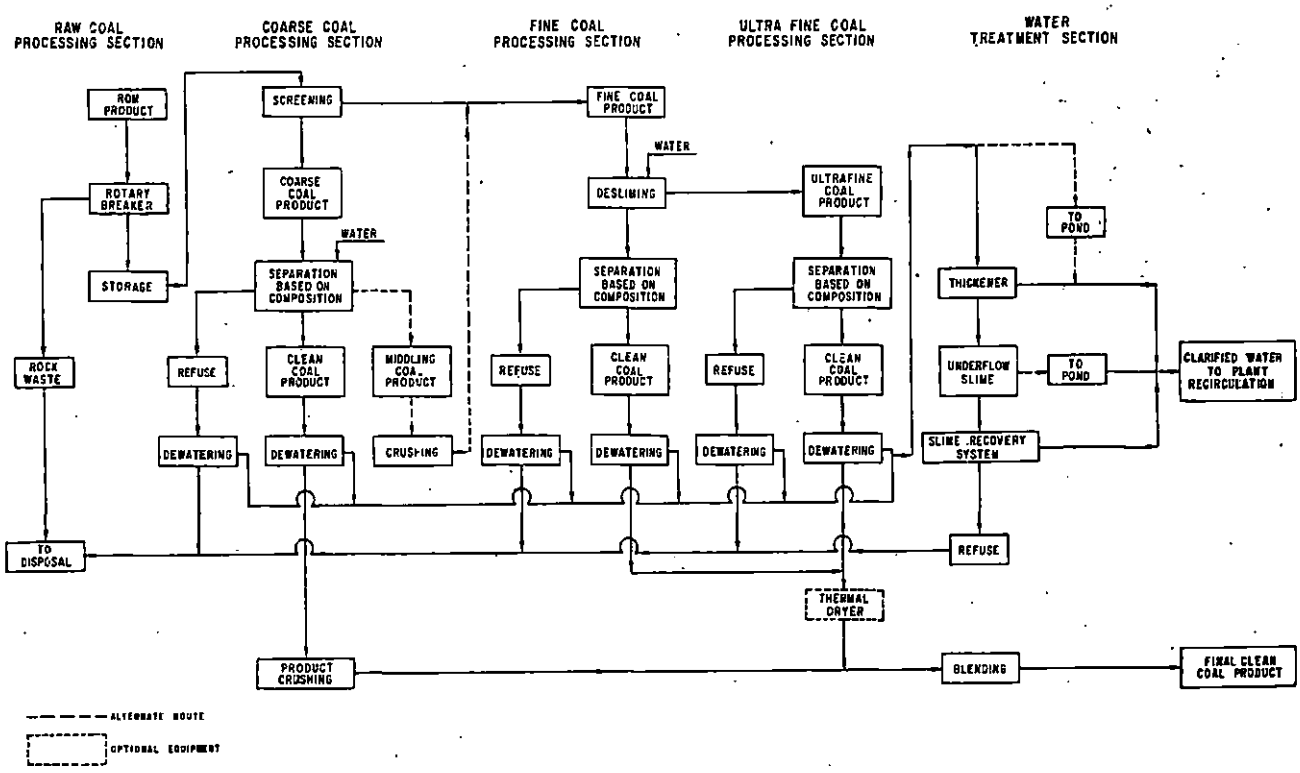

Fig. 3.2 Schematic Flow Diagram of Closed Circuit Coal Preparation Plant

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Table 3.3 Enhancement of Coal Quality by Beneficiation[a]

Coal Source Region	Coal Characteristics[b] Coal Seam Analysis	As Mined[c]	Level 3[d] Beneficiation	Level 4 Beneficiation
Northern Appalachian				
Ash (%)	14.7	17.7	7.4	5.8
Sulfur (%)	3.07	2.98	1.96	1.62
Btu/lb	11,475	11,120	12,821	13,233
lbs $SO_2/10^6$ Btu	5.08	5.08	2.90	2.32
Southern Applachian				
Ash (%)	11.2	14.2	4.3	3.9
Sulfur (%)	0.93	0.90	0.81	0.81
Btu/lb	12,720	12,330	14,030	14,261
lbs $SO_2/10^6$ Btu	1.61	1.61	1.10	1.08
Mid-Western (Eastern Block)				
Ash (%)	14.1	17.1	7.0	5.3
Sulfur (%)	3.92	3.80	2.72	2.47
Btu/lb	11,412	11,070	12,714	13,134
lbs $SO_2/10^6$ Btu	6.52	6.52	4.06	3.57
Mid-Western (Western Block)				
Ash (%)	14.5	17.5	6.5	5.8
Sulfur (%)	3.72	3.61	2.15	2.06
Btu/lb	11,018	10,680	12,425	12,674
lbs $SO_2/10^6$ Btu	6.41	6.41	3.29	3.00

[a] *Report on Sulfur Oxide Control Technology*, U.S. Department of Commerce, Commerce Technical Advisory Board (Sept 1975).

[b] Based on information from *Steam Electric Plant Factors*, National Coal Association, Washington, D.C. (1974), and A. W. Deurbrouch, *Sulfur Reduction Potential of the Coals of the United States*, Report of Investigation 7633, U.S. Bureau of Mines (1972).

[c] Run-of-Mine (ROM) coal. Assumes the ash content is increased by 3% due to inert material added by the mining operation.

[d] This cleaning level corresponds to the Level 2 defined previously in this report.

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potential of the coal, and this can vary from less than 10 to more than 90%, depending on the characteristics listed above.

From an equipment point of view, the major constraints are in the area of processing the very fine particles which are required for maximum component liberation and product recovery. The use of operations requiring ultrafine particles generally results in lower unit capacities, reduced separation efficiencies and yields, greater costs, greater difficulty in complying with environmental regulations, and more extensive dewatering systems.

The most significant environmental control problems associated with present coal preparation facilities are: (1) closing of the plant water circuit for zero process water discharge to the environment, (2) disposal of sludge from the wastewater treatment systems, (3) prevention of drainage and runoff from coal storage and refuse, and (4) noise control for crushing and grinding operations.

The costs of dealing with all of the above factors contribute to the ultimate cost of cleaned coal, and that cost is a primary factor in determining the extent to which such fuel will be used by the utility industry. In particular, the use of beneficiated coal must compare favorably with other options available to meet pollutant emissions standards. In that context, a recent U.S. Department of Commerce study concluded that coal cleaning would produce an incremental increase in generating costs of from 0.5 to 2 mills per kWh. On the other hand, the incremental cost for lime/limestone flue gas desulfurization was 4 to 6 mills per kWh.

In those situations where acceptable low sulfur coals are not available or coals cannot be totally cleaned to meet existing sulfur emission regulations, combinations of coal preparation and flue gas desulfurization appear promising. The removal of sulfur and mineral matter refuse by washing reduces the amount of SO_2 to be removed by flue gas processing, lowers the amount of lime/limestone required, with a consequent reduction in sludge and ash, and gives an overall cost advantage in many instances. Specific site, market, and lead-time constraints will determine the most economical and practical control technology mix for a given plant.

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In general, the costs of these processes appear comparable to those for FGD, which are at least a factor of 10 higher than the costs of combustion modification techniques. Consequently, these processes are expected to find little use in the United States unless and until the NO_x emission regulations are made considerably more stringent.

4.4 SOLID WASTE DISPOSAL

If NO_x control can be achieved through combustion modifications, no additional contribution will be made to the solid waste disposal problem. This is just as well, since the combination of ash and FGD scrubber sludge may severely tax the waste-handling capabilities of power plants, as noted previously, and may also pose environmental problems of a chemical nature.

The disposal of the unused ash involves potential problems of pollution of surface and subsurface water. The ash consists chiefly of the oxides of silicon, aluminum, and iron, but most of the trace elements present in the coal are also present in the ash. In a recent investigation of leachates from a number of ash ponds, it was found that concentrations of As, Ba, B, Cr, Hg, Mo, and Se exceeded one or more of the water quality criteria at one or more of the power plants, sometimes by an order of magnitude. The leachability of various species in the ash will be determined largely by solubility, with about 2-5% of the fly ash being soluble in water. The resulting solution is usually alkaline due to the presence of free lime, but some ashes from eastern coals produce acid leachates. In these acidic liquors, concentrations of sulfate, iron, zinc, lead, cadmium, and maganese often exceed criteria for discharge into streams. Attenuation of the leachate contents by percolation through soil is expected in many cases to provide substantial protection against trace elements reaching an aquifer, but disposal sites will need to be monitored and controlled.

The potential for contamination of groundwater by leachates can be reduced by preventing or diverting flows of surface and subsurface waters (e.g., by maintaining a suitable system of subsurface and trench drains). Protection against erosion and liquefaction can be achieved by good compaction, proper drainage, and development of a suitable vegetative cover.

However, ash does not readily support most plant growth. This is due partly to the lack of necessary nutrients and partly to the presence of

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toxins. Boron, in particular, may be 20 times as available in fresh ash as in normal soil. Fortunately, several plant species have been identified as tolerant of ash conditions. These include some grasses and members of the beet and cabbage families.

Thus, it seems reasonable to conclude at this time that, while disposal of ash continues to pose an environmental problem, the problem is not much worse than other waste disposal situations and is one that can be managed by careful monitoring and by optimum employment of currently available technology.

The problems involved in the disposal of wastes from lime or limestone scrubbing (or the double alkali process) are much greater because the crystalline nature of the calcium sulfite hemihdrate makes it impossible to physically dewater the sludges to the extent required to support weight. The sludges can contain varying amounts of $CaSO_4$ and unreacted $CaCO_3$, but the major component in sludges from high sulfur coals is the troublesome sulfite. The sludges can also contain varying amounts of fly ash, from a few percent when particulates are collected dry prior to scrubbing up to the total weight of fly ash when collection is incorporated with the FGD process. The behavior of representative sludges in ponding and in vacuum filtration is shown in Table 4.3. It may be noted that the solids content of high sulfite sludges increases with ash content but not enough to permit compaction. For

Table 4.3 Comparison of Typical Sludge Dewatering Properties

Sludge Type	Approximate Degree of Dewatering, percent solids		Approximate Percent Solids for Optimum Compaction
	Settling	Filtration	
High $CaSO_3 \cdot 1/2\ H_2O$ (low fly ash)	30-35	50	80
High $CaSO_3 \cdot 1/2\ H_2O$ (high fly ash)	35-40	55-60	80
High $CaSO_4 \cdot 2\ H_2O$ (low fly ash)	60-65	80	90

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this reason, separately collected fly ash has usually been combined with scrubber slurries before ponding, dewatering by centrifugation, or vacuum filtration.

The ponding of such mixtures presents many problems. The permeability of the mixtures is low (10^{-4} cm/sec, 100 ft/yr) and problems arising from the leaching of trace elements will be similar to those encountered in disposal of fly ash alone. Samples of scrubber wastes have been found to contain various trace metals (As, Cd, Cr, Pb, Hg, and Se) in amounts exceeding EPA Proposed Public Water Supply Intake Criteria. Hg and Se exceeded the criteria by more than an order of magnitude in every case. Leaching of the calcium solids can give rise to excessive oxygen demand and total dissolved solids. An impervious liner of clay, cement, or synthetics will therefore be required for the pond. Capital costs for such liners can range from $5/kW for clay up to $40/kW for 47-mil, doubly-reinforced plastic.

An overriding objection to simple ponding of the sludges, however, is the fact that reclamation of the land is not possible and large areas of land are permanently withdrawn from use. The weight of dry calcium solids from L/LS FGD of a coal containing 3% sulfur and 12% ash is approximately equal to that of the ash. Since the ponded sludge/ash mixtures contain only about 50% solids, whereas ash ponded alone contains 80% solids, the area required for disposal of the sludge/ash mixture is more than three times that for the ash alone. It can be anticipated that as more FGD systems come on line that simple ponding will not be permitted, particularly since other options are available or being developed.

Chemical fixation of L/LS sludges is already being carried out at a number of FGD installations. Several proprietary additives are available that can be used to increase the compressive strength and decrease the permeability of sludge/ash mixtures. Quantities of additives corresponding to 5-10% of the weight of dry calcium solids are sufficient to lead to formation of a low grade concrete from sludges that have been adequately dewatered.

Utilities have also concocted their own fixation recipes, adding a few percent of lime or portland cement and sometimes additional fly ash. In at least one case, the fixed sludge has been certified by EPA for, and actually used, in a landfill operation. Leaching tests of sludges fixed with proprietary additives and cured have shown premeabilities in the range of 10^{-5} to

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10^{-7} cm/sec, which is within the limits of acceptability for landfill. One of the more uncertain aspects of FGD economics, however, is the projected cost of fixing, transporting and disposing of the wastes. Better definition of these costs, as well as realistic information on the capital and operating costs of regenerable FGD processes, are needed to determine the proper direction for further developmental efforts on FGD.

An alternative approach to waste disposal that is actively being investigated and shows promise involves oxidation of the spent (ash-free) scrubber liquor to convert the calcium sulfite to calcium sulfate. Since gypsum can be satisfactorily dewatered and disposed of, environmental problems would be eliminated if complete oxidation can be achieved. It has been shown possible to grow Kentucky 31 grass in a forcibly oxidized limestone sludge by adding only fertilizer and water.

4.5 WASTEWATER CONTROL

Processes such as dewatering must also be considered in light of the wastewater treatment and disposal problems they aggravate or create. These are part of the overall wastewater control picture that is receiving increasing scrutiny in many quarters as it is related to power plant operation. One result is a shift in emphasis from once-through water systems to water recycle.

For purposes of this report, liquid effluents can be divided into three categories: (1) blowdown and equipment cleaning waste, (2) solids handling water, and (3) coal cleaning and conversion process water. Characterization of these effluents is the topic of several current studies, but the available data show that the waste streams can be highly variable, making treatment problems site and plant specific. Cooling tower blowdown water typically contains high concentrations of suspended and dissolved solids, and sometimes significant amounts of residual chlorine. Chromium, zinc, phosphate, or other corrosion inhibitors and biocides may also be found. The best available treatment is lime-soda softening followed by reuse as makeup water. Boiler blowdown can be treated similarly.

Equipment cleaning waste originates mainly from boiler and boiler tube cleaning, and contains high levels of toxic chemicals. It appears that the necessary treatment steps will include pH adjustment, precipitation, sedimentation, filtration, ion exchange or reverse osmosis, and ammonia removal.

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Solids handling water includes that used to sluice fly ash to settling ponds. The main problems with ash pond effluents are suspended solids and trace elements combined with large variations in pH. Treatment methods will have a high degree of site specificity depending principally on the pH range. It is likely that this water will have to be recycled to meet the 1983 BATEA requirements.

Coal cleaning and preparation techniques produce effluents high in suspended solids and trace metals. The majority of these processes are using recirculating water systems with treatment by thickeners, filters, or settling ponds in the cycle. Specific information on coal preparation is given in Chapter 3 of this report.

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6 FUTURE PROGRAM EFFORTS AND RECOMMENDATIONS

During the coming year, this program will be moving forward on a number of fronts. The combustion processes and control technologies covered in this report will be monitored and significant achievements will be analyzed. In addition, certain areas crucial to those technologies will receive the kind of in-depth analyses that have not been possible thus far.

The scope of the program will also be expanded to take in several additional areas of interest. These include production and combustion of solvent refined coal, and the low-Btu gasification of coal with combined-cycle combustion. Both of these technologies appear to show promise for the economic and environmentally acceptable utilization of coal in power generation. The list of potential pollutants under consideration will be enlarged by the addition of studies dealing with the emission and control of the trace elements present in coal.

Another important effort during the coming year will be a comparative evaluation of the various control options. A significant start has already been made in this area by a subcontractor to the ECT project who has scoped out a possible control evaluation and selection procedure, as well as defining the numerous technical parameters required for the process.

In general, the technologies will be broken down into modules which can then be combined to form a variety of different systems. Typical modules would be fuel, fuel pretreatment, combustion, and emission posttreatment. For each module, the factors to be analyzed will include such things as the required input, resource requirements, economic considerations, performance, applicability, environmental consequences, and output characteristics.

While this approach gives great flexibility, it also requires the manipulation of many parameters and very large amounts of data. A computerized data base is planned to facilitate that task. This base will provide the information required by other computer programs which will actually perform the necessary calculations leading to the technological, economic, and environmental output factors for each module. These calculational programs will be developed over a period of time in such a way that the level of sophistication is commensurate with the available data.

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The results of the evaluations should provide insight into the optimum control technology choices under various assumptions regarding location, new or existing capacity, economic climate, and environmental regulations. It is expected that these evaluations will be a continuing component of this program, and that the procedure will be continually developed and refined as experience is gained and more data are accumulated.

In that regard, a paucity of data has already been established in several areas, as noted previously in this report. To alleviate this situation, a number of research and development needs have been identified and summarized below. No attempt has been made to identify priorities.

Health Effects:

- Evaluation of the health effects associated with the release of trace elements, heavy metals, and radionuclides from coal combustion.
- Comparison of the potential health impacts of airborne versus waterborne pollutants, incorporating factors such as environmental sinks, food chains, synergisms, and other factors affecting the biologically effective dose to man.
- Development of quantitative mortality projection models or descriptions for the health impacts of combustion effluents in order to provide a basis for comparing the mitigating effects of various control technologies on public health.
- Preparation of a detailed generic assessment of all of the occupational and public health risks arising from the complete coal fuel cycle.

Low Sulfur Coal:

- Evaluation of the technical aspects of using low sulfur coal in existing utility boilers designed for midwestern bituminous coal.
- Evaluation of the capital and operating cost differentials for new utility boilers designed for low sulfur western coal as versus those designed for midwestern coal.

Coal Preparation:

- Continuation of studies on the characteristics of U.S. coal seams, particularly with respect to trace elements and coal washability.
- Characterization of runoff and wastewater drainage effluents from preparation facilities.
- Development of improved pollution control technologies for all emissions, including noise, from preparation facilities.

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- Development of improved techniques for the treatment and disposal of fine-coal wastes.
- Development and evaluation of improved fine-coal dewatering, handling, and drying techniques.
- Optimization of process conditions for the various desulfurization methods under development (especially chemical), and assessment of their potentials for extracting nitrogen, trace elements, and mineral impurities.
- Evaluation of the economics and feasibility of employing chemical processing for additional beneficiation after physical cleaning.

Flue Gas Desulfurization:

- Development of flue gas desulfurization (FGD) processes which produce marketable and/or easily disposable end products for conventional power plant combustion systems.
- Development and demonstration of promising regenerable FGD processes.
- Development of techniques for the direct reduction of SO_2 with coal.
- Development of technology for the chemical fixation of FGD wastes.
- Development of a cost-effective process for oxidizing FGD solids to produce $CaSO_4$.
- Comparison on economic and environmental grounds of FGD waste disposal alternatives.

Nitrogen Oxides Control:

- Development and demonstration of improved burner designs.
- Systematic and long-term evaluation of corrosion under modified combustion conditions.
- Evaluation of the effect of combustion modification on the emission of other pollutants, such as primary sulfate, trace elements, and hydrocarbon particulates.
- Development of improved methods for removal of NO_x by flue gas treatment, both by reduction to N_2 and by oxidation to NO_2 for removal by wet scrubbing.

Particulate Control:

- Development of a particulate size-distribution measurement method applicable to fuel combustion emission sources.
- Development of control technology for removing particulates from high temperature and high pressure gases (1700-2700°F and 200 psia).

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- Development of control technology for removal of fine particles (<1 μm diameter) with an efficiency of over 99%.
- Determination of the ultimate fate of additives used to improve the performance of electrostatic precipitators, and evaluation of their potential for deleterious environmental effects.

Fluidized Bed Combustion:

- Development and demonstration of a feasible sorbent regeneration method.
- Development of synthetic sorbents with improved reactivity, regenerability, and attrition resistance.
- Evaluation of control options for the reduction of NO_x emissions.
- Determination of the ultimate disposition of trace elements from coal.
- Determination of the chemistry of hydrocarbon emissions, and the effects of temperature and controls on their formation and disposition.
- Evaluation of potential turbine materials and gas requirements for turbine use.
- Development of particulate removal methods for application to hot gas streams.
- Evaluation of the relationship between operating variables and the cost of electricity.

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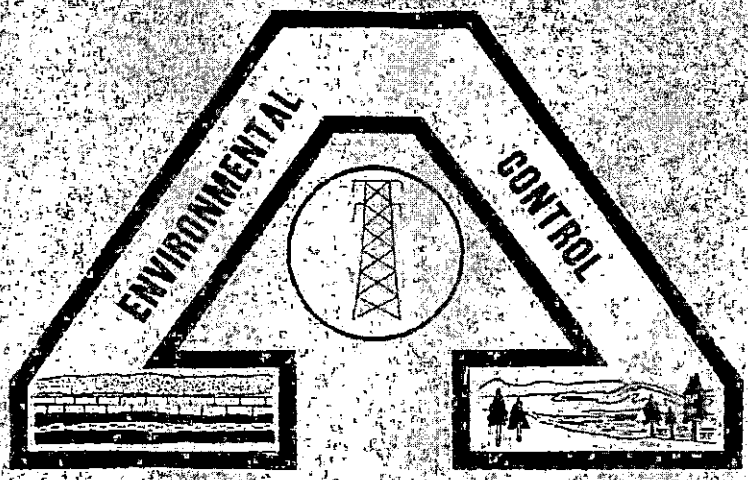

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ENVIRONMENTAL CONTROL IMPLICATIONS OF GENERATING ELECTRIC POWER FROM COAL

TECHNOLOGY STATUS REPORT

Volume II

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ENVIRONMENTAL CONTROL IMPLICATIONS OF GENERATING ELECTRIC POWER FROM COAL

ABSTRACT

This is the first in a series of reports evaluating environmental control technologies applicable to the coal-to-electricity process. The technologies are described and evaluated from an engineering and cost perspective based upon the best available information obtained from utility experience and development work in progress. Environmental control regulations and the health effects of pollutants are also reviewed.

Emphasis is placed primarily upon technologies that are now in use. For SO_2 control, these include the use of low sulfur coal, cleaned coal, or flue-gas desulfurization systems. Electrostatic precipitators and fabric filters used for the control of particulate matter are analyzed, and combustion modifications for NO_x control are described. In each area, advanced technologies still in the development stage are described briefly and evaluated on the basis of current knowledge.

Fluidized-bed combustion (FBC) is a near-term technology that is discussed extensively in the report. The potential for control of SO_2 and NO_x emissions by use of FBC is analyzed, as are the resulting solid waste disposal problems, cost estimates, and its potential applicability to electric utility systems.

The report is divided into two volumes. Volume II presents the detailed technology analyses complete with reference citations. This same material is given in condensed form in Volume I, although the references are omitted. A brief executive summary is also given in Volume I.

1 INTRODUCTION

1.1 THE ERDA PROGRAM ON ASSESSMENT OF ENVIRONMENTAL CONTROL TECHNOLOGY FOR POWER GENERATION FROM COAL

In March of this year a program was begun at Argonne to evaluate technologies for controlling the environmental impacts of processes for generating electric power from coal. The program is being carried out for ERDA's Division of Environmental Control Technology as part of its effort to assess the effectiveness of methods for controlling pollutant emissions from energy extraction, conversion, and utilization processes being developed by ERDA.

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The control technologies considered in the Argonne program include conventional coal combustion processes with add-on stack-gas cleaning, processes that involve the production and use of a cleaned or solvent-refined coal, and processes such as fluidized-bed coal combustion and low-Btu gasification/combustion in which the combustion and pollutant removal operations are combined. Methods for controlling environmental impacts associated specifically with the mining and transporting of coal are not covered in this work, but are being addressed in other ERDA programs at Argonne and elsewhere.

The focus of this program is the preparation of a series of comparative engineering assessments, based on performance, costs, and availability, of alternative processes for abatement of environmental impacts from coal utilization for power generation. It is intended that these assessments be based on available information obtained from all relevant technology development work in progress and that they be kept current as new information becomes available. Coal-to-electricity technologies have, of course, been subjected to a considerable investigation already and are being evaluated in several current studies. Consequently, it seems appropriate to state at the outset the reasons for carrying out yet another study. First, ERDA is required to review the status of environmental control technologies for power generation and to develop independent positions on their technical and economic feasibility. This program is to provide information and recommendations for that effort. In addition, there are important differences in emphasis and approach between the present assessment study and others. In particular, there appears to be no other effort to compare all current and near-term control technologies for coal utilization on an in-depth engineering and cost basis. Such comparative evaluations of the alternative control technologies for coal utilization can be expected to be of considerable value in the selection of control systems for new power plants, and in planning development and demonstration programs for improved control technologies. Also there is apparently no other program that provides for a continuing effort to maintain a current file of information on control technologies for coal-to-electricity processes, as this program does. Because of this it should be possible to follow progress in technology development work and trends in overall performance of control systems, and to anticipate effects of changes in emission regulations on control technology requirements more readily.

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The evaluation of the performance of control system options is to take account of all potential direct and indirect environmental impacts of coal utilization. Direct impacts that are considered include emission of atmospheric pollutants, such as particulates, sulfur oxides, nitrogen oxides, hydrocarbons, and the trace elements in coal; pollutants in process wastewater, including polyaromatic hydrocarbons and trace metals; and groundwater contamination by infiltration of pollutants from landfill burial of waste ash, coal fines, and scrubber sludge. Examples of indirect impacts are pollutant emissions from the production of process materials such as limestone used in scrubbers and fluidized-bed combustion units and from the production of steam, electricity, and other utilities used to operate the process or its control systems. The control technologies are to be evaluated in the context of existing and anticipated emissions regulations for coal-fired power plants. The regulations themselves are to be appraised in the light of the cost penalties that they impose on the electric utility sector and of information about the health and ecological effects produced by environmental disturbances from power plants. The program also includes monitoring of investigations of health and ecological effects of all pollutants from each technology. It is not intended, however, that the program is to undertake any new research on health or ecological effects of pollutants from coal utilization processes, nor will it provide any new data on these effects.

The information on pollutant emissions and other disturbances associated with the various control options for coal utilization processes are then to be used for comprehensive assessments of their present and future usefulness. These assessments are to take account of all factors that may affect their potential for utilization. In addition to their environmental impacts, these factors include the time frame for availability of demonstrated technology, capital and operating costs, overall energy efficiency, operating reliability, adaptability of existing facilities for retrofit or modifications, and potential for improved control efficiency. Consideration is also to be given to the availability of needed hardware, manpower, materials, and transportation facilities. The assessments are to give attention to the important site-specific factors associated with the technologies.

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To be able to make comparisons among a number of complex alternatives involving a large number of factors, it is necessary to make use of a systematic procedure for bringing these factors together on a common basis and weighing them in accordance with appropriate criteria. Considerable attention must be given to the selection and development of the criteria for comparison and a suitable procedure for carrying out necessary information handling and analysis. These activities have been major components of the work to date, and will continue to be so during the next year. It is planned that the first comprehensive comparative evaluation of the control technology alternatives will be made in the latter half of FY 1977.

1.2 CONTENT AND ORGANIZATION OF REPORT

The principal activity of the Argonne staff during the first six months of the program has been the compilation of current information on the performance and costs of conventional combustion/stack gas cleaning systems, coal preparation processes, use of low sulfur western coal as a sulfur emission control strategy, and fluidized-bed combustion technology. The purpose of this report is to discuss the current status of each of these technologies and to provide a preliminary evaluation of their apparent potential for meeting environmental protection requirements in a cost-effective manner. The intention here is to present neither detailed descriptions of these technologies nor comprehensive analyses of their relative strengths and limitations. However, it is intended that the currently available information on all of the important environmental control issues associated with each technology be discussed and that areas where needed information is lacking be identified.

The order of presentation of the report is as follows. In Chapter 2 the current environmental protection regulations, both federal and state, pertaining to power plants are described. These include ambient air quality standards and stack gas emission regulations for air pollutants as well as water quality and effluent discharge regulations. The current understanding of the health effects of coal combustion pollutants is summarized in Chapter 3. The pollutants covered include sulfur oxides, nitrogen oxides, particulates including fines and trace elements, and carcinogenic hydrocarbons.

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Chapter 4 contains a discussion of conventional combustion processes with stack gas cleaning for control of pollutant emissions. The discussion covers the current status of lime/limestone scrubber technology and other flue gas desulfurization systems of both throwaway and regenerable types. Control of particulate emissions in power plant stack gases by means of electrostatic precipitators and other devices is included, as is nitrogen oxides emission control by combustion modification techniques and stack gas cleaning. Disposal/utilization of waste solids and control of water effluents associated with these technologies are also addressed. Control of sulfur emissions from coal combustion by means of coal pretreatment (washing and cleaning) and coal selection (low sulfur coal) is described in Chapter 5. Finally, the potential of fluidized-bed combustion for utility application, and remaining problems, are discussed in Chapter 6.

The material presented herein has been obtained from a large number of sources including reports available in the open literature, direct communication with equipment vendors and architect/engineering firms, and private consultants. Wherever appropriate, the sources of information have been cited by referral to a list of references found at the end of each chapter or major subsection. The Argonne staff assumes responsibility, of course, for the accuracy of all other statements, as well as the conclusions and recommendations that are given.

1.3 FUTURE WORK ON THE PROGRAM

During the coming year work will continue to compile and evaluate information needed for the assessment of the combustion processes and control technologies covered in this report. Two developing technologies, production/combustion of solvent refined coal and low Btu coal gasification/combined cycle generation, will be added to the program. It is planned that this work will be carried out primarily by private companies and a number of consultants under contract to Argonne to contribute their expertise to the program. Four subcontractors have already begun work on the program, and at least four more subcontract programs are planned. It is our intention to make extensive use of qualified experts for the information required in the assessments of these technologies.

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During the last half of the year the comparative evaluation of the currently available environmental control options for coal combustion will be initiated by the Argonne staff using the information on the technologies developed by subcontractors and consultants. This assessment will cover all of the environmental control issues associated with conventional combustion and stack gas cleaning, the use of low sulfur coal and cleaned coal, and combinations of these options. A report describing these issues and the relative advantages and disadvantages of the control technology options will be issued at the end of the year in December 1977.

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reach opposing conclusions and there are only a few points of common agreement: (1) Class I areas present a major obstacle to growth, (2) industry capital costs will increase as a result of prevention of significant deterioration regulations, (3) facility size, emission control technology, and siting will be influenced by the regulations, and (4) future growth will be restricted by the elimination of Class III areas.

2.2 WATER QUALITY REGULATIONS

The Environmental Protection Agency has developed effluent limitation guidelines and new source performance standards for wastewater discharges from steam electric power generating plants as outlined in Table 2.14, which is taken from an Environmental Protection Agency development document.[13] These regulations fall into two categories: (1) best practicable control technology currently available (BPCTCA), and (2) best available technology economically achievable (BATEA). These standards must be met by July 1, 1977 and July 1, 1983 respectively. It should be noted that with technologies designated as BPCTCA or BATEA, terms such as "best practicable" or "best available" do not limit the choice to a single process. Any technology that meets the stated effluent limitations may be used. Table 2.15 summarizes the major water pollutants from coal-fired power plants, their sources, and current applicable treatment technologies. Although the information in this table is several years old, it is expected that the relative costs and capabilities of the treatment technologies have not changed significantly. The current investigations of treatment methods described in Chapter 4 will provide updated and more complete information on the performance of these systems.

Other regulations that affect the discharge of wastewater from power plants include receiving-water quality standards, pretreatment standards, limitations for toxic substances, drinking-water standards, and specific state and local standards.[14]

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Table 2.14 Summary of Effluent Limitations Guidelines and Standards for Pollutants Other Than Heat from Steam Electric Power Generating Plants[13]

Source	Pollutant Parameter	Effluent Limitations[a]		
		BPCTCA (1977)	BATEA (1983)	New Sources
Nonrecirculating cooling water	Free Available chlorine		0.2 (0.5 max)[b]	
	Total residual chlorine		[b]	
Cooling tower blowdown	Free available chlorine		0.2 (0.5 max)[b]	-
	Total residual chlorine		[b]	
	Chromium, total	No limitation	0.2 (0.2 max)	-
	Zinc, total	"	1.0 (1.0 max)	-
	Total phosphorus (as P)	"	5.0 (5.0 max)	-
	Corrosion inhibiting materials other than Cr, Zn, and P	"	Case-by-case	-
	All corrosion inhibiting materials	"	-	No discharge
Ash transport	Total suspended solids	30 (100 max)	-	-
	Oil and grease	15 (20 max)	-	-
Bottom ash transport	Total suspended solids	-	2.4 (8.0 max)	1.5 (5.0 max)
	Oil and grease	-	1.2 (1.6 max)	0.75 (1.0 max)
Fly ash transport	Total suspended solids	-	30 (100 max)	No discharge
	Oil and grease	-	15 (20 max)	No discharge
Low-volume wastes				
Boiler Blowdown	Total suspended solids		30 (100 max)	
	Oil and grease		15 (20 max)	
	Copper, total		1.0 (1.0 max)	
	Iron, total		1.0 (1.0 max)	
Metal equipment cleaning wastes	Total suspended solids		30 (100 max)	
	Oil and grease		15 (20 max)	
	Copper, total		1.0 (1.0 max)	
	Iron, total		1.0 (1.0 max)	
Others, except sanitary wastes and radwastes	Total suspended solids		30 (100 max)	
	Oil and grease		15 (20 max)	
Rainfall runoff from materials storage piles and construction activities	Total suspended solids		Not to exceed 50 mg/ℓ	
Rainfall runoff from other sources[c]	All pollutant parameters		No limitation	
Sanitary wastes and radwastes	All pollutant parameters		No limitation	
All sources	Polychlorinated byphenyls		No discharge	
	pH value[d]		Within the range 6.0-9.0 at all times	

[a]Note: Numbers are concentrations, mg/ℓ, except for pH values. Effluent limitations, except for pH and rainfall runoff, are quantities of pollutants to be determined by multiplying the concentration indicated times the flow of water from the corresponding source. Effluent limitations are averages of daily values for 30 consecutive days (maximum values for any one day are determined from the numbers in parentheses), except for pH and rainfall runoff. In the event that waste streams from various sources are combined for treatment or discharge, the quantity of each pollutant attributable to each waste water source shall not exceed the limitation for that source. No limitations are prescribed for sources/pollutants not specified in this table.

[b]Note: Neither free available chlorine nor total residual chlorine may be discharged from any unit for more than two hours (aggregate) in any one day and not more than one unit in any plant may discharge free available chlorine or total residual chlorine at any one time. Exceptions to be made, on a case-by-case basis, if discharger demonstrates that limitations must be exceeded in order for the cooling system to operate efficiently.

[c]Note: ...and from facilities designed, constructed and operated to treat the volume of material storage runoff and runoff from construction activities that is associated with a 10-yr, 24-hr rainfall event.

[d]Note: From all sources except nonrecirculating cooling water, rainfall runoff from sources other than materials storage piles and construction activities[c], sanitary wastes and radwastes.

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Table 2.15 Chemical Wastes Control and Treatment Technology[13]

Pollutant Parameter	Control and/or Treatment Technology	Effluent Reduction Achievable	Industry Usage	Costs	
				Capital	Operating
Common: pH	Neutralization with chemicals	Neutral pH	Common	$10-20,000 (tanks, feeder, etc.)	$3-30,000 (chemicals, labor, etc.)
Dissolved Solids	1. Concentration and evaporation	Complete removal	Not generally in use - de salinization technology	$250,000-$1,660,000 costs are significantly less in areas where evaporation ponds are feasible.	$150,000-$450,000 costs are significantly less in areas where evaporation ponds are feasible.
	2. Reverse osmosis	50-95%	Not in use - desalinization technology	50-80 ¢/1000 gal. total cost.	
	3. Distillation	60-90%	Not in use - desalinization technology	80-150 ¢/1000 gal. total cost.	
Suspended Solids	1. Sedimentation	90-95%	Extensive	$1000-$20,000/MW based on 500 gpd/MW	1-20¢/1000 gallons
	2. Chemical coagulation and precipitation	95-99%	Moderate	$10,000-$35,000/MW based on 500 gpd/MW	1-20¢/1000 gallons
	3. Filtration	95%	Not generally practiced-water treatment technology.	$7,000-$30,000/MW based on 500 gpd/MW	1-20¢/1000 gallons
Specific: Phosphate (Blowdown, Chemical Cleaning, Floor & Yard Drains, Plant Laboratory & Sampling)	1. Chemical coagulation and precipitation		Not generally practiced-water treatment technology.	$10,000-$35,000/MW based on 500 gpd/MW	1-20¢/1000 gallons
	2. Deep well disposal	Ultimate disposal	not practiced	Costs extremely variable-dependent primarily on geologic conditions.	
Iron (Water Treatment, Chemical Cleaning Coal Ash Handling Coal Pile Drainage)	1. Oxidation, chemical coagulation & precipitation	Removal to 0.1 mg/ℓ	Limited usage	$150-4,000x10^3	10-100¢/1000 gallons
	2. Deep well disposal	---As described above---			
Copper (Once-through Condenser Cooling)	1. Replace condenser tubes with stainless steel or titanium.	Elimination of discharge.	Done in several plants where tubes have erroded or corroded-not done for environmental reasons.	Prohibitively expensive-would not be done except where retubing is required for process reasons.	No incremental operating cost.
Copper (Blowdown, Chemical Cleaning)	1. Chemical coagulation and precipitation	Removal to 0.1 mg/ℓ	Limited usage	$100-$9,000/1000 gpd capacity	10-350¢/1000 gallons
	2. Ion exchange	Removal to 0.1 mg/ℓ	Not practiced	$400-$1200/1000 gpd capacity	31-81¢/1000 gallons
	3. Deep well disposal	---As described above---			
Mercury (Coal Ash Handling & Coal Pile Drainage)	1. Reduction & precipitation	Removal to 0.3 mg/ℓ	Limited usage	$700/1000 gpd	7-27¢/1000 gallons
	2. Ion exchange	Removal to 0.1 mg/ℓ	Not practiced	$18,000-$22,000/1000 gpd	$1/1000 gallons
	3. Adsorption	Removal to 50 µg/ℓ	Not practiced	$5000-$50,000/1000 gpd	$0.50-$2/lb. Mercury removed

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Table 2.15 (Cont'd)

Pollutant Parameter	Control and/or Treatment Technology	Effluent Reduction Achievable	Industry Usage	Costs Capital	Costs Operating
Vanadium (Chemical Cleaning)	1. H_2S treatment precipitation	Removal of low concentrations difficult to achieve	Not practiced	Cost data not available	
	2. Ion exchange		Not practiced	Cost data not available	
Vanadium (Oil Ash Handling)	1. Convert to dry collection	Ultimate Disposal	Practiced in several plants	Cost data not available	
	2. Total recycle with blowdown & precipitation	Complete recycle of liquid	Not generally practiced	Cost data not available	
Chlorine (Once-through Condenser Cooling)	1. Control of residual Cl_2 with automatic instrumentation	Control to 0.2 mg/ℓ	Limited usage in the industry-technology from sewage treatment practiced in some plants-all systems are not capable of being converted to mechanical cleaning.	$5,000	Negligible
	2. Utilize mechanical cleaning	Eliminates Cl_2 discharge		No cost data available	
Chlorine (Recirculating)	1. Control of residual Cl_2 with automatic instrumentation	----------As described above----------			
	2. Reduction of Cl_2 with sodium bisulfite	Below detectable limits	Being installed in a new nuclear facility; however excess $NaHSO_3$ is discharged	No cost data available	
Aluminum/Zinc (Water Treatment, Chemical Cleaning, Coal Ash Handling, Coal Pile Drainage)	1. Chemical precipitation	Removal to 1.0 mg/ℓ	Limited usage	$500-$3000/1000 gpd	10-180¢/1000 gallons
	2. Ion exchange	Similar to copper	----------		
	3. Deep well disposal	----------As described above----------			
Oil (Chemical Cleaning, Ash Handling, Floor & Yard Drains)	1. Oil-water separator (sedimentation with skimming)	Removal to 15 mg/ℓ	Common usage	$1,500-$15,000 based on .500 gal/MW 25-400 MW range	No data
	2. Air flotation	Removal to 10 mg/ℓ	Limited usage	$5,000-$50,000	No data
Phenols (Ash Handling, Coal Pile Drainage, Floor & Yard Drains)	1. Biological treatment	Removal to 1 mg/ℓ	Not practiced in the industry.	$150-$2800/1000 gpd	22¢/1000 gallons
	2. Ozone treatment	Removal to <0.01 mg/ℓ	Not practiced in the industry	No data	No data
	3. Activated carbon	Removal to <0.01 mg/ℓ	Not practiced in the industry.	$50-$350/1000 gpd	4¢-15¢/1000 gallons
Sulfate/Sulfite (Water Treatment, Chemical Cleaning, Ash Handling, Coal Pile Drainage, SO_2 Removal)	Ion exchange (sulfate) Oxidation & ion exchange (sulfite)	75-95%	Not practiced in the industry.	Total cost of $2.00/1000 gallons	
Ammonia (Water Treatment, Blowdown, Chemical Cleaning, Closed Cooling Water Systems)	1. Stripping	50-90%	Not practiced; several installations in sewage treatment	Total cost - 3¢/1000 gallons	
	2. Biological nitrification	Removal to 2 mg/ℓ	Not practiced for these waste streams	No data available	
	3. Ion exchange	80-95%	Not practiced	Total cost - 10¢/1000 gallons	

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Table 2.15 (Cont'd)

Pollutant Parameter	Control and/or Treatment Technology	Effluent Reduction Achievable	Industry Usage	Costs	
				Capital	Operating
Oxidizing Agents (Chemical Cleaning)	Neutralization with reducing agent and precipitation where necessary.	Neutral pH & 95% removal	Limited usage	No data available	
BOD/COD (Sanitary Wastes)	Biological treatment	85-95%	Common practice	$25,000-$35,000	Negligible
COD (Water Treatment, Chemical Cleaning)	1. Chemical oxidation	85-95%	Limited usage	No data available	
	2. Aeration	85-95%	Not practiced	No data available	
	3. Biological	85-95%	Not practiced	No data available	
Fluoride (Chemical Cleaning)	Chemical precipitation	Removal to 1 mg/ℓ	Limited usage	Total cost - 10-50¢/1000 gallons	
Boron (Low Level Radwastes)	Ion exchange	Removal to 1 mg/ℓ	Not generally practiced - radioactive material would concentrate on ion exchange resin requiring inclusion in solid radwaste disposal system.	No data available	

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27. C. E. Brackett and J. A. Barsin, *The Dual Register Pulverized Coal Burner,* Proceedings of NO_x Control Technology Seminar, EPRI SR-39 (Feb. 1976).

28. M. P. Heap, T. M. Lowes, R. Walmsley, and H. Bartelds, *Burning Design Principles for Minimum NO_x Emissions,* Proc. Coal Combustion Seminar, NTIS No. PB-244 210, pp. 141-171 (Sept. 1973).

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35. Y. Habib and W. F. Bischoff, *Dry System for Flue Gas Cleanup,* Oil and Gas Journal, pp. 53-55 (Feb. 24, 1975).

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4.4 DISPOSAL OF SOLID AND LIQUID WASTES

4.4.1 Summary

The increased use of coal for power generation will result in increased land requirements for the disposal of ash and sulfur abatement wastes as well as increased potential for contamination of water supplies.

Annual production of ash by the electric utilities is already approaching 60 million tons. Despite intensive efforts to increase utilization of

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ash in the construction industry and for soil stabilization, more than 80% of the ash produced at the present time is merely ponded or used as landfill.

The major environmental problem in ash disposal is that the quantities of trace metals and dissolved solids in leachates and runoff from the disposal sites can exceed water quality criteria, sometimes by an order of magnitude. Attenuation of the leachate contents by percolation through soil is expected to provide substantial protection against contamination of aquifers by trace elements in some cases, but attenuation of some elements, such as selenium and boron, is known to be ineffective. In most cases, therefore, it will be necessary to install and maintain a suitable system of subsurface and trench drains to reduce the possibility of ground water contamination. Some control measures are already being employed by most utilities.

Land requirements for disposal of the ash from power plants are also significant. About 120 acres, ponded to a depth of 30 feet, are required for disposal of the 5 million tons of ash that might be accumulated by a 1000-MWe coal-fired power plant during its lifetime. Until recently ash ponds were merely abandoned, but reclamation is clearly desirable and will be required in most cases. Gradual development of a suitable vegetative cover should be possible if the landsite is carefully selected and the landfill is properly protected against erosion.

The use of lime or limestone scrubbing to control sulfur-oxide emissions from power plants adds a new dimension to waste disposal problems and dramatically increases land requirements and costs. The calcium solids produced in the scrubbing operation weigh close to five times as much as the sulfur in the coal and, additionally, exhibit a strong tendency to retain water. Fly ash is commonly collected with the scrubber solids or added afterwards to increase the solids content, but even then the mixtures cannot be dewatered by settling or filtration to the extent required to support equipment or structures. For a plant burning coal with 3% sulfur and 12% ash, the sludge/fly ash mixtures will typically retain an equal weight of water and require more than three times the amount of land for disposal than would ash alone. Leachates and runoff from the disposal ponds, like those from ash ponds, can result in contamination of water supplies with trace elements and dissolved solids. The problem is a serious one

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because lime/limestone scrubbers are currently scheduled to be installed on 25,000 MWe of generating capacity by 1980, and could be required on all coal-fired power plants by legislation now pending.

In most of the FGD systems now operating, the sludge is discharged to an excavated pond without further treatment, but several options for mitigating the water-pollution or land-use aspects of disposal are available or under investigation. Leaching can be controlled by installation of an impervious liner in the pond. Clay liners, at a cost of about $5/kW, are being installed in a few of the newer FGD systems. Other barriers, including heavy duty plastics at costs up to $40/kW, are also being investigated, but the long term integrity of any liner remains an uncertainty.

A second approach that addresses both the permeability and the physical instability of the sludges is that of chemical stabilization. A number of recipes involving the addition of lime or cement have been concocted by the utilities, and proprietary additives are offered by several companies. After curing for a month or more, stabilized sludges exhibit permeabilities in the range of 10^{-6} cm/sec and compressive strengths of 300-400 psi. Sludges at five of the operating FGD systems are being stabilized. In the most ambitious project (the Bruce Mansfield plant of Pennsylvania Power Co.), thickened slurry is mixed with the stabilizing agent and pumped seven miles to a disposal area formed by constructing a 450-ft dam in a large ravine. The costs of stabilization and disposal are not well established, but a recent estimate equivalent to 0.9 to 1.4 mills/kWh indicates that they can contribute significantly to total FGD costs.

An alternative approach to waste disposal that is actively being investigated and shows promise involves oxidation of the spent (ash-free) scrubber liquor to convert the calcium sulfite to calcium sulfate. Since gypsum can be satisfactorily dewatered and disposed of, environmental problems would be eliminated if complete oxidation can be achieved

Power plant liquid wastes that require control include blowdown and equipment cleaning wastes. Cooling tower blowdown water typically contains high concentrations of suspended and dissolved solids, and sometimes significant amounts of residual chlorine. Chromium, zinc, phosphate, or other corrosion inhibitors and biocides may also be found. The best available

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treatment is lime-soda softening followed by reuse as makeup water. Boiler blowdown can be treated similarly.

Equipment cleaning waste originates mainly from boiler and boiler tube cleaning, and contains high levels of toxic chemicals. It appears that the necessary treatment steps will include pH adjustment, precipitation, sedimentation, filtration, ion exchange or reverse osmosis, and ammonia removal.

4.4.2 Fly Ash and Bottom Ash

4.4.2.1 Introduction

All coal-fired boilers produce ash in amounts depending on the inorganic mineral (ash) content of the coal being burned. This by-product has value as a utilizable raw material, but unfortunately only a minor fraction is marketed. The balance must be disposed of in a manner that will do the least environmental damage to the atmosphere, land, and water and will be at the same time reasonable in cost.

As the use of coal for electric power generation increases, so also will the annual production of ash -- for which utilities will need to find purchasers or else safe methods and sites for dumping. Added to this is the possibility, even likelihood, that more stringent regulations may require control measures to be instituted for reducing the environmental impact of the several hundred million tons of ash that were stockpiled (dumped) during the past several decades when pollution problems were of lesser priority.

Disposal of ash by landfill (the time-honored method) involves potential problems of pollution of surface and subsurface water. Leaching tests on ash samples from existing power plants suggest that runoff and seepage from ash dumps may exceed established water quality criteria with respect to concentrations of various chemical species, including toxic trace elements. Other problems associated with disposal by landfill are structrual stability, wind erosion, and the unsightliness of the ash pile. Utilities are well aware of these problems; they and various other private and public institutions are developing and/or installing control technology to minimize or resolve them.

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A great deal of R&D has been performed to investigate various end uses for ash. Significant beneficial uses have been developed, many of them of large-tonnage potential.

This section of the report assesses the current status of the disposal problem and the direction and promise of R&D designed to alleviate it. The report also assesses the current status, as well as progress and outlook, for utilization. Where appropriate, areas requiring further information, R&D, and/or assessment are identified.

4.4.2.2 Magnitude and Nature of the Problem

Quantities Expected

The amount of ash depends, of course, on the ash content of the coal, the amount of coal burned, and the efficiency of the ash collection devices.

Coals vary considerably in ash content. For example, coal burned at five utility stations was found to range from 10 to 25% ash.[1] As indicated in Table 4.17, the current average ash content of coal burned by utilities is about 15% by weight.

Greater efficiency of coal cleaning lowers the ash content considerably, but this is not expected to have a significant impact on the national ash-disposal burden within the next 5-10 years.

More than 90% of the coal currently used by electric utilities is burned in pulverized-coal boilers. In such boilers 70-80% of the ash is produced in the form of fly ash, which is carried out of the combustor in the flue gases and is separated from these gases by electrostatic and/or mechanical collectors. The remainder of the ash drops to the bottom of the furnace as bottom ash or slag. The amounts of each type of ash produced in the U.S. during several recent years are listed in Table 4.17. It is noted that the percentage of ash collected as fly ash has risen from 65% in 1971 to 71% in 1975.

As emission regulations were tightened in recent years, utilities installed more efficient ash collection devices. At one time an efficiency of 95% was considered satisfactory, but regulations now require 99% or higher.[2] It is conceivable that growing concern over the health hazards

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associated with the emission of very fine particulates could lead to requirements for collecting 99.9% or more of the fly ash. Although this would add but little to the total bulk of ashes collected, it could exacerbate some of the ecological and pollution problems associated with disposal/utilization.[3]

Characteristics of Ash

The identities and concentration ranges of major chemical constituents in samples of fly ash and bottom ash from the region of southwestern Pennsylvania are listed in Table 4.18. The chemical compounds that are most abundant in the ash are the oxides of silicon, aluminum, and iron. Although a rather wide concentration range is indicated for each major constituent, the ranges listed for fly ash rather closely resemble those listed for bottom ash.[4]

Table 4.19 shows concentrations of selected trace elements in the coal, bottom ash, and fly ash at the R.A. Allen Steam Plant of the TVA in Memphis, Tennessee. The coal burned at this plant is a mix of coals from southern Illinois and western Kentucky containing about 12% ash (dry basis), and the boilers are of the cyclone-fed type. Analyses were performed on samples of fly ash obtained both upstream and downstream from the electrostatic precipitators.

Table 4.17 Megatons of Coal Ash Collected in the U.S.[a]

	Year					
Type	1971	1973	1974	1975	1980[b]	1985[c]
Fly Ash	27.7	34.6	40.4	42.3		
Bottom Ash	10.1	10.7	14.3	13.1		
Boiler Slag	5.0	4.0	4.8	4.6		
Total	42.8	49.3	59.5	60.0	75.0	120.0
Coal Consumed	-	-	390	403		
Calculated Average Ash Content	-	-	15.3%	14.9%		

[a]Compiled by National Ash Association and Edison Electric Institute.

[b]Projection by R.E. Morrison, American Electric Power Services Co.

[c]Projection based on expected doubling in coal-fired power generation, 1975→1985.[2]

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Table 4.18 Major Chemical Constituents of Fly Ash and Bottom Ash from the Southwestern Pennsylvania Region [a]

Constituent	Fly Ash (% by Weight)	Bottom Ash (% by Weight)
Sulfur Trioxide	0.01-4.50	0.01-1.0
Phosphorus Pentoxide	0.01-0.50	0.01-0.4
Silica	20.1-46.0	19.4-48.9
Iron Oxide	7.6-32.9	11.7-40.0
Aluminum Oxide	17.4-40.7	18.9-36.2
Calcium Oxide	0.1-6.1	0.01-4.2
Magnesium Oxide	0.4-1.2	0.5-0.9
Sodium Oxide	0.3-0.8	0.2-0.8
Potassium Oxide	1.2-2.4	1.7-2.8
Titanium Oxide	1.3-2.0	1.3-1.8

[a]A.M. DiGioia et al., cited by Ref. 4.

Of the trace elements measured, eight (As, Cd, Cu, Ga, Pb, Sb, Se, and Zn) were more concentrated (6- to 100-fold) in the fly ash than in the bottom ash, and tended to be more concentrated (4- to 5-fold) in the (presumably more finely divided) fly ash discharged up the stack than in that collected by the precipitator. Thirteen trace elements (Ba, Ce, Co, Eu, Hf, La, Mn, Rb, Sc, Sm, Sr, Ta, and Th) showed little preferential partitioning between the bottom ash and the collected or discharged fly ash. The elements Cr, Cs, Ni, U, and V showed behavior intermediate between the above groups. Mass balance calculations indicated that some of the Se, most of the Hg, and probably most of the Cl and Br went up the stack in the gaseous state.[5]

Hulett et al., also have studied fly ash from TVA's Allen Steam Plant.[6] They found that particle compositions vary with particle size, and that the interior of a particle has a different composition than the surface. Iron and aluminum tend to concentrate in the interior, while sulfur (occurring as sulfate) seems to concentrate on the surface.

Fly ash agglomerate contains hollow spheres (cenospheres), which themselves are packed with smaller cenospheres that are in turn also packed with spheres 1 μm or less in diameter.[7] These systems of cenoshperes are called plerospheres. The formation of the aluminosilicate plerospheres probably results from rapid differential heating of the noncombustible coal fraction and subsequent evolution of gas from thermal decomposition and dehydration.

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Table 4.19 Concentrations of Selected Trace Elements in Coal and Ash at TVA's Allen Steam Plant [a]

Element	Element Concentration (ppm)			
	Coal[b]	Bottom ash	Inlet fly ash[c]	Outlet fly ash[d]
As	4.45	18	110	440
Ba	65	500	465	750
Br	3.7	2	∿4	
Cd	0.47	1.1	8.0	51
Ce	8.2	84	84	120
Cl	914	<100	<200	
Co	2.9	20.8	39	65
Cr	18	152	300	900
Cs	1.1	7.7	13	27
Cu	8.3	20	140	
Eu	0.1	1.1	1.3	1.3
Ga	4.5	5	81	
Hf	0.4	4.6	4.1	5.0
Hg	0.122	0.028	0.050	
La	3.8	42	40	42
Mn	33.8	295	298	430
Ni	16	85	207	
Pb	4.9	6.2	80	650
Rb	15.5	102	155	190
Sb	0.5	0.64	12	55
Sc	2.2	20.8	26	36
Se	2.2	0.08	25	88
Sm	1.0	8.2	10.5	9
Sr	23	170	250	
Ta	0.11	0.95	1.4	1.8
Th	2.1	15	20	26
U	2.18	14.9	30.1	
V	28.5	260	440	1180
Zn	46	100	740	5900

[a]Adapted from Ref. 5.
[b]Mixture of coals from southern Ill. and western Ky. Ash content ∿12%.
[c]Collected upstream from electrostatic precipitator.
[d]Collected downstream from electrostatic precipitator.

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Microcrystals observed on the surface of the cenospheres appear to contain high concentrations of calcium and sulfur (probably $CaSO_4$ or its dihydrate). It is suggested that these microcrystals are probably formed by the leaching of metal oxides in the ash by condensed sulfuric acid. In connection with health hazards associated with inhalation of fine particulates, these microcrystals may, because of their increased surface area and potentially toxic chemical composition, have biological implications more critical than expected for the cenosphere material.[7]

The significance of the compositions and properties of the various components of ash will be discussed in subsequent sections on disposal and utilization. Suffice it to say here that the disposal technology chosen and the hoped-for end use will need to be based on specific chemical and physical characteristics of the ash produced at each site.

4.4.2.3 Ash Disposal Technology

The principal means of ash disposal in the electric utility industry is a landfill operation that involves dumping the ashes into shallow ponds or lagoons, usually on the site of the plant where the ashes are produced. This practice can result in serious degradation of the land if the filled lagoons are not subsequently reclaimed or the contents sold for industrial utilization.

Reclamation has not been practiced much in the past, but with increasing concern for the environment greater care will have to be given to site selection, to management of the landfill, including monitoring for potential water pollution, and to functional and aesthetic restoration of the dump after it is filled.

Pollution from Ash Dumps

Leaching by percolation of rain, melted snow, or surface runoff represents the greatest pollution threat posed by ash dumps. In fact, it is a threat wherever ashes are exposed to rain or surface water. However, ash that is hauled away and put to use in embankments, road and base construction, and the like (where it is spread or mixed with soil, sand, gravel, and/or stabilized by cementitious reactions) will yield a leachate that is less apt

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to be saturated and is more readily attenuated by the underlying or adjoining soil. Moreover, in such applications, the elements being leached will probably be exhausted in some reasonably short time.

Table 4.20 compares the equilibrium concentrations of various trace elements in ash leachates from five different power plants with the various water quality standards.[1] Concentrations that exceed one or more of the standards are encircled in the table. Note that the concentrations of As, Ba, B, Cr, Hg, Mo, and Se exceeded one or more of the water quality criteria at one or more of the power plants. The pH of the leachates studied ranged from 8.2 to 12.5.

The leachability of a given species in the ash will be determined largely by its solubility. Generally about 2-5% of fly ash is water-soluble.[8] The resulting solution is usually alkaline due to the effect of free lime, although some ashes, especially from eastern coals, produce acidic leachates. These acidic liquors often exceed stream criteria with respect to sulfate, total iron, zinc, lead, cadmium, and manganese, but they are usually acceptable with respect to copper.

Aside from solubility, another factor influencing the leachability of ash is the possibility that some of the solubles may become fixed by participation in a pozzolanic reaction.[9]

The engineer in charge at an ash dump has recourse to several options to reduce potential contamination of groundwater by leachate. Among these are:

1. Excluding, intercepting or diverting all or part of the surface flow and subsurface water.
2. Maintaining a suitable system of subsurface and trench drains.[10]

Attenuation of the leachate contents by percolation through soil is expected in many cases to provide substantial protection against trace elements reaching an aquifer.[1] Laboratory attenuation (percolation) data obtained on soils at utility stations indicate that after 10 years of continuous flow, the level of chromium and selenium (at soil depths of 30-50 ft) would still be 95% less than it is in the original ash leachate. Boron and arsenic were also significantly sorbed by the same soil.

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Table 4.20 Equilibrium Concentrations of Trace Elements in Coal Ash Leachate[1]

	Station Number					Water Quality Criteria[a]		
	1	2	3	4	5	Surface Water FWPCA (mg/ℓ)	Irrigation FWPCA (mg/ℓ)	Public Water Supply Intake EPA (mg/ℓ)
Bottom Ash (wt %)	20	20	20	50	100			
Precipitator Ash (wt %)	80	80	80	50	--			
pH	12.5	9.5	12.2	12.0	8.2			
Element (ppm)								
Sb	.006	.018	.033	.022	.0087	--	--	--
As	<.002	.084	.015	.072	.006	0.05	1.0	0.1
Ba	40	<.3	<.3	<.3	<.3	1.0	--	--
Be	.003	.00064	.0007	.001	.00026	--	--	--
B	.03	16.3	.21	1.1	.048	1.0	0.75	1.0
Cd	<.001	.0025	<.01	<.001	.0011	0.01	0.005	0.01
Cr	<.001	.21	.11	1.0	.014	0.05	5.0	0.05
F	2.3	1.4	2.0	17.3	1.4	--	--	--
Ge	<.01	<.01	<.01	<.01	<.01	--	--	--
Hg	.0006	.0005	.015	.0003	.0003	--	--	0.002
Pb	.0068	.0027	.024	.0043	.0063	0.05	5.0	0.05
Mn	<.002	<.002	<.002	<.002	<.002	0.05	2.0	--
Mo	.047	.052	.05	.69	.010	--	0.005	--
Ni	<.05	.015	.025	<.05	.046	--	0.5	--
Se	.009	.0005	.033	.47	<.0005	0.01	0.05	0.01
V	<.1	<.1	<.1	<.2	<.1	--	10.0	--
Zn	.038	.025	.19	.005	.0175	5.0	5.0	5.0
Cu	<.035	.031	.092	.013	.015	1.0	0.2	1.0

[a]FWPCA = Federal Water Pollution Control Administration.

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The EPA is funding a TVA study that will: (1) assess the effect of pH adjustment on the leaching of ash dumps, (2) define sampling and analytical procedures for effective monitoring of ash dumps, (3) characterize and quantify the effects of coal ash leachate on groundwater quality, and (4) study fly-ash handling systems and methods of disposal, utilization, and treatment. ERDA has indicated that leaching from ash dumps will continue to be of interest.[12]

Controlling Erosion of Ash dumps

The following guidelines have been given for protecting ash dumps from erosion and liquefaction:[9]

1. Control internal erosion by making use of a properly designed drainage and filter system to ensure that fine material is not carried off by seepage water.

2. Control external erosion by providing a suitable vegetative cover on the downstream slope and slope protection on the upstream slope. Adequate spillway or runoff diversion capacity should be provided and maintained.

3. Control liquefaction by good compacting and proper drainage.

On the downstream slope it would be sufficient to cover the compacted ash with gravel and topsoil, followed by seeding with a close-turfing grass. The upstream slope can be protected against erosion by a protective blanket consisting of an impervious clay-shale layer on a rock-fill layer, or else a fine-rock layer.

Ash deposited in lagoons may pose a dust hazard as the material dries out. The small, hollow cenospheres have a low density and are susceptible to wind erosion. Proper compaction of the ash helps to prevent this. Also, in some instances, the ash tends to form a skin that, if undisturbed, protects it against blowing. Spraying the surface with polymer emulsions is also effective in preventing wind erosion. Long-term control is best achieved by establishing a suitable vegetative cover.[13]

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Reclamation of Ash Piles

Ash does not readily support plant growth. This is due partly to lack of the necessary nutrients (a need that can be supplied by application of fertilizers) and partly to the presence of inhibiting elements such as boron. Yet natural colonization of an ash surface by vegetation often takes place. The first plant to appear is usually a moss, which can cover a moist ash surface within six months and which effectively binds together the ash particles to inhibit erosion. A common weed is usually the next colonizer to appear, and this can be followed by a range of other plants.[13]

Tests on ash piles have shown that boron may be 20 times as available in fresh ash as it is in a normal soil. Chemical treatments for removing the excess boron proved to be too expensive. Fortunately, various useful plant species tolerate ash conditions. The clover family is, in general, quite tolerant. Some grasses, particularly rye grasses, are tolerant. Of the arable crops, those of the beet and cabbage families do well. Sugar beets, fodder beets, and mangels benefit from the boron in the ash, provided it is not too high. Considerable success has been obtained with rye and wheat on a field scale, and (at a later stage) even with the relatively intolerant barley.[13] Of course, if the ash can be covered with topsoil to a depth of perhaps 12 inches, then a great range of crops can be grown on the site. However, cost usually makes this tactic impractical.

A variety of trees (alder, honey locust, spruce, poplar, and willow) are tolerant to ash conditions, but their growth is not sufficiently vigorous to sustain commercial timber production. A number of shrubs can also be grown on ashes. Thus it should be possible to landscape an ash disposal site with these tolerant species.[14]

Other Methods of Ash Disposal

Direct deposition of ashes in underground mines is a possible disposal option. Filling of deep mines with power plant ash has been used as a mine subsidence prevention technique.[8] The feasibility of this approach is currently being investigated by the Bureau of Mines for disposal of lime/limestone scrubber sludges.

Another possible method of ash disposal that is partly dumping and partly beneficial use would be the utilization of ashes in the rehabilitation

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of areas which have been desecrated by strip mining, quarrying, and the like. It has been suggested that in these cases the cost of ash disposal could be shared by the utilities and other organizations (presumably the original desecrators, land developers, or local governments).[9]

Conclusions

Subject to the findings of ongoing R&D, it seems reasonable to conclude at this time that while disposal of ash continues to pose an environmental problem, the problem is not much worse than other waste disposal situations and is one that can be managed by careful monitoring and by optimum employment of currently available technology.

4.4.2.4 Utilization of Ash Wastes

Commercial use of ashes is an attractive alternative to disposal by dumping or landfill. First, it represents a means of alleviating the ecological impact resulting from disposal of ashes in lagoons or land sites. Second, to the extent that the ashes are sold or given away to be put to some practical use, it reduces disposal costs. Third, there are technical as well as economic advantages to the user who utilizes ash as a raw material, e.g., for structural compositions, pavings, etc.

Industry, governmental agencies, universities, and other nonprofit institutions have over the years conducted and/or sponsored extensive investigations aimed at developing and perfecting various beneficial end uses for coal ash. As noted in the following pages, these efforts have borne fruit.

For the past 10 years, the National Ash Association has fostered development of markets for power plant ash and promoted its use for new applications. The NAA is a trade association sponsored by 30 of the electric utility companies of the nation, some coal companies and the National Coal Association, some university faculty members, and an impressive number of industrial firms active in utilizing ash and/or doing research on its uses.

If full usage of ash does not eventually become a reality, it will not be for lack of effort by organizations such as the NAA, the Bureau of Mines, Dept of Transportation, the EPA, and various state and local governmental agencies, as well as commercial ash-utilization firms.

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Extent of Utilization

European countries utilized a major fraction of their national production of fly ash in 1971 (79% in the Federal Republic of Germany, 65% in France, 54% in the United Kingdom, 44% in Belgium, and 44% in Poland).[3]

In contrast, U.S. utilization in the past three years was only 14-17%. However, it is encouraging to note the growth in actual tonnage of ash consumed in beneficial end uses. The tonnage utilized in 1975 was over three times that utilized in 1966 (9.8 compared to 3.1 million tons), even though the percent utilization showed only a modest increase (from 12.1 to 16.4%). Thus as the production of ash expands over the next few years, a greater tonnage may be utilized -- but not necessarily a higher percentage.

As seen from the data in Table 4.21, specific end uses can be identified for about 45% of the fly ash utilized, 48% of the bottom ash, and 80% of the boiler slag; the balance in each instance is identified either as "ash removed from plant sites at no cost to utility" or as "ash utilized from disposal sites after disposal costs." However, all these categories represent ash for which the utilities are no longer responsible and which no longer poses a disposal problem for them.

The bulk of the ash sold in the U.S. is marketed by a relatively few companies specializing in the promotion and sales of ash -- or by utility companies that have their own active sales organizations.[3] Collins[15] suggests that tax reductions, increased subsidies, or reduced transportation costs might be used as incentives for the expanded use of recyclable materials such as fly ash.

The Markets

The construction industry currently consumes the largest amount of fly ash. As Table 4.21 shows, one of the main markets for ash is its use as a component in portland cement compositions. Another is its use for soil stabilization and in pavements. Blast grit and roof granules constitute another substantial market.

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Table 4.21 Commercial Utilization of Ash in the U.S. in 1975[a]
(Kilotons)

Use	Fly Ash	Bottom Ash	Boiler Slag
Type 1-P Cement	225	70	36
Partial Substitute for Cement	945	-	-
Lightweight Aggregate	90	35	-
Stabilization & Roads	450	525	72
Filler in Asphalt Mix	135	-	-
Ice Control	-	280	54
Blast Grit & Roof Granules	-	420	864
Misc.	180	350	414
Ash Removal at no Cost to Utility[b]	1,080	875	270
Ash Utilized[b] from Disposal Sites	1,395	945	90
1975 Total Utilized	4,500	3,500	1,800

[a]Compiled by the National Ash Association and Edison Electric Institute.

[b]Specific end use not known.

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Cement and Concrete. Blended cements are usually made by intergrinding cement clinker with industrial by-products such as fly ash or granulated blast-furnace slag. Fly ash is attractive for this purpose because it is widely produced in large amounts and in a form that is usually immediately suitable for the purpose.

Research by the Bureau of Reclamation showed that replacement of 15-30% of cement in normal density concrete by fly ash improves sulfate resistance of test specimens by an average of 50-100%[16] and prevents or greatly retards corrosion of the reinforcing steel.[17] During the last 20 years at least 50 dams, or locks and dams, were built that employed fly ash in the concrete used in their construction. For example, the Dworshak Dam in Idaho required 7.5 million cubic yards of concrete that consumed 250,000 tons of fly ash.[18]

There are several economic and ecological advantages in utilizing fly ash as a substitute for part of the cement used in concrete construction.

1. Cost. Where the delivered price of cement is about $30/ton, fly ash will cost $6-$7/ton.

2. Convenience. It takes less pouring time and less finishing time than does standard concrete.[19]

3. Conservation. There is a considerable saving in energy (1,300 kWh/ton for cement vs. nominal kWh/ton for waste fly ash).[20] The savings are almost directly proportional to the degree of ash substitution.[21]

4. Expands production. Plant capacity is extended with practically no investment in new facilities.

Aggregates for Lightweight Concrete. A considerable quantity of fly ash was utilized in 1975 for producing lightweight concrete, and this use is expected to expand rapidly. Its resistance to freezing and thawing makes lightweight aggregate prepared from sintered fly ash more valuable to roadbuilders and to the concrete construction industry.[22] The sintered ash is produced by heating pelleted fly ash at about 2300°F. Incidentally, carbon impurities (unburnt coal and soot) in the fly ash act as fuel to supply part of the heat. Pelleting is necessary to control dust emissions during the sintering.

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Lime- and Cement-stabilized Fly-Ash Pavements. The use of lime/fly-ash aggregate (LFA) and lime/cement/fly-ash aggregate (LCFA) mixtures in pavement construction has increased substantially during recent years. During 1971, nearly 2 million tons of LFA materials were placed in the United States, with over 1 million tons placed in the Chicago area alone. Perhaps the largest job utilizing LFA and LCFA materials was the construction in 1967 of the Newark Airport. More than 2 million tons of LFA and LCFA were used as base materials for the runway and taxiway systems serving jumbo jets. Five years later the pavements were observed to be in excellent condition.

Asphalt Pavements. In general, power plant aggregates (ash and slag) can be successfully used in asphaltic compositions.[23] The advantages of fly ash as mineral filler in asphalt paving are lower cost, acceptable size, graduation without processing, and superior resistance to water.[19]

Road Fill. The light weight of fly ash makes it extremely attractive as road fill, especially when embankments have to be constructed over poor ground, such as alluvial clay or silt, where excessive weight might cause settlement beyond allowable limits and, in the worst case, could produce a complete failure of the subsoil.

The wet weight of fly ash per compacted cubic yard is between 0.9 and 1.1 tons, depending on the source and moisture content of the material. This compares very favorably with the weight of traditional filling material.[22]

Slag as Anti-skid Agent. Boiler slag has been used with some success in West Virginia in deslicking applications. The dramatic reduction shown in the reported accident data before and after deslicking is evidence of the anti-skid characteristic of this mixture.[24]

Sand-Blasting Grit. Significant amounts of bottom ash and boiler slag are being used for this purpose.[25]

Load-bearing Fill. Because of its high load-bearing capacity, fly ash is often used as load-bearing structural fill for industrial buildings, schools, etc. Its light weight and self-hardening properties make fly ash an ideal construction raft for building development over poor ground.

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Settlement is reduced to a minimum; the hardened fly-ash raft forms a monolithic structure that can then bridge weak spots in the subgrade and thus reduce differential settlement.[22]

Recently, the Central Illinois Light Company blended 400,000 cubic yards of weak loess clayey-silt soil with 3% lime and 5% fly ash to provide a base on which to place a 7-foot-thick concrete slab to support the boiler and turbine generator of a 400-MWe power plant.[24]

Brick. Extensive R&D has been conducted on fly-ash brick by the Coal Research Bureau of West Virginia University (CRB/WVU) -- an effort that was crowned by commercial success. A fly-ash brick plant designed to produce 35 million bricks yearly, using a process developed at the CRB/WVU, is operating at Edmonton, Alberta. The demand for fired products from fly ash has led to the construction of a second plant for the manufacture of paving tile. Further expansion is reportedly being considered for this plant. However, efforts to expand the use of fly ash in the manufacture of ceramic brick in the U.S. have not resulted in consumption of substantial quantities.

Miscellaneous Uses. Other actual or potential uses for fly ash, bottom ash, and/or boiler slag are:

1. As an agricultural soil amendment.
2. As a component of grout.
3. In production of mineral wool.
4. As a filler or extender in a variety of materials.
5. For extinguishing burning spoil piles.
6. As a source of chemicals (sulfur, alumina, iron oxide, etc.).

R&D. A number of federal government agencies have initiated research programs to investigate possible uses of various wastes in construction. For example, the Federal Highway Administration has sponsored programs investigating sulfate wastes, fly ash, and bottom ash. EPA has funded research on the combined use of fly ash and coal waste as base-course material and an evaluation of various processes to stabilize chemical sludges. The Bureau of Mines research program is aimed at developing new and improved ways (some of which utilize ash) to stabilize, reclaim, or utilize mineral wastes.

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The Federal Energy Administration has funded an investigation of the engineering properties of concrete mixes made from low-percentage blended cements using various types of fly ashes, slags, and cement-kiln dusts. ERDA is studying the economic and energy-saving aspects of increased use of blended cements.

Impact of Flue Gas Desulfurization and Fluidized-bed Combustion

Where coal-fired power plants are equipped with *FGD* scrubber systems employing lime or limestone, the disposal of ashes is usually linked with disposal of the spent sorbent (sulfited and sulfated stone). As pointed out in Section 4.4.3.2, the scrubber effluents can contain varying amounts of fly ash, and additional fly ash is sometimes added to improve the rate of drainage of excess water from the waste sludge, and also to improve its physical strength. In fact, most fixation recipes designed to stabilize and solidify the partially dewatered sludges utilize fly ash for its pozzolanic (cement forming) properties.

Ashes produced by an *FBC* unit are apt to be "contaminated" with some spent sorbent, which consists mainly of calcium sulfate, lime and limestone (plus some magnesia in the case of dolomite). Such contamination may for some end uses be beneficial (e.g., landfill revegetation, reclamation, base-course paving), while in other end uses it would probably be harmful (e.g., concrete, concrete block, cement, etc.). For example, ASTM C618 limits the SO_3 (sulfate) content of fly ashes for use in concrete to 5%. Furthermore, FBC ashes may cause "unsoundness" because of their content of CaO and MgO. These compounds will slowly hydrate after the cement paste matrix has hardened. The products of the hydration have significantly larger volumes than the initial compounds. These increases in volume result in internal stresses that may eventually cause total disruption of the hardened cement.

Pollution Accompanying the Utilization of Ashes

Dust. Control of dust will always be necessary wherever dry fly ash is handled. Hauling waste ash, even dampened fly ash, in open-bodied dump trucks will not be tolerated much longer. Tank trucks would minimize the dust problem.[26]

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Dust is a threat in the sintering of fly ash for use in synthetic aggregates. However, this nuisance can be controlled by spraying with water; by adjustment of flow, pressure, and moisture; and by dust collection systems.[19]

Leaching. The leaching of compositions containing ash may not be a serious problem, because the ash is either well diluted with soil or other ingredients that may attenuate the more harmful components of the leachate, or the ash is stabilized (rendered less soluble and/or unavailable) by cementitious reactions. However, the leaching aspect certainly needs to be more fully investigated.

4.4.3 Flue Gas Desulfurization (FGD) Wastes

4.4.3.1 Introduction

Lime/limestone scrubbers have been selected for a large fraction of installed and planned FGD systems. They are scheduled to be installed on 5500 MWe of capacity by the end of 1976, and on more than 30,000 MWe of capacity by the end of 1980.[27] Large quantities of watery wastes will be generated in the operation of these scrubbers, and their disposal presents major problems with respect to land use and water quality. The raw sludges usually cannot be dewatered sufficiently to support people or equipment and must be disposed of by ponding. Reclamation of the disposal ponds may be impossible unless the wastes can be permanently stabilized by chemical fixation. In addition, overflow and leaching from the ponds can contaminate water supplies with soluble species present in the waste liquor and the settled solids.

The objectives of this report are: (1) to define the physical and chemical characteristics of the wastes and the magnitude of the disposal problem, (2) to assess the environmental acceptability and costs of available and developing technology for disposal or utilization, and (3) to identify information gaps and needed research or development.

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There is also a problem with drainage from the refuse pile resulting from the coal washing/preparation. This effluent is very similar in composition to acid mine drainage, and can be treated as such.[55] The waste may be neutralized with lime, limestone, soda ash, or caustic soda. Again, this transfers the real problem to one of sludge disposal. Battelle's total environmental assessment of an FBC boiler plant will include coal preparation, and therefore may contain the most current and complete analysis of this waste.

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THE DISPOSAL AND RECLAMATION OF SOUTHWESTERN COAL AND URANIUM WASTES

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1.0 INTRODUCTION

One of the major environmental problems confronting the coal and uranium industries of the Southwest is the disposal and reclamation of the large volumes of wastes produced by mining, processing, and on-site utilization of these resources. Wastes and drainages are produced during coal mining and cleaning, and the burning of coal in modern boilers produces large quantities of ash and sluige. Likewise, uranium mining and milling generates large amounts of solid and liquid waste materials. The wastes from both of these industries must be carefully deposited in waste disposal sites, and reclamation measures taken to ensure their long term stability. In this paper, the types of wastes produced by the coal and uranium industries in the Southwest will be described, some of the potential environmental impacts from these materials will be considered, and the procedures in current use for the disposal and reclamation of these wastes will be discussed.

2.0 DISPOSAL AND RECLAMATION OF COAL WASTES

Coal is a type of combustible rock that is formed from plant remains and various inorganic components. Because of this, coal is a highly heterogeneous material that contains a wide variety of rock and mineral impurities in addition to the carbon-like matrix. Most of the environmental contamination and waste materials produced by coals are a direct consequences of these impurities.

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In each step of the coal processing cycle, from mine to eventual utilization, various wastes or effluents are produced that must be treated, stored, or disposed of (Fig. 1.). These for the most part are high volume wastes that have the potential for causing great environmental damage if not properly handled. The coal industry of the Southwest is still in its infancy, but dramatic increases in the use of coal from the region (with the accompanying necessity to devote greater attention and resources to waste disposal and reclamation) will be necessary if our nation is to decrease its dependence on foreign energy sources and meet future energy needs.

2.1 COAL MINING WASTES

Coal is removed from the earth by two principal kinds of mining: strip mining and underground mining. In the Southwest, strip mining is the dominant form of coal extraction because most of the coal now being mined in this region is deposited relatively close to the surface.[1] In the strip mining of coal, heavy equipment such as power shovels, bulldozers, trucks, and draglines are used to remove the overburden and expose the coal seam, and remove the coal from the mine pit. In the past, many strip mines were simply abandoned with little or no effort to reclaim them after the accessible coal had been removed, but with the passage of the federal Surface Mining Control and Reclamation Act (1977) such practices are no longer allowable. Strip mine reclamation has become an integral part of the mining operation.

The surface mining act specifies that all surface soil must be carefully removed during mine development and stored so that it can be used later during reclamation. The remaining overburden must also be stored for reuse. As the coal is removed from the ground, the overburden is

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progressively backfilled into the previously mined areas. When the mining operation is completed the remaining overburden is put into the mine, the top soil is replaced, and native ground cover is reestablished.

Although adherence to the federal strip mine act eliminates the necessity to separately dispose of solid mine wastes, the problem of ground water contamination or disruption during or subsequent to mining remains a bothersome problem without an easy solution. Much of the strip-able coal in the southwestern region lies above major aquifers, but for that which does not, diversion and pumping of water from mining sites must be done. After mining is completed, it is very difficult to restore the condition of the original aquifers. Western coals and coal spoils are far less likely to produce contaminated drainages when gro. water passes through them than are eastern coals;[2] however, it would be a recommended practice to monitor the groundwater downfield from recently reclaimed mining areas to assure that undesirable contaminants are not being released.

In the underground mining of coal, access shafts are sunk vertically into the coal seam or mine shafts are bored directly into coal outcroppings; from these access points mine tunnels are distributed into the coal seam. Conventional room and pillar mining is most often practiced in the under-grourd mining of coal; however, some highly mechanized forms of mining, such as long-wall mining, are becoming more popular where conditions permit their use.[3]

The underground mining of coal produces a large amount of spoil or mineral wastes. These are the overburden and rock removed from the mine shafts while gaining access to the coal seams, and the rock intrusions in the seams themselves. It has not yet proven feasible to replace under-ground mine spoils back into the mine, so these wastes must be discarded at the surface. The usual practice for disposing and re'aiming western

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mine spoils is to place them into a depression or gully, were they can be compacted and graded to prevent erosion and perhaps seeded with native vegetation.[4] Nearby strip mines also provide a convenient place for the disposal of underground mine spoils.

One of the most serious environmental problems associated with the underground mining of southwestern coals is the possible disruption and degradation of aquifers located in the coal seam or associated strata. There are no effective remedial measures for restoring the original aquifer drainage once mining has disrupted it. Therefore, the best means of avoiding aquifer damage during underground coal mining is to preplan the mining operation with as much knowledge as possible of the geohydrology of the area.

2.2 COAL CLEANING WASTES

Coal, as mined, contains a great deal of extraneous rock and mineral matter. These constituents usually comprise about 10% to 20% of raw coals, but they can run as high as 50% for some coals.[5] The rock and mineral matter is expensive to ship, and it dilutes the energy content of the coal, but, of most importance from an environmental viewpoint, these impurities produce undesirable gaseous and particulate pollutants when the coal is burned. Therefore, about one-half of the total coal mined in the United States is prepared or cleaned prior to utilization to remove some of the noncombustible materials. Currently little western coal is washed or cleaned before combustion, but the demand for higher quality coal will undoubtedly result in a higher proportion of these coals being cleaned in the future.

Coal cleaning is largely a mechanical process, involving a series of crushing, sizing, separating and drying steps. In most cases, the coal is separated from the mineral matter on the basis of density. Modern coal

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preparation plants can recover about 90% of the energy content of the coal, while reducing the mineral content of the coal considerably.[6]

The wastes produced by coal cleaning are similar in composition to the spoil materials produced by coal mining. However, because cleaning wastes are more finely divided than mine wastes, they present a greater problem with regard to disposal and reclamation. The drainages from cleaning waste disposal sites are often contaminated with dissolved and suspended solids.[7] Also, because they contain some residual coal, cleaning waste dumps frequently catch fire; and, because of the poor structural quality of coal cleaning wastes, disposal areas for these materials often exhibit structural instabilities.[7]

The disposal and reclamation of coal cleaning wastes is governed by the Federal Coal Mine Health and Safety Act of 1969. Site choice and preparation methods are clearly defined by the act. Basically, the act specifies that coal cleaning wastes are to be discarded on an impermeable layer of clay, crushed refuse, or some other suitable material, and that successive additions of waste be compacted as they are added to the dump. Erosion stability of a completed refuse disposal area is provided by grading, followed by the addition of clay, top soil, or some other sealant. Although precautions are to be taken to direct surface and ground waters away from the disposal site, any water that does pass through the site must be impounded and treated, if necessary.

2.3 COAL COMBUSTION WASTES

The burning of coal, and the use of pollution control devices such as scrubbers and precipitators, produces large volumes of solid waste materials that need to be disposed of in environmentally compatible ways. The bulk of the residue is bottom ash formed by the nonvolatile mineral matter in

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the coal, and fly ash, which is a fine particulate material removed from the boiler effluents by precipitators or scrubbers. More than 60 million tons of bottom ash, fly ash and scrubber sludge are produced annually in the United States from coal combustion.[8] There is growing awareness that the discarded wastes from coal combustion are a serious potential source of surface and ground water contamination.

There is not yet federal legislation specifically addressing the disposal and reclamation of the various forms of coal combustion wastes. However, both the Federal Water Pollution Control Act (FWPCA) and The Resource Conservation and Recovery Act (RCRA) apply to coal combustion wastes, and, in effect, dictate to some extent how these w' .s can be disposed.

Land filling and ponding are the two most prevalent methods for disposing of coal combustion wastes.[9] Land disposal sites for ash include gullies, natural depressions, excavated areas, and depleted strip mines. One disadvantage of using land fill methods for disposing of coal ash in the southwestern region is that considerable maintenance is needed to reduce ash loses from the dump by the winds that frequent the area.

Much of the ash produced by coal combustion is discharged into ash ponds. With increasing frequency fly ash and scrubber sludge are being discharged into the same pond.[9] In these ponds the solids are allowed to settle, and the water is decanted off into holding ponds or recycled for process use.

About 4×10^3 acre-ft of land are required for the disposal of the 5×10^6 tons of ash that accumulate in the lifetime of a 1000 MWe coal-fired power plant.[9] If scrubber sludge is also ponded in the same area, land requirements increase disproportionately due to the relatively large volume occupied by the sludge/ash mixtures.[9]

The reclamation of ash and sludge ponds is tricky business due to high amounts of residual water that these wastes retain. Often it is necessary

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to add cement, thickeners or stabilizing agents to the dried solids before reclamation can proceed.[9,10] Frequently stabilizing agents are added directly to the sludges before ponding, thus alleviating the need to rework the material during reclamation. The final stages of ash and sludge pond reclamation include compacting the dried stabilized solids, adding top soil and establishing vegetation to reduce surface erodibility.

The control of contaminated leachates and seepages from disposal ponds for fly ash and scrubber sludge represents, perhaps, the most significant environmental problem facing the southwestern coal and utilities industries. Many trace contaminants that are present in the fly ash or sludge can be mobilized by the waters present in the ponds.[9,10] The transport of contaminants from the disposal ponds into shallow or deep aquifers could result in degradation of the quality of these waters. Frequently, ash and sludge disposal areas are lined with impermeable materials to reduce the loss of water from them.[9,10] Nonetheless, careful monitoring of the surface and subsurface effluents from disposal ponds is a necessity in any well planned disposal and reclamation scheme for coal combustion wastes.

3.0 DISPOSAL AND RECLAMATION OF URANIUM MINING AND MILLING WASTES

In addition to coal, the southwestern region of the United States is blessed with an abundance of uranium ore. In fact, about 50% of our current national production of uranium concentrate comes from the San Juan Basin.[11] The uranium contents of the ores of the region are quite low (usually about 0.2%)[12] hence, a relatively large volume of waste material is produced by the uranium mining and milling industries compared to most other primary minerals extraction processes.

Precluding the possible disposal of reactor wastes in southwestern sites, the major types of wastes and effluents produced by the uranium industry in the region are depicted in Fig. 2. There are many analogies between the disposal and reclamation of coal mine and combustion wastes and uranium mining and milling

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wastes; however, the mobile radioactive and nonradioactive components in many uranium wastes pose a far greater potential for environmental harm than do most coal wastes, dictating that much more care and judgement be exercised in disposing of uranium industry wastes.

3.1 URANIUM MINING WASTES

There are three forms of mining practiced by the uranium industry: open pit, underground, and in situ leach mining. Most of the uranium ore in the Southwest is extracted either by underground or open pit mining.[13] Nationally, about 2% of the total uranium concentrate produced results from in situ leach mining, although this form of mining is likely to become more prevalent as dwindling resources force the exploitation of lower grade ores.

Underground mining of uranium ore produces many of the same types of waste materials as does the mining of coal. These include both mine spoils and mine drainage. Mine wastes (rock and soil) are generated while gaining access to the ore bearing strata, and associated rock and lower grade ores are removed as waste during the development of the mine. Often groundwater intrudes into the mining area and mine dewatering is required. The volumes of water pumped from active underground uranium mines vary between 20 and 4000 gal/min.[14] The quality of these water discharges is variable, but sometimes treatment may be needed to reduce contaminant levels, or contaminated water is ponded and evaporated.

The solid wastes or spoils produced by underground mining of uranium ore is usually discarded in convenient nearby disposal sites. Uranium mine spoils and ores are generally not considered to be highly hazardous materials; however, there are documented instances where the contaminated drainages from surface accumulations of these materials have caused severe environmental damage to plants and animals.[15]

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Mine water from underground uranium mines is usually pumped into surface drainage channels or into evaporation ponds. Some mine water is also used as process water for mining and milling operations. Where the volumes of water involved are very large, care must be exercised in disposing of them. Seepage from mine water holding ponds can pass through tailings or mine spoil disposal sites, picking up contaminants from these sources, and transporting these contaminants into the environment.

In some parts of the Grants Mineral Belt, mine dewatering has been shown to result in degradation to the quality of aquifers in the area.[16] This was due to the acute drawdown of the aquifer volume and subsequent increases in the salt contents of the water. Such consequences of mine dewatering activities may dictate in the future that mine waters be reinjected back into the strata in which they originated.

Open pit mining of uranium ore is practiced where the ore deposits are located relatively near the surface, usually at depths of less than 500 ft.[17] In a fashion similar to coal mining, overburden is removed with front end loaders, and scrapers. Additional spoils are produced during the mining operation when low grade ores are discarded or stored, or additional overburden must be removed to expose ore pockets. Water encountered during the open pit mining of uranium is either diverted away from the mining site or is pumped to the surface and released or impounded. Here too, aquifer disruption and loss of ground water quality are difficult problems to circumvent.

There are no federal laws pertaining specifically to mine spoils or reclamation following either the strip or underground mining of uranium ore. The recently enacted Uranium Mill Tailings Radiation Control Act (UMTCA) does instruct EPA and NRC to report to Congress by 1980 concerning the locations and potential environmental hazards of uranium mine wastes, along with recommendations to eliminate these hazards. For the time

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being FWPCA and RCRA provide the major guidelines for the dipsosal and reclamation of these wastes. Reclamation practices for both underground and open pit mine wastes produced by uranium extraction are similar to these employed for coal mine wastes.

In many instances, it is not practical to mine certain uranium ores, due to the inaccessability of the deposits or to the low quality of the ore. Such deposits may instead be exploited by in situ leaching techniques.[18] In situ leach mining involves the pumping of chemical leach solutions into the ore deposit through an injection well, forcing the leachate through the ore to dissolve or mobilize the uranium compounds, and collecting the pregnant leach solutions at a series of recovery wells. The uranium-bearing solutions are then processed at the surface to recover the uranium.

In situ leach mining is advantageous in that it produces very small amounts of waste materials or aqueous effluents to be disposed and reclaimed. However, these apparent advantages may be more than offset by the environmental problems caused by the escape of the chemical leach solutions into subsurface water systems. Unfortunately, even the best efforts at geologic mapping cannot result in the total assurance that a leach mining site is hydrologically isolated from its surroundings.

3.2 URANIUM MILLING WASTES

Uranium milling is the process in which crushed and powdered uranium ores are subjected to a series of chemical leaching and extraction steps to remove the minute amount of uranium from the ore. These chemical processing steps partially break down the structure of the ore matrix, thereby releasing the uranium contained within. As mentioned earlier, more than 99% of the contents of the uranium ore are eventually discarded as mill wastes. One very important consequence of the milling operation is that it also

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mobilizes other potentially harmful components in the ore (such as toxic trace elements or other radioactive substances) that are released as wastes i tailings disposal sites. In addition mill tailings also contain small amounts of chemicals and solvents used in the milling processes.

Tailings are discharged from uranium mills in the form of aqueous slurries. Typical mill tailings slurries contain water, sand, silt and various slimes. The slurries are pumped into impoundments where the solids settle out and the remaining water is decanted into evaporating ponds, or is recycled back into the mill. However, seepage or overflow from tailings ponds or holding ponds often escapes into the environment. When this happens there is the strong likelihood that these waters will carry undesirable quantities of radioactive and nonradioactive contaminants with them.[19,20]

Until recently the legal basis for regulating the disposal and reclamation of uranium mill wastes was quite confusing. NRC (or individual states in agreement with NRC) held licensing authority over active tailings disposal operations, but this authority terminated when the license was withdrawn at the cessation of the mill operation. The responsibility for inactive tailing disposal areas was left piecemeal up to the individual states. In late 1978, Congress passed UMTCA, which directs that NRC provide licensing authority over both active and inactive mill tailings disposal sites. EPA is charged by the act with developing standards for tailings areas, and DOE is responsib for the development of control and reclamation methods for both active and inactive disposal areas.

Environmentally, mill tailings disposal sites are particularly troublesome because they can be the source of both atmospheric and water-borne contaminants.[19,20] Radon, a radioactive gas, is produced by radioactive

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decay within the tailings materials, and may be emitted to the atmosphere if precautions are not taken to seal the surface of the tailing pile.[19] In addition, as alluded to earlier, the large volumes of contaminated water in or near tailings dump sites can seep or discharge into surface or groundwater systems. Thus, the disposal and reclamations of uranium mill tailings must provide for the containment of radon gas, the containment of aqueous solutions, and long-term resistance to erosion.

Past practices, where mill tailings were discarded without much regard to environmental consequences, are no longer acceptable. Although the details of current mill tailings disposal and reclamation strategies will depend both on the nature of the disposal site and the volume of the materials involved, several key components will be present in each.[2] In the future, mill tailings will more than likely be deposited into impoundments or settling ponds that are lined with an impermeable layer of rock, clay or other stable material. Frequently, stabilizing and flocculating agents will be used to more efficiently promote dewatering, and to assure the stability of the dried tailing solids. All waste water will be recycled, evaporated or treated prior to release. Upon completion of a disposal site, the entire site will be capped with another impermeable layer of clay, asphalt or concrete to retain radon and promote stability. Finally, the capping agent may be covered with soil and plant growth reestablished.

4.0 SUMMARY

The types of solid wastes and effluents produced by the southwestern coal and uranium mining and milling industries were considered, and the current methods for the disposal and reclamation of these materials were discussed. The major means of disposing of the solid wastes from both industries is by land fill or in some

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instances ponding. Sludges or aqueous wastes are normally discharged into settling and evaporative ponds. Basic reclamation measures for nearly all coal and uranium waste disposal sites include solids stabilization, compacting, grading, soil preparation and revegetation. Impermeable liners and caps are beginning to be applied to disposal sites for some of the more harmful coal and uranium waste materials.

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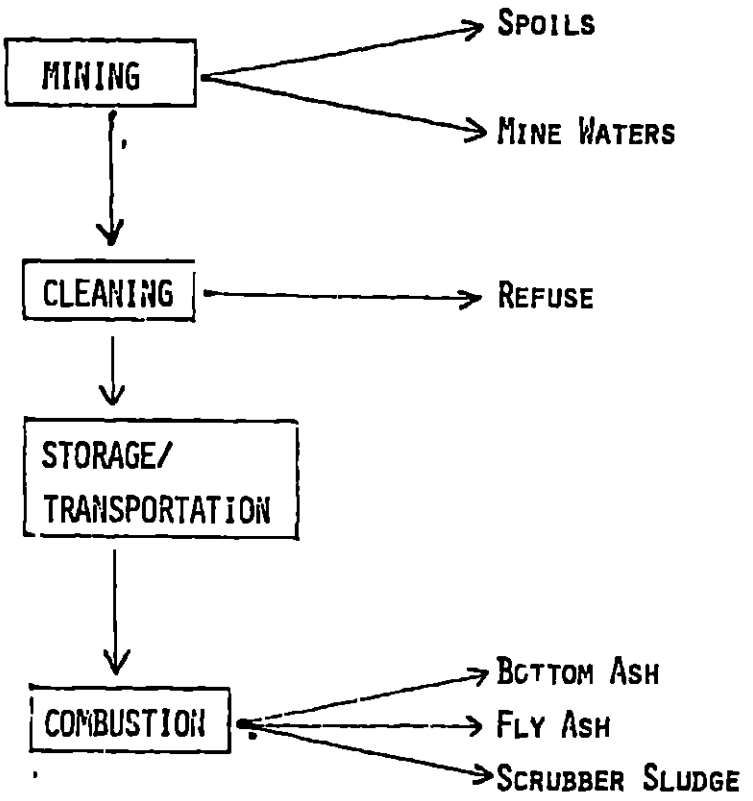

Fig. 1. Wastes produced by coal mining and combustion.

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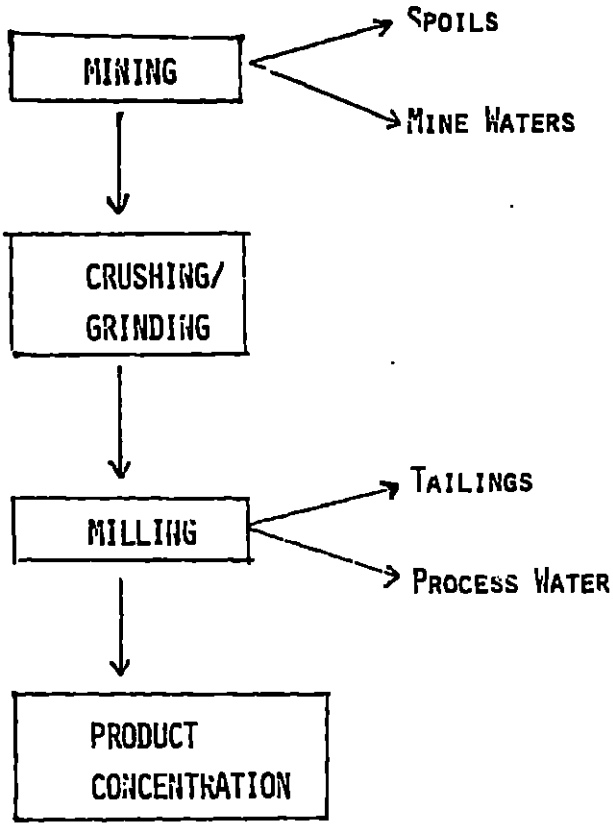

Fig. 2. Wastes produced by uranium mining and milling.

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Health and Environmental Impacts of Increased Generation of Coal Ash and FGD Sludges

Report to the Committee on Health and Ecological Effects of Increased Coal Utilization

by Chakra J. Santhanam,* Richard R. Lunt,* Sandra L. Johnson,* Charles B. Cooper,* Philip S. Thayer,* and Julian W. Jones†

This paper focuses on the incremental impacts of coal ash and flue gas desulfurization (FGD) wastes associated with increased coal usage by utilities and industry under the National Energy Plan (NEP). In the paper, 1985 and 2000 are the assessment points using the baseline data taken from the Annual Environmental Analysis Report (AEAR, September 1977). In each EPA region, the potential mix of disposal options has been broadly estimated and impacts assessed therefrom. In addition, future use of advanced combustion techniques has been taken into account.

The quantities of coal ash and FGD wastes depend on ash and sulfur content of the coal, emission regulations, the types of ash collection and FGD systems, and operating conditions of the systems and boiler. The disposal of these wastes is (or will be) subject to Federal and State regulations. The one key legal framework concerning environmental impact on land is the Resource Conservation and Recovery Act (RCRA). RCRA and related Federal and State laws provide a sufficient statutory basis for preventing significant adverse health and environmental impacts from coal ash and FGD waste disposal. However, much of the development and implementation of specific regulations lie ahead.

FGD wastes and coal ash and FGD wastes are currently disposed of exclusively on land. The most common land disposal methods are impoundments (ponds) and landfills, although some mine disposal is also practiced. The potential environmental impacts of this disposal are dependent on the characteristics of the disposal site, characteristics of the coal ash and FGD wastes, control method and the degree of control employed. In general, the major potential impacts are ground and surface water contamination and the "degradation" of large quantities of land. However, assuming land is available for disposal of these wastes, control technology exists for environmentally sound disposal.

Because of existing increases in coal use, the possibility of significant environmental impacts, both regionally and nationally, exists regardless of whether the NEP scenario develops or not. Existing baseline data indicate that with sound control technology and successful development and implementation of existing regulatory framework, regional scale impacts are likely to be small; however, site-specific impacts could be significant and need to be evaluated on a case-by-case basis.

Both Federal and privately-funded programs are developing additional data and information on disposal of FGD sludges and coal ash. Continuation of these programs will provide additional vital information in the future. However, further information in several areas if desirable: further data on levels of radionuclides and trace metals in these wastes: studies on biological impacts of trace metals; and completion of current and planned studies on disposal problems associated with advanced combustion techniques like fluid bed combustion.

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Executive Summary

In meeting the requirements of the National Energy Plan (NEP), the Committee on Health and Ecological Effects of Increased Coal Utilization

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commissioned 12 studies, including this paper. The paper focuses on the incremental impacts of coal ash and FGD wastes associated with increased coal usage by utilities and industry under NEP.

In this paper 1985 and 2000 are the assessment points using the baseline data taken from the Annual Environmental Analysis Report (AEAR, under ERDA Contract EE-01-77-0135, September 1977). In each Federal region, the potential mix of disposal options has been broadly estimated and impacts assessed therefrom. Potential impacts are dependent on the characteristics of the wastes and the disposal sites. Future use of advanced combustion techniques has been taken into account.

Technology and Production of Wastes

Coal-fired utilities and industrial boilers generate two types of coal ash: fly ash and bottom ash. Fly ash is collected by mechanical collectors — electrostatic precipitators, fabric filters, or wet scrubbers. Flue gas desulfurization (FGD) can be accomplished by nonregenerable or throwaway systems which result in FGD wastes and regenerable systems which produce a saleable product (sulfur or sulfuric acid). At present, 50,000 MW of coal-fired utility boilers are committed to flue gas desulfurization; 90% of these use nonregenerable systems. Nonregenerable systems require wet scrubbing technology. The four principal types of systems are those based on direct limestone, direct lime, alkaline fly ash and dual alkali. Lime, limestone, and fly ash systems are commercially available while dual alkali systems represent second generation processes now reaching commercial demonstration.

The quantities of coal ash and FGD wastes depend on ash and sulfur content of the coal, emission regulations, the types of ash collection and FGD systems, and operating conditions of the systems and boiler. To meet New Source Performance Standards (NSPS), a typical utility operating at 70% load produces 100-500 tons of dry, ash-free sludge annually per megawatt of capacity. Using baseline data in the AEAR, production of coal ash and FGD wastes was estimated. The increased generation of coal ash and FGD wastes in each Federal region is shown in Table 1.

Disposal Options and Regulatory Considerations

At present, control technology for environmentally sound disposal of coal ash and FGD waste exists. This paper assesses the impacts on that basis. The disposal of FGD waste and coal ash will be subject to Federal and State regulations. While several Federal laws address disposal, the one key legal framework concerning environmental impact on land is the Resource Conservation and Recovery Act (RCRA). RCRA and related Federal and State laws (e.g., Clean Air Act and Federal Water Pollution Act) provide sufficient statutory basis for preventing significant adverse health and environmental impacts from coal ash and FGD waste disposal. However, much of the development and implementation of specific regulations lie ahead, including those with respect to wastes considered in this paper. Therefore, throughout this paper it is assumed that adequate regulatory authority exists but that potential impact issues require discussion so that future regulatory planning can focus on prevention or minimization of adverse impacts appropriately.

Table 1. Increased generation of ash and FGD wastes — cumulative[a].

Federal region	Coal ash only		FGD sludges only		Coal ash and FGD sludges	
	1985	2000	1985	2000	1985	2000
1	18	16	24	5	20	12
2	15	21	26	6	19	15
3	8	17	45	88	14	28
4	2	2	19	28	6	9
5	2	4	12	22	4	8
6	58	22	77	60	63	15
7	2	4	21	33	7	13
8	18	37	67	150	20	43
9	56	28	911[b]	> 1000[b]	64	38
10	104[c]	147[c]	596[b]	616[b]	119[c]	166[c]
National average	9	12	26	36	12	19

[a]All baseline data from the Annual Environmental Analysis Report (AEAR). Percentage incremental increase under NEP (over pre-NEP) is shown. All FGD systems assumed to be nonregenerable. Boilers assumed to meet NSPS standards in 1985 and BACT in 2000.
[b]Total sludge production in Regions 9 and 10 is low (less than 1% of national).
[c]Total ash and sludge production in Region 10 is low (less than 2% of national).

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At present FGD wastes and coal ash are disposed of exclusively on land. Ocean disposal may be a technically feasible alternative but current regulatory disincentives preclude ocean disposal of FGD wastes and coal ash. In the future, ocean disposal of treated and sulfate-rich sludges may be carried out to a limited extent in regions where there are no mines available and disposal sites for land impoundments are scarce. However, if regulations constrain ocean disposal, use of regenerable systems would be employed in such regions.

The most common land disposal methods are impoundments (ponds) and landfills, although some mine disposal is also practiced. Future disposal methods assumed in each region are shown in Table 2.

Table 2. Disposal Methods.

EPA Region	Method
1, 2	Impoundment, landfill, ocean
3, 4, 5, 6, 7	Impoundment, landfill, mine
8, 9, 10	Impoundment, mine

The following impact assessments are based upon this assumed mix of disposal options.

Environmental Impacts

Environmental impacts are dependent on the characteristics of the disposal site, characteristics of the coal ash and FGD wastes, control method and the degree of control employed. Impacts are site-specific and cannot be easily generalized over a region. Furthermore, the existing regulatory framework, if successfully implemented, should prevent or minimize significant adverse impacts. Against this background, some broad generalizations on the potential environmental issues can be made on a regional or national basis. Potential impacts are assessed on the combined generation of ash and FGD waste by utility and industry. Regional baseline data are not available at present for industry alone, but wastes from industry will grow rapidly, becoming a very significant part of the national waste generation by 2000.

Potentially important impacts in most regions will not come from the differences between NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops. Existing baseline data indicate that with sound control technology and successful development and implementation of existing regulatory framework, regional scale impacts are likely to be small; site-specific impacts could be significant and need to be evaluated on a case by case basis.

Land-Related. Projected incremental land requirements under NEP (over pre-NEP) for disposal of coal ash and FGD wastes are about 11% by 1985 and 19% by 2000. Projected total acreage involved under NEP is less than 21,000 acres by 1985 and less than 75,000 acres by 2000.* The existing regulatory framework, if successfully implemented, will minimize impacts on geology and soils. The magnitude of the incremental land use from a public policy viewpoint is not significant on a regional or national basis. However, the land required in a given locality could require modifications of land use planning and practices on a site-specific basis.

Water-Related. On a regional basis, hydrologic impacts are expected to be quite small. An important potential impact is the contamination of groundwater by leachate from the sludge/ash disposal area. In light of the existing data on sludge properties and on the effectiveness of the various controls, there appear to be adequate means for controlling the quantity of sludge leachate and, to some extent, its quality. Thus, the impacts due to the incremental sludge or sludge plus ash caused by NEP will become a site-specific question as to whether a potential disposal operation is feasible and to what extent control measures are required. Since regulatory authority is available to prevent deterioration of groundwater to the extent that its existing end-use is altered, impact on groundwater quality should be minimal.

Air-Related. Sludge and ash disposal methods entail significant levels of moisture in the disposed materials. Generally the high moisture content of the material would mitigate fugitive dust generation for most operations, and impacts on air quality on a regional basis would be small.

Biotic Impacts. Regional impacts on vegetation and wildlife are primarily a function of the additional

*EPA policy involves use of metric units; however, this paper uses some nonmetric units for the reader's convenience. Metric conversion factors are provided in Table 3 for readers more accustomed to the metric system.

Table 3. Metric conversion factors.

Nonmetric	Multiplied by	Yields metric
Acres	4048	m^2
BTU	1054.8	joules
	0.252	kcal
ft	0.3048	meters
ft^3	0.02832	m^3
in	2.54	cm
lb	0.4536	kg
mph	1.609	km/hr
psi	703.1	kg/m^2
tons	907.2	kg

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land area required for landfill and impoundment disposal. Potential adverse impacts are: vegetation loss at the disposal site and effects on adjacent vegetation and habitat. Potential positive impacts include reclamation of surface-minded lands. Potential impacts on terrestrial or aquatic biota due to trace contaminants in leachate reaching surface waters are not well understood and need to be evaluated on a case by case basis. The existing regulatory framework provides mechanisms for the prevention of significant adverse biotic impact.

Health Impacts. As in the environmental impacts discussed above, the available regulatory framework, if successfully developed and implemented, should prevent adverse health impacts. With that in mind, potential impact issues can be: occupational (i.e., effects on workers in the disposal area); local (i.e., effects on persons near the site due to fugitive dust and impacts on local ground and surface waters; or remote (e.g., effect of materials, mainly trace metals, carried as leachate and turning up in water supplies.

The potential impacts in most areas would not come from the differences between the NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops. Existing baseline data is limited but suggests that, with sound control technology and successful implementation of the existing regulatory framework, regional impacts are likely to be small. However, additional data are needed in this area.

Data Gaps and Research Needs

The Environmental Protection Agency (EPA), the Department of Energy (DOE), the Electric Power Research Institute (EPRI), and others have ongoing programs to develop more baseline data and information on disposal of FGD sludges and coal ash. Continuation of these programs will provide additional vital information in the future. In addition, from the environmental and health viewpoints, further information in several areas is desirable: data on levels of polycyclic aromatics (if any), radionuclides, and trace metals in these wastes; studies on biological impacts of trace metals including their potential synergistic impacts; and completion of current and planned studies on disposal problems associated with advanced combustion techniques like fluid bed combustion.

Introduction

Overview

The National Energy Plan (NEP) calls for study of the health and environmental impacts of increased coal utilization. The Committee on Health and Ecological Effects of Increased Coal Utilization was established to fulfill this requirement. The Committee commissioned the preparation of a number of working papers to review the current state of knowledge on key topics concerning increased use of coal. This paper addresses the health and environmental impacts associated with the increased generation of coal ash and flue gas desulfurization (FGD) sludges under the proposed National Energy Plan (NEP). The paper was prepared by using the available baseline data in the Annual Environmental Analysis Report (AEAR), a MITRE report to ERDA under Contract EE-01-77-0135, September 1977.

Approach

The proposed National Energy Plan (NEP) emphasizes among other things conservation and increased energy efficiency and a shift toward increased use of coal with adequate environmental safeguards. The increased use of coal will lead to an increased generation of coal ash, including fly ash and bottom ash and flue gas desulfurization (FGD) sludges.

This paper focuses on the impacts associated with the disposal of the above wastes. Utilization of the above wastes in any commercial manner which is technically and economically feasible in many cases and any consequent impacts are excluded from this study. The following aspects of increased coal use are, among others, outside the scope of this paper: wastes generated during mining of coal, including coal washing; sources associated with the transportation of coal; direct air pollution associated with power plant emissions; sludges from water pollution control activities; and wastes from coal processing (liquefaction, gasification, metallurgical coking, and other direct use of coal in processing).

In order to place this assessment in perspective, the following are noted.

The incremental impacts associated with increased coal ash and FGD sludge generation have been the focus of attention. The two basic scenarios determining the incremental impact are: that under the proposed National Energy Plan (NEP) and that under restrained (except for EPA regulations) conditions described as pre-NEP. The incremental impacts and, where appropriate, baseline impacts in 1985 and 2000 were chosen as assessment points, using the AEAR. Important impacts in most areas will not arise out of the differences between NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops.

Impacts associated with coal ash alone are examined separately from those associated with FGD

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sludges and coal ash together. FDG sludge is frequently disposed of in combination with coal ash. Hence, the impacts of this combined disposal the impact of coal ash disposal alone are dealt with separately.

Both regional and national impacts are examined. Local and regional impacts are more important than averaged national impacts. Due to lack of baseline data, impacts associated with industry alone in each region have not been considered. Assessment has been based on the combined impact of industries and utilities in each region.

In each Federal region, a potential mix of disposal options has been broadly estimated and impacts assessed on this basis.

Potential impacts are dependent on the characteristics of the wastes and the disposal site. Therefore, it is necessary to integrate the method of disposal, type of control technology and the degree of control in light of these site-specific and waste-specific characteristics.

The current regulatory framework established by air, water and solid waste legislation, if successfully developed and implemented, would minimize or prevent sludge and ash disposal practices with significant adverse impacts.

Baseline data on waste generation does include probable contribution of advanced combustion techniques (like fluid bed combustion) for coal.

Present Technology and Production of Coal Ash in FGD Sludges

Coal Ash. Coal-fired utility and industrial boilers generate two types of coal ash: fly ash and bottom ash. Both constitute the noncombustible (mineral) fraction of the coal and the unburned residuals. Fly ash, which accounts for the majority of the ash generated, is the fine ash fraction carried out of the boiler in the flue gas. Bottom ash represents that material which drops to the bottom of the boiler and is collected either as boiler slag or dry bottom ash, depending upon the type of boiler.

The total amount of coal ash produced is directly a function of the ash content of the coal fired. Thus, the total quantity of ash produced can range from a few percent of the weight of the coal fired to as much as 35%. The partitioning of ash between fly ash and bottom ash usually depends upon the type of boiler. Standard pulverized coal fired boilers typically produce 80-90% of the ash as fly ash. In cyclone-fired boilers the fly ash fraction is usually somewhat less, 65-80% of the total ash created.

Fly ash carried in the flue gas stream can be collected in a number of ways to meet current particulate emission control limitations. Typical methods include mechanical collection, electrostatic precipitation, fabric filtration and wet scrubbing. Mechanical collectors generally are not capable of meeting present emissions control limitations and, when used, are generally followed by either an electrostatic precipitator or high efficiency wet scrubbing systems.

FGD Sludges. FGD systems can be generally categorized into two groups: nonregenerable, or throwaway, systems which produce a waste material for disposal; and regenerable, or recovery, systems which produce a saleable byproduct (sulfur or sulfuric acid). There are now over 50,000 MW of coal-fired electric utility boilers in the United States to which flue gas desulfurization systems are being applied (including systems in operation, under construction, or in procurement). About 90% of this capacity involves nonregenerable systems, most of which employ lime or limestone to produce a solid waste, calcium-sulfur salt for disposal. This technology can be expected to dominate in boiler applications of flue gas desulfurization systems for the foreseeable future.

All commercial nonregenerable processes today involve wet scrubbing where gases are contacted at some stage with aqueous slurries or solutions of absorbent. Although most nonregenerable systems can withstand relatively high levels of particulate and trace contaminants and many in the past have been designed for simultaneous SO_2 and particulate removal, most systems being installed today, particularly on utility-scale boilers, follow high efficiency electrostatic precipitators in order to ensure a more reliable service. The notable exceptions to this are systems which utilize the alkalinity in the fly ash for SO_2 control and therefore frequently remove fly ash and SO_2 simultaneously.

The principal types of nonregenerable systems producing solid wastes for disposal are: direct limestone scrubbing, direct lime scrubbing, alkaline fly ash scrubbing, and double (dual) alkali scrubbing.

Most nonregenerable systems in operation today are lime or limestone scrubbing systems. These utilize a slurry of lime or limestone for SO_2 removal and can produce a waste ranging from a slurry to a relatively dry filter cake. Lime, limestone and flyash scrubbing are now considered to be a commercially available technology. A number of these systems have demonstrated high availability and reliability on utility-scale boiler applications. Double (dual) alkali systems represent a second generation technology which is now reaching commercial demonstration. Double alkali systems utilize solutions for sodium salts for SO_2 removal which are then reacted with lime outside the scrubber system to produce a waste discharged as filter cake.

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The quantity of ash-free waste solids produced from nonregenerable systems is dependent upon a number of factors including: the sulfur content of the coal; the SO_2 emissions regulations; the type of FGD system and its operating conditions; and the boiler operating conditions. In general, the quantity of dry, ash-free sludge produced varies from 2.2 to about 3.0 times the quantity of SO_2 removed from the flue gas. A typical utility operating at a 70% load factor and meeting current New Source Performance Standards (NSPS) for SO_2 would produce anywhere from 100-500 tons of dry, ash-free sludge annually per MW of capacity.

Characteristics of Coal Ash and FGD Sludges

Coal Ash Characteristics. The chemical composition of coal ash (bottom ash, fly ash, and slag) varies widely, in concentrations of both major and minor constituents. Table 4 shows a compilation of chemical composition of both fly ash and bottom ash from the firing of a wide range of different coals. The principal factor affecting the variation in the composition is the variability in the mineralogy of the coal. However, differences in composition can exist between fly ash and bottom ash (or boiler slag) generated from the same coal due to differences in the degree of pulverization of the coal prior to firing, the type of boiler in which the coal is fired, and the boiler operating parameters and combustion efficiency. Regardless of the type of ash (either fly ash or bottom ash), more than 80% of the total weight of the ash is usually made up of silica, alumina, iron oxide, and lime. It should be noted that the compositional breakdown shown in Table 4 reflects only the elemental breakdown of the constituents reported as their oxides and not necessarily the actual compounds present.

While the major constituents of bottom ash and fly ash are generally similar, there is usually an enrichment of trace elements in the fly ash as compared with the bottom ash based upon the total quantity of trace elements in the coal fired. A few of the elements originally present in the coal (notably sulfur, mercury, and chlorine) are almost completely volatilized and leave the boiler as gaseous species which are not collected downstream in dry ash collection equipment. However, these can be collected in wet scrubber systems, as discussed later.

Up to 10% of fly ash can be water-soluble, so the potential exists for release of contaminants through leaching. The principal soluble species are usually calcium, magnesium, potasssium, sulfate, and chloride. Leachates resulting from ash are usually alkaline due to the presence of calcium oxide and other alkaline species, although some ashes have been found to be inherently neutral or even acidic.

Table 4. Range of coal ash compositions.[a]

Major constituents (wt %)	
Silica (as SiO_2)	25–60
Alumina (as Al_2O_3)	10–30
Ferric oxide (as Fe_2O_3)	5–40
Lime (as CaO)	0.5–25
Magnesia (as MgO)	0.2–8.0
Potassium oxide (as K_2O)	0.1–4.0
Sodium oxide (as Na_2O)	0.1–4.0
Titanium dioxide (as TiO_2)	0.5–2.5
Sulfur trioxide (as SO_3)	0.2–20
Carbon and volatiles	ND–2
Selected trace constituents (ppm)	
Antimony	ND–200
Arsenic	ND–1,000
Barium	50–10,000
Beryllium	ND–200
Boron	15–6,000
Cadmium	ND–0.5
Chloride	—
Chromium	5–500
Cobalt	5–400
Copper	20–3,000
Fluoride	—
Lead	10–1,500
Manganese	50–10,000
Mercury	0.01–100
Molybdenum	5–1,500
Nickel	15–70
Phosphorus	5–10,000
Selenium	1–50
Thorium	—
Uranium	—
Vanadium	10–1,000
Zinc	25–15,000

[a]Source: (*1*, *2*).

The physical properties of fly ash vary with the type of coal fired, the boiler operating conditions, and the type of fly ash collector employed. A mechanical collector, which generally removes only the heaviest fly ash fraction, produces a relatively coarse material with the consistency of a fine sand. In contrast, the ash removed in an electrostatic precipitator is usually finer, with silt-like grading. The range of specific gravities of fly ash depends upon particle size distribution and fly ash composition; however, specific gravities typically range from approximately 1.9 to 2.7. A small portion of the fly ash (< 4%) consists of cenospheres (hollow spheres) which have an apparent density less than water. Bulk densities of fly ash, because of the variations in specific gravity and particle size distribution, vary greatly. Bulk densities of fly ash, therefore, vary greatly, although the typical range for fly ash compacted at optimum bulk density would be 110-135 lb/ft^3.

An important property of coal fly ash is its poz-

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zolanic activity. Pozzolanic activity in fly ash either by the lime in it or by the addition of lime causes the fly ash to aggregate and harden when moistened and compacted. Because of the presence of pozzolanic activity in some fly ashes, the engineering properties of fly ash vary greatly. In general, untreated fly ash (that to which lime has not been intentionally added) exhibits engineering properties similar to soils of equivalent particle size distributions. Permeabilities of compacted fly ash samples generally range from 5×10^{-5} cm/sec to 5×10^{-6} cm/sec. Treatment of pozzolanic fly ashes with lime can result in significant increases in compressive strength and increases in permeability (depending upon the amount of lime, the water content, curing time, and degree of compaction).

Bottom ash can be collected either dry or in a molten state, in which case it is generally referred to as bottom slag. Dry-collected bottom ash is heavier than fly ash, with a larger particle size distribution. Since it has a similar chemical composition to that of fly ash, it behaves similarly, although pozzolanic activity is usually somewhat less in bottom ash.

Boiler slag is a black glassy substance composed chiefly of angular or rod-like particles, with a particle size distribution ranging from fine gravel to sand. Boiler slag is porous, although not of so great a porosity as dry bottom ash. It is generally less reactive in terms of its pozzolanic properties than either dry bottom ash or fly ash.

Because of the similarities between bottom and fly ash, they have been grouped together for environmental impact assessments. Both bottom ash and fly ash are frequently disposed of in pond disposal areas. Typically, bottom ash and fly ash would be sluiced to a central disposal pond where the ash would be allowed to settle out and the overflow liquor discharged or returned for sluicing. Analyses of pond liquors indicate total dissolved solids levels on the order of hundreds of ppm, the major constituents being calcium, magnesium, sodium, sulfate, and chloride, with lesser amounts of silicates, iron, manganese, and potassium.

FGD Sludge Characteristics. Both the chemical composition and the physical and engineering properties of the sludge produced by any FGD system at any particular time will depend upon a variety of factors including: the composition of the coal burned; the type of boiler and its operating conditions; the method of particulate control employed; and the type of FGD system and the way in which it is operated. Sludge characteristics, therefore, and the chemical composition in particular can vary over extremely wide ranges.

The principal substances making up the solid phase of FGD sludges are calcium-sulfur salts (calcium sulfite and/or calcium sulfate) along with varying amounts of calcium carbonate, unreacted lime, inerts and/or fly ash. The ratio of calcium sulfite to calcium sulfate (the latter present as $CaSO_4 \cdot \frac{1}{2} H_2O$ or as gypsum, $CaSO_4 \cdot 2H_2O$) will depend principally upon the extent to which oxidation occurs within the system. Oxidation is generally highest in systems installed on boilers burning low sulfur coal or in systems where oxidation is intentionally promoted. Fly ash will be a principal constituent of sludge only if the scrubber serves as a particulate control device in addition to SO_2 removal or if separately collected fly ash is admixed with sludge. The amount of inerts and unreacted raw materials (lime and/or limestone) in sludges will depend upon the quality and utilization of raw materials (system stoichiometry). Table 5 outlines typical composition data on both.

A variety of trace elements find their way into FGD sludges from a number of sources: from coal where they are present either as mineral impurities or as organometallic compounds; from lime, limestone, or other reagents used in SO_x removal; and also from the process water make-up used. The greatest source of trace elements, though, is from the coal fired, and the levels of trace elements depend primarily upon their level in the coal, the amount, if any, of ash that is collected or admixed with the sludge, and the efficiency of the scrubber system in capturing trace metal vapors and fine particulates. Most of the elements in coal are not highly volatile and will be retained in the ash matrix (either as fly ash or bottom ash). The concentrations in the sludge of those elements that are most highly volatile (notably arsenic, mercury, selenium, beryllium, chloride, and fluoride) will depend upon the extent to which they are present and released from the coal, and more importantly, the efficiency with which they are cap-

Table 5. Properties of untreated FGD sludges (typical)[a]

Category	Major chemical constituents (dry basis), wt %	Solids, %
Sulfate-rich	80-95% $CaSO_4 \cdot 2\ H_2O$	75-90
	0-10% $CaSO_3 \cdot xH_2O$	(filtered)
	5-10% $CaCO_3$, $MgCO_3$, Inerts[b]	50-65
	0-10% Solubles—Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-	(settled)
	pH = 6.5 – 8	
Sulfite-rich	40-85% $CaSO_3 \cdot \frac{1}{2} H_2O$	55-75
	5-50% $CaSO_4 \cdot xH_2O$	(filtered)
	5-10% $CaCO_3$, $MgCO_3$, CaO, inerts[b]	35-60
	1-10% Solubles: Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, CO_3^{2-}	(settled)
	pH = 6.5 – 9	

[a]Source: (2).
[b]Silica and other nonreactive materials entering with lime and/or limestone.

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tured in the FGD scrubber. Mercury and selenium are likely to be present in the flue gas as elemental vapors that might not be scrubbed efficiently. On the other hand, chlorides and fluorides are almost completely released from the coal and are very efficiently scrubbed. Fluorides usually end up in the solid phase of the sludge (as CaF_2), and chlorides, in the liquor phase ($CaCl_2$ is very soluble).

Liquid phases of FGD sludges contain dissolved in them a variety of substances ranging from traces of a variety of metals to substantial amounts of commonly occurring ions such as sodium, calcium, magnesium, chloride, and sulfate. As was the case with composition of sludge solids, concentrations of soluble substances in sludge liquors can vary by two orders of magnitude or more. The total dissolved solids (TDS) level can vary from about 2500 mg/l. to as much as 100,000 mg/l., depending upon the chloride/sulfur ratio in the coal, type of system, and the extent to which solids are dewatered (and washed), if at all. However, because of the insolubility of many of the trace metal hydroxides, only a very small fraction of the total amount of almost every trace metal present in the sludge is found dissolved in the sludge liquor. Tables 6 and 7 give ranges of trace element concentrations in FGD sludges, liquors and elutriates measured in samples from operating systems.

For the most part, FGD sludges are fine grained, with particle size distributions falling in the range of 5-50 μm, a range corresponding to silty to fine sandy soil. However, particles both smaller (< 1 μm) and larger (at least 200 μm) have been observed. Viscosity of FGD sludges and the extent to which they can be dewatered depend upon the size and shape of the crystals and the quantity of fly ash present. The highest viscosities have been observed for agglomerated sulfite-rich crystals. These become difficult to pump at greater than 40% solids. They can be typically thickened to 20-40% solids and filtered to 45-75% solids. The lowest viscosities have been observed for sludges containing a high fraction of gypsum and/or fly ash. These sludges can be pumped as slurries in concentrations as high as 70% solids or more. Sulfate-rich sludges can usually be thickened to 30-60% solids and filtered to 60-90% solids. These improved dewatering characteristics (which lead to lower volume and better handling characteristics) of sulfate-rich sludges are the rationale behind intentional oxidation in the scrubber system.

If the solids content of FGD sludges is increased sufficiently by filtration, centrifugation, or other means as addition of fly ash, they are amenable to compaction into a material which can be quite firm and which, if confined, can support considerable weight. The unconfined compressive strengths of such materials frequently range from nil to 50 psi or more.

Treatment of FGD sludges by the addition of lime and fly ash (or a similar source of silicate) can produce a relatively hard material when compacted. Such materials generally exhibit unconfined compressive strengths in the range of 100-400 psi (or higher). Treatment also tends to reduce permeability. Reported values of permeability coefficients for treated materials range from 10^{-5} to 10^{-7} cm/sec, as compared with 10^{-4} to 10^{-5} cm/sec for untreated compacted materials.

Preliminary data on leachate potential obtained from accelerated laboratory leach tests and field testing in ponds indicate that treatment, in addition to increasing strength and reducing permeability, may reduce the concentration of dissolved solids and the predominant soluble ions which constitute TDS in leachates. In addition, the improved handling properties of treated sludges in many cases permit better control of sludge placement and therefore better control of environmental impacts through

Table 6. Concentrations of trace elements in FGD sludges (typical).[a]

Element	Concentration ranges, ppm	Median concentration, ppm[b]	Number of observations	Range of trace elements measured in coal, ppm
Arsenic	3.4-63	33	9	3-60
Beryllium	0.62-11	3.2	8	0.08-20
Cadmium	0.7-350	4.0	9	—
Chromium	3.5-34	16	8	2.5-100
Copper	1.5-47	14	9	1-100
Lead	1.0-55	14	9	3-35
Manganese	11-120	63	5	—
Mercury	0.02-6.0	1	9	0.01-30
Nickel	6.7-27	17	5	—
Selenium	< 0.2-19	7	9	0.5-30
Zinc	9.8-118	57	5	0.9-600

[a]Source: (2).
[b]Values as reported.

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Table 7. Concentrations of chemical species in FGD sludge liquors and elutriates (typical).[a]

Species	Eastern coals			Western coals		
	Range in liquor, ppm	Median, ppm	Number of observations	Range in liquor, ppm	Median, ppm	Number of observations
Antimony	0.46-1.6	1.2	4	0.09-0.22	0.16	2
Arsenic	<0.004-1.8	0.020	15	<0.004-0.2	0.009	7
Beryllium	<0.0005-0.05	0.014	16	0.0006-0.14	0.013	7
Boron	41	41	1	8.0	8.0	1
Cadmium	0.004-0.1	0.023	11	0.011-0.044	0.032	7
Calcium	470-2,600	700	15	240-(~45,000)[b]	720	6
Chromium	0.001-0.5	0.020	15	0.024-0.4	0.08	7
Cobalt	<0.002-0.1	0.35	3	0.1-0.17	0.14	2
Copper	0.002-0.4	0.015	15	0.002-0.6	0.20	7
Iron	0.02-0.1	0.026	5	0.42-8.1	4.3	2
Lead	0.002-0.55	0.12	15	0.0014-0.37	0.016	7
Manganese	<0.01-9.0	0.17	8	0.007-2.5	0.74	6
Mercury	0.0009-0.07	0.001	10	<0.01-0.07	<0.01	7
Molybdenum	5.3	5.3	1	0.91	0.91	1
Nickel	0.03-0.91	0.13	11	0.005-1.5	0.09	6
Selenium	<0.005-2.7	0.11	14	<0.001-2.2	0.14	7
Sodium	36-20,000[c]	118	6	1,650-(~9,000)[c]	—	2
Zinc	0.01-27	0.046	15	0.028-0.88	0.18	7
Chloride	470-5,000	2300	9	1,700-43,000[b]	—	2
Fluoride	1.4-70	3.2	9	0.7-3.0	1.5	3
Sulfate	720-30,000[c]	2100	13	2,100-18,500[c]	3,700	7
TDS	2,500-70,000[c]	7000	—	5,000-95,000[b]	12,000	3
pH	7.1-12.8	—		2.8-10.2	—	

[a]Source: (3).
[b]Levels of soluble chloride components in sludges are dependent upon the chloride-to-sulfur ratio in the coal. The highest levels shown are single measurements for a Western limestone scrubbing system operating in a closed-loop using cooling tower blowdown for process makeup water.
[c]Levels of soluble sodium salts in dual alkali sludge (filter cake) depend strongly on the degree of cake wash. The highest levels shown reflect single measurements on an unwashed dual alkali filter cake.

better disposal site management. Sludge treatment processes are now commercially offered. Several such sludge treatment and disposal facilities are in full-scale operation on utility FGD systems in the U.S.

Regional Coal and Waste Relationships

Four representative coals were selected as the basis for the estimation of sludge and ash production rates: Appalachian, interior, Texas lignite and mountain. Table 8 summarizes the characteristics of these coals, and Table 9 gives assumed regional distribution of coal consumption by coal type and the predominant types of sludges produced by coal type and region. The coal characteristics reflect assumptions regarding coal cleaning prior to combustion.

Sulfate-rich sludges are produced predominantly from low sulfur coal where scrubber oxidation rates are highest. Thus, sulfate-rich sludges are assumed to be the predominant type of sludge produced from mountain coals. Since essentially all of the coal burned in Regions 7, 8, 9 and 10 is mountain coal, these regions would generate sulfate-rich waste.

Sulfite-rich sludge is produced from high sulfur coals. Therefore, sulfite-rich sludges would be produced from interior coal and would be the predominant type of sludge generated in Region 4.

With intermediate sulfur coals, either sulfate- or sulfite-rich sludges can be produced depending upon the type of FGD system and the boiler operation. In Regions 1-3, 5, and 6, the mix of coals would be expected to result in a mix of sulfate- and sulfite-rich sludges.

Table 10 shows the quantities of sludge and ash calculated for each type of coal under NEP and pre-NEP regulatory calculated assumptions. Under pre-NEP, an emission standard for SO_2 of 1.2 lb/10^6 BTU is assumed for Eastern states and 0.6 lb/10^6BTU is assumed for Western states. Under NEP, 90% SO_2 removal and 90% scrubber availability are assumed for all coals and boilers.

Regulatory Considerations

The disposal of FGD sludges and coal ash is subject to regulations at both Federal and State levels.

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Table 8. Coal/ash/sludge relationships (typical)[a].

Coal type	Coal region	Coal characteristics: HHV, BTU/lb	Sulfur: %	Sulfur: lb/10⁶ BTU	Ash: %	Ash: lb/10⁶ BTU	Sludge type
I	Appalachian	11,850	2.5	2.1	8.7	7.4	Sulfate- or sulfite-rich
II	Interior	11,419	4.1	3.6	10.3	9.0	Sulfite-rich
III	Texas Lignite	7,500	1.8	2.4	11.0	14.7	Sulfate- or sulfite-rich
IV	Mountain	9,000	1.03	1.15	9.2	10.2	Sulfate-rich

[a]Source: (3).

State regulations governing waste disposal on land can be more stringent than corresponding Federal regulations.

At present, FGD sludges and ash are disposed of exclusively on land. Ocean disposal may be a technically feasible alternative. In the future, ocean disposal may be carried out to a limited extent in regions where there are no mines available and where disposal sites for land impoundments are scarce.

Disposal on Land. There are four major impact issues concerning land disposal: waste stability/consolidation, groundwater contamination, surface water contamination, and fugitive emissions.

These are essentially regulated under the Federal legislative framework listed in Table 11 and are briefly discussed below.

The Resource Conservation and Recovery Act is the major federal environmental legislation regulating disposal in mines, landfills and impoundments. Section 4004(a) of the Act requires development of criteria to classify disposal areas as either open dumps or sanitary landfills. The criteria will address land disposal broadly — including impoundments, land spreading and surface mine disposal. Following the promulgation of criteria, state plans will be developed so that existing open dumps will be closed or upgraded and future land disposal will meet sanitary landfill criteria. The criteria are expected to prohibit any groundwater contamination which would require additional groundwater treatment for intended uses. To achieve the criteria in an environment where accessible groundwater is useful for potable or irrigation supply, it is likely that either: (1) the disposal sites would be lined or have adequate impermeability and soil attenuative capacity to protect groundwater quality (unlined sites must also have a contingency plan to control contamination when/if it occurs); or (2) the waste would be admixed with a fixation agent (e.g., fly ash and lime).

Under the Safe Drinking Water Act, states are required to adopt programs prohibiting underground injection of wastes without a permit. Regulations for

Table 10. Sludge and ash production rates by coal type.[a]

Coal type	Sludge type	Annual tons of dry sludge/MWe[b]: pre-NEP[c]	Annual tons of dry sludge/MWe[b]: NEP[d]	Annual tons of dry ash/MWe
I	Sulfite	210	240	225
	Sulfate	260	300	
	Avg. region	235	270	
II	Sulfite	420	420	275
III	Sulfite	250	280	450
	Sulfate	310	340	
	Avg. region	280	310	
IV	Sulfate	145	160	310

[a]Source: (4).
[b]70% load factor; 10 × 10⁶ BTU/MWe/hr.
[c]Assuming NSPS = 1.2 for I, II, III; NSPS = 0.6 for IV.
[d]Assuming 90% SO_2 removal (90% available).

Table 9. Coal/sludge/consumption relationships.[a]

EPA Region	Approximate coal consumption, %: I	II	III	IV	Predominant sludge type	Acre-ft/1000 tons dry sludge[a]
1, 2, 3	100	0	0	0	Sulfite or sulfate	0.8
4	50	50	0	0	Sulfite	0.9
5	25	50	0	25	Sulfite or sulfate	0.9
6	0	10	50	40	Sulfite or sulfate	0.8
7, 8, 9, 10	0	0	0	100	Sulfate	0.6

[a]Source: (3).
[b]Assuming no ash and typical sludge properties (compacted or settled).

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Table 11. Federal regulatory framework for coal ash and FGD sludge disposal.

Impact issue	Legislation	Administrator
Groundwater contamination	Resource Conservation and Recovery Act of 1976	Environmental Protection Agency
	Safe Drinking Water Act of 1974	Environmental Protection Agency
Surface water contamination	Federal Water Pollution Control Act Amendments of 1972	Environmental Protection Agency
Sludge stability/ consolidation	Surface Mining Control and Recalamation Act of 1977	Office of Surface Mining Reclamation and Enforcement
	Dam Safety Act of 1972	Army Corps of Engineers
	Federal Coal Mine Health and Safety Act of 1969	Mining Enforcement Safety Administration
	Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration
Fugitive air emissions	Clean Air Act of 1974	Environmental Protection Agency
	Federal Coal Mine Health and Safety Act of 1969	Environmental Protection Agency
	Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration

Source: (5).

the state underground injection control programs were promulgated by the EPA and apply to all deliberate subsurface emplacement of wastes by wells. The principal regulatory objective is protection of groundwater from endangerment of viable drinking water sources. This may influence underground mine disposal of FGD wastes.

There would be some relevance of FGD waste disposal to regulation of effluent discharges under the Federal Water Pollution Control Act Amendments. For example, some current Effluent Limitation Guidelines are based on the principal chemical constituents typically found in drainage from certain industrial activities. Introduction of a waste material could alter the designation of significant constituents which should be limited, as well as the final effluent concentrations which are achievable by available technology, resulting in a need to modify the Effluent Limitation Guidelines for the Utility or Mining industry categories. Similarly, new guidelines may be needed for discharges from landfill and impoundment disposal operation.

The Clean Air Act would be the primary vehicle for regulating fugitive emissions which may result from the handling and storage of FGD waste. Regulation would be accomplished under provisions of the Act requiring that no emitting source interfere with the achievement and maintenance of National Ambient Air Quality Standards (e.g., standards for particulates). In some cases, fixation of waste or dust suppression methods may be required.

Federal mine disposal regulation for purposes of groundwater protection would probably occur under the Resource Conservation and Recovery Act, and disposal would have to meet sanitary landfill criteria. However, the physical stability of FGD storage piles or mine disposal would be regulated under the Surface Mining Control and Reclamation Act. Under this Act, placement of any waste within a surface mine is prohibited if it would pose an environmental or health hazard or cause physical instability of the mine area.

The physical stability of impounded wastes may be regulated under the Dam Safety Act. Under this Act, an initial inspection and inventory of existing dams was accomplished along with recommendations of dam specifications and inspection procedures to be included in further laws and regulations. Eventually states will establish their own programs consistent with federally provided model legislation and guidelines.

Standards promulgated under the Federal Metal and Nonmetallic Mine Safety Act are designed to protect miners from accident and disease. The standards would apply to air contamination from fugitive air emission of particulates or sulfur dioxide, to noise, waste stability, and safeguards for mechanical and electrical equipment. Similarly, standards promulgated under the Occupational Safety and Health Act would focus on protecting workers in all aspects of FGD waste disposal outside of the mine fenceline.

Disposal in the Ocean. Regulation of dispersed ocean dumping of treated and untreated FGD waste falls under the Marine Protection Research and Sanctuaries Act and is administered by the En-

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vironmental Protection Agency. The dumping would be required to occur at EPA prescribed dumpsites under the following conditions: trace contaminant (e.g., Hg, Cd) content of the dumped materials would be no higher than 50% above that of background sediments at the dumpsite; concentrations of the dumped material in the water column 4 hr after release would not exceed 1% of the 96-hr LC_{50} of the material to local sensitive species; and no feasible alternatives to ocean disposal are available.

If treated, bricklike FGD waste is used to create artificial fishing reefs with EPA concurrence, the activities would not be subject to ocean disposal criteria.

Disposal and Utilization Options

Disposal. There are now a number of methods being employed for the disposal of FGD sludges and power plant coal ash. The most common method of disposal today is impoundment (ponds), although some mine disposal is also being practiced. In the future, in addition to impoundments, landfills (i.e., sanitary landfill disposal in which layers of waste are covered with layers of soil) would become a major option. The types of impoundments include both lined and unlined wet ponds and dry pits. In wet impoundments, sluiced ash or FGD sludge (often combined with ash) slurry is piped to the pond area where the solids settle out. The supernatant is then collected via overflow weirs and either discharged or recycled to the scrubber or ash sluicing system. Wet impoundments are used almost exclusively for on-site disposal at the power plant. In addition to the disposal of untreated wastes, they are sometimes used for treated materials (admixed lime and fly ash; or admixed lime, fly ash and FGD sludge).

Dry impoundments and landfills are used for the disposal of dry ash or dewatered (or treated) sludges. They can be either offsite or onsite; however, they are usually located close to the waste source because of the high cost of transportation. In dry impoundments or landfills, the wastes are collected and trucked to the disposal area. In landfills, the ash or sludge would be mixed with and then spread over layers of soil. In some cases, fly ash alone is spread as a cover material. The operation of a dry impoundment would be much the same except that untreated sludge mixed with ash (or treated sludge) would be layered in 6-in. to 1-ft. lifts and compacted.

There are three options for surface mine disposal of dry wastes: (1) disposal on the working pit floor prior to return of overburden; (2) dumping in spoil banks prior to reclamation; and (3) mixed with overburden. Sludge or ash would be transported to the mine via rail or truck and then truck-dumped in the disposal area. There is a limited amount of fly ash and/or FGD sludge disposal now being practiced using the first two disposal options. Disposal of FGD sludges in active mines leads to less fugitive SO_x emissions because active mines are less acidic than inactive or depleted mines; therefore the sulfur compounds in the wastes are less likely to be dissolved (releasing SO_2) in the less acidic environment.

In a few instances, fly ash has also been disposed of in underground mines. The fly ash is sluiced and pumped into mine voids through boreholes. Supernatant can be recovered via dams and sump pumps and returned to a disposal basin or recycled for use in ash sluicing. No commercial scale FGD sludge disposal in underground mines is now being practiced.

All of these options will undoubtedly continue to be used in the future. However, based upon the impending regulations prohibiting groundwater contamination, unlined impoundments are expected to decrease in usage. Mine disposal is expected to increase in use due to the convenience and the elimination of the large tracts of land required for impoundments.

Ocean disposal of treated and sulfate-rich sludges may also be carried out to a limited extent in regions where there are no mines available and disposal sites for land impoundments are scarce. Ocean disposal could take the form of reef construction on the continental shelf (shallow ocean disposal) using treated material or dumping of treated or sulfate-rich material off the shelf (deep ocean disposal). Ocean disposal would probably be more likely to be practiced in Regions 1 and 2. However, should regulations constrain any form of ocean disposal, it is likely that use of regenerable systems would be employed in areas where land disposal is impractical.

Table 12 lists the potential disposal options and sludge types appropriate to each disposal option envisioned for the foreseeable future. Table 13 lists the anticipated significance of each disposal option in each Federal region. This disposal scenario was compiled based on current trends in regulations, existing data on characteristics of various types of sludges, and expected impacts associated with such operations.

Utilization. There are numerous uses of coal ash that have been developed both in the United States and Europe. However, at present, only about 20% of the total ash produced in the United States is being marketed. Fly ash, bottom ash and boiler slag, all of which comprise coal ash, are used in somewhat different applications. Only fly ash appears to be useful in FGD sludge treatment.

Some of the more important markets for ash in the United States include: manufacture of cement and concrete, light aggregate for construction, filler (and

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Table 12. Sludge options vs. disposal scenarios.

Disposal scenario	Requirements	Sludge options
Land Disposal		
Landfill	Immediate workability Mixed with soil	Sulfate-rich (Dry) sulfite-rich Sulfate-rich + ash Sulfite-rich + ash Treated soil or brick
Managed impoundment	Immediate workability	Sulfate-rich Sulfate-rich + ash Sulfite-rich + ash Treated soil
Unmanaged impoundment	Lined pond	Any
Surface mine	Dry, soil-like	Same as landfill
Ocean disposal		
Shallow Dispersed	No (or low) COD availability[a] No (or low) ash Soluble	Sulfate-rich
Shallow concentrated	Stable Low COD availability[a] Non-dispersing	Treated, bricklike
Deep concentrated	Low TOS availability	Sulfate-rich Treated soil or brick

[a]Chemical oxygen demand (COD) is directly related to sulfite concentrations.

Table 13. Disposal scenarios (1985-2000).

EPA Region	Disposal methods (significance)[a]	
	FGD sludge	Ash
1 and 2	Impoundment (H) Landfill (H)[b] Ocean (H)[c] Mine (L)	Impoundment (H) Landfill (H)[b] Ocean (L)[c] Mine (L)
3 and 4	Impoundment (H) Mine (H) Landfill (M)[b] Ocean (L)[c]	Impoundment (H) Mine (H) Landfill (M)[b] Ocean (L)[c]
5, 6 and 7	Impoundment (H) Mine (H) Landfill (M)[b] Ocean (L)[c]	Impoundment (H) Mine (H) Landfill (M)[b] Ocean (L)[c]
8, 9 and 10	Impoundment (H) Mine (H) Landfill (L)[b] Ocean (L)[c]	Impoundment (H) Mine (H) Landfill (L)[b] Ocean (L)[c]

[a]Importance (significance) of each disposal option described in parentheses: (H) = High in importance in the region; (M) = Medium in importance in the region; and (L) = Low in importance in the region.

[b]Landfill refers to sanitary landfill type of disposal wherein the layers of wastes are covered with layers of soil.

[c]If regulations preclude all forms of ocean disposal, then it is likely that ash utilization and the use of regenerable systems would take up the slack where land disposal is impractical.

antiskid additive) for asphalt, landfill cover, extraction of mineral values, blasting (abrasion) compound, and soil additive.

In addition, there are numerous research and development programs being pursued to enhance existing markets and open new markets.

In contrast to coal ash, there are essentially no markets developed for utilizing wastes from nonregenerable FGD systems in the United States. In Japan, gypsum is produced in FGD systems and is marketed for use in wallboard production and the manufacture of cement.

However, in the United States, there is little or no current market for gypsum as a byproduct material. Other possible uses of nonregenerable wastes that continue to be explored include use as a fertilizer base or additive, a concrete additive, a low grade construction base for construction of artificial reefs, for soil amendments, and for fume subsidence control.

As an alternative to nonregenerable systems, regenerable systems produce sulfur or sulfuric acid as byproducts. Markets for these products, though, are quite limited and the cost for producing the byproduct with flue gas desulfurization systems is high. However, there are two circulstances under which the regenerable processes can find successful appli-

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Table 14. Regional ash distributions: cumulative quantities.[a]

Federal Region	1975 10^6 tons	1985 Pre-NEP, 10^6 tons[a]	1985 NEP, 10^6 tons[a]	1985 Δ, 10^6 tons[a]	1985 Δ/Pre-NEP, %	2000 Pre-NEP, 10^6 tons[a]	2000 NEP, 10^6 tons[a]	2000 Δ, 10^6 tons[a]	2000 Δ/Pre-NEP, %
1	0.3	8.19 (4.10)	9.64 (4.82)	1.45 (0.73)	18	28.29 (14.14)	32.86 (16.43)	4.58 (2.29)	16
2	1.6	27.31 (13.66)	31.51 (15.76)	4.20 (2.10)	15	98.28 (49.14)	118.71 (59.36)	20.43 (10.22)	21
3	8.4	108.34 (54.17)	117.38 (58.69)	9.04 (4.52)	8	317.45 (158.73)	371.74 (185.87)	54.29 (27.15)	17
4	13.6	156.10 (78.05)	159.55 (79.78)	3.45 (1.73)	2	467.57 (233.79)	479.24 (239.62)	11.67 (5.84)	2
5	19.4	232.54 (116.27)	237.93 (118.97)	5.39 (2.70)	2	660.29 (330.15)	686.49 (343.25)	26.20 (13.10)	4
6	0.6	36.32 (18.16)	57.34 (28.67)	21.02 (10.51)	58	253.79 (126.90)	322.55 (161.28)	68.76 (34.38)	27
7	2.0	36.93 (18.47)	37.57 (18.79)	0.64 (0.32)	2	128.84 (64.42)	133.89 (66.95)	5.05 (2.53)	4
8	1.7	24.48 (12.24)	28.82 (14.41)	4.34 (2.17)	18	68.60 (64.30)	94.17 (47.09)	25.57 (12.79)	37
9	0.3	10.71 (5.36)	16.69 (8.35)	5.98 (2.99)	56	84.23 (42.12)	107.67 (53.84)	23.44 (11.72)	28
10	0.3	0.81 (0.41)	1.65 (0.83)	0.84 (0.42)	104	3.62 (1.81)	8.94 (4.47)	5.32 (2.66)	147
Total	48.2	641.73 (320.89)	698.08 (349.07)	56.32 (28.19)	9	2,110.95 (1,056.50)	2,356.26 (1,178.16)	245.31 (122.68)	12

[a]Numbers of 1000's of acre-ft are in parentheses. Numbers may not add up to the last digit due to roundoff.

cation and would be used: in specific locations where a market for the products exists; in areas where availability of disposal options for nonregenerable processes is so constrained that the cost of waste disposal is high.

It is important to note that most regenerable systems also produce wastes; e.g., blowdown from prescrubbers (which remove fine particulate matter and chlorides from the flue gas prior to its entering the sulfur dioxide absorber) and blowdown of contaminants from the regenerative portion of the process.

Coal Ash-Related Impacts

Projected Production and Trends

In order to gain an insight into the impacts associated with coal ash alone, estimates of the generation of coal ash and FGD sludges have been projected separately in each Federal region. The estimates on the generation of coal ash developed in the Annual Environmental Analysis Report have been used as the basis for these impact projections.

Table 15. Generation of coal ash: industrial utility breakdown.[a]

	1985 Pre-NEP, 10^3 tons (% of total)	1985 NEP, 10^3 tons (% of total)	1985 Δ, 10^3 tons (% of total)	2000 Pre-NEP, 10^3 tons (% of total)	2000 NEP, 10^3 tons (% of total)	2000 Δ, 10^3 tons (% of total)
Industrial	9466 (11.7)	18,987 (20.7)	9521 (83.1)	21,977 (19.0)	43,518 (33.6)	21,541 (154.6)
Utility	71,011 (88.3)	72,947 (79.3)	1936 (16.9)	93,446 (81.0)	85,842 (66.4)	− 7604 (− 54.6)
Total	80,477	91,934	11,457	115,423	129,360	13,937

[a]Source: (5). Basis: National Annual Waste Rates (Only boilers over 25 MWe included in industrial total)

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Table 16. Generation of FGD sludges: industrial utility breakdown.[a]

	1985			2000		
	Pre-NEP, 10^3 tons (% of total)	NEP, 10^3 tons (% of total)	Δ, 10^3 tons (% of total)	Pre-NEP, 10^3 tons (% of total)	NEP, 10^3 tons (% of total)	Δ, 10^3 tons (% of total)
Industrial	1200 (5)	6500 (20)	4900 (60)	5800 (15)	23,100 (40)	18,000 (95)
Utility	23,200 (95)	26,100 (80)	3300 (40)	32,900 (85)	34,600 (60)	1000 (5)
Total	24,400	32,600	8200	38,700	57,700	19,000

[a]Source: (5)

The estimates presented in Table 14 include electric utilities and largescale industrial boilers (> 25 MWe). The data presented are the cumulative generation of fly ash through 1985 and 2000 under NEP and under pre-NEP conditions. Tables 15 and 16 present the overall national breakdown between industries and utilities. It is clear that industrial wastes grow rapidly and become a significant part of the total wastes. However, data on regional breakdown of industrial waste generation are unavailable as of this writing. Hence, the specific impacts associated with industry alone are not considered separately in this paper. The impacts discussed are broadly caused by wastes from utilities and industries. Tables 8-10 outline the characteristics of coal, the quantities of ash produced from various coals, and the estimated mix of coals used in each EPA region.

The cumulative percentage increase of coal ash generated in each EPA region under the NEP (compared to pre-NEP) is shown in Figure 1. The incremental percentages increase of coal ash under the NEP is relatively small.

It should be noted that coal ash can be utilized commercially. (Examples of commercial utilization

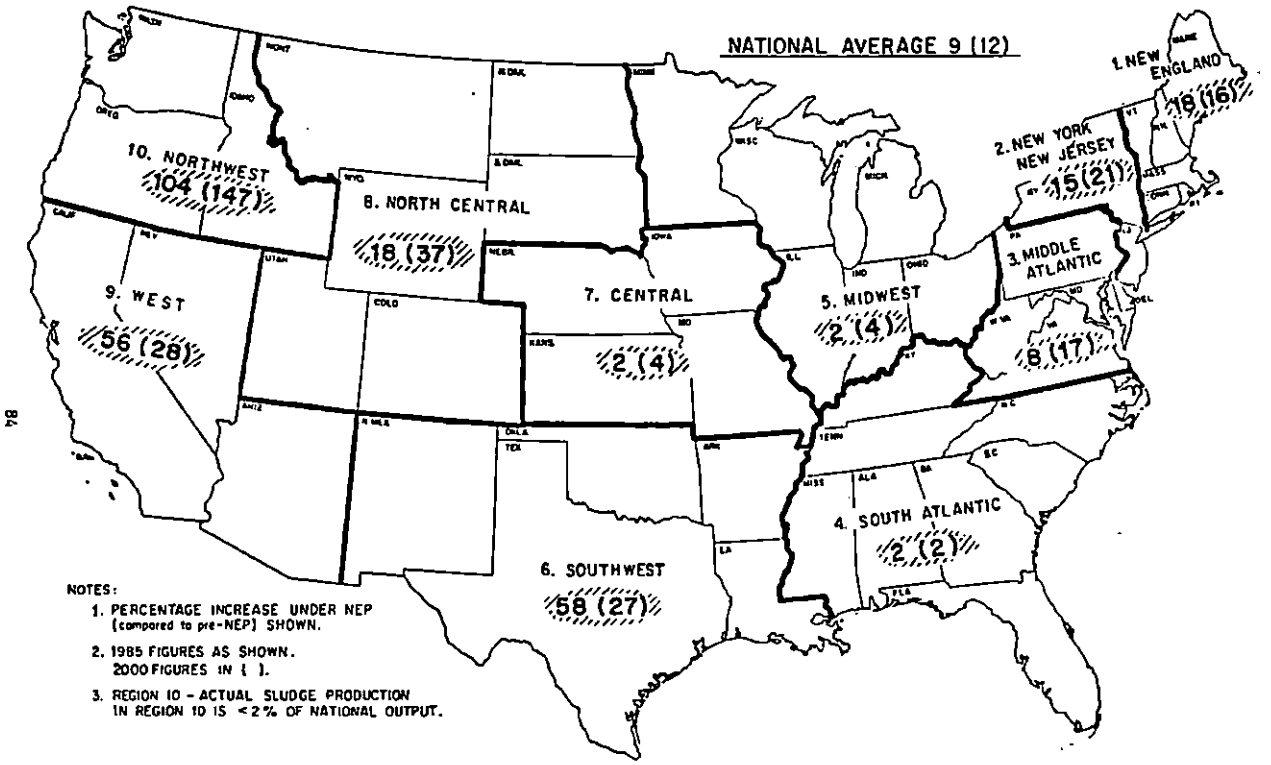

FIGURE 1. Regional coal ash generation cumulative percentages in 1985 and 2000.

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include use in manufacture of cement, mixing with asphalt, and as light aggregate for concrete road beds); mixed with FGD sludge and subject to chemical treatment prior to disposal; or directly disposed of in landfills.

The net amount of coal ash, in particular fly ash, available for disposal independent of FGD sludge would be small for the following reasons. Assuming all FGD sludge were treated (or admixed) and that fly ash is required in the ratio of 50:50 to FGD sludge for treatment (in addition to lime), the net amount of fly ash left over for disposal/utilization is negligible except in Regions 6, 8, 9, and 10. Utilization of coal ash is likely to increase in future years.

The remainder of this section concerns impacts associated with direct disposal of coal ash alone.

In this paper, the combined impact of wastes generated by industries and utilities is addressed. Baseline data are not available as of this writing to consider the impact of wastes from industrial boilers alone. It should be noted, however, that preliminary estimates indicate that by 2000, the generation of such wastes by industry, which is presently negligible, will be a sizable percentage of the total generation of ash and FGD wastes.

Regional and National Environmental Impacts

The existing regulatory framework governing disposal of ash/sludge, if successfully implemented, should prevent or minimize significant adverse environmental impacts. Hence, discussion on environmental impact of ash or sludge disposal is basically an attempt to focus on potential environmental issues. The impact assessment in Sections 2.2, 2.3, 3.2, and 3.3 should be read against this background.

Land-Related Impacts. The additional land area required for cumulative disposal of coal ash if disposed of alone is not great. By 1985, the incremental land requirements under NEP (compared to that under pre-NEP) is about 9% on a national scale. By 2000, the incremental land requirements under NEP are only 12% which would amount to less than 5000 acres of direct disposal area.

Depending upon whether or not the particulate level from fugitive emissions is significant, disposal of fly ash could affect nearby land use patterns. Land-use regulations may restrict disposal to areas where residential, commercial or recreational activity is remote from the disposal area (i.e., buffer zones are required), thereby substantially increasing the land area temporarily affected by the disposal action. Adverse affects of coal ash disposal can be ameliorated by prudent engineering and design. Furthermore, commercial utilization of fly ash (as in cement manufacture, as aggregate, etc.) reduces land use impact. On balance, land-related impact associated with coal ash disposal alone will be site specific. The overall incremental land requirements under NEP are such that the impacts on land use policy on a regional scale are not very significant in any region.

Water-Related Impacts (Coal Ash). The potential water related impacts are those of a hydrologic nature (This would be insignificant on a regional basis for coal ash disposal on an incremental basis under NEP) and those occurring as a result of leachate moving from the ash disposal area and impacting water quality.

As in all other impacts, site-specific implementation of available regulations and control technology to the appropriate degree is the overriding factor; if prudently applied and practiced, this could prevent adverse water related impacts.

A potentially important impact issue is that associated with the movement of leachate from ash disposal. The site-specific significance of contaminants in leachate depends on: whether the surrounding area groundwater is of very high quality or highly mineralized and attenuation, displacement, and dilution mechanisms which retard or prevent the movement of many chemical species in soil media.

Application of fly ash to soils could increase the availability of trace elements. The impact of leachate is also ash specific; chemical treatment and compaction reduce permeability.

It appears that movement of trace metals and principal chemical species (Ca, SO_4, Cl, etc. through soil into underground water) through leachates is one significant environmental impact issue. The regulatory objectives of RCRA, if successfully implemented, would prevent contamination of groundwaters to any level preventing continuation of existing use. This would impact siting considerations. The maximum incremental increase under NEP in coal ash production is likely in Regions 3, 5, 6, and 9. Region 10, while showing a large percentage increase, is not projected to be a major generation center.

Air Quality Impacts. A number of sources of atmospheric dust can be related to the disposal of coal ash. The dust generated from these sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Although no reliable emissions data exist for these sources, implications of potential impacts can be made based on the physical characteristics of the ash, the disposal methods and the climatological characteristics of the area. The dust generation process is comprised of two basic physical phenomena, which are particularly applicable to dry materials: pulverization and abrasion of surface material by the application of

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mechanical force during the disposal operation (loading, transporting, dumping, etc.); and entrainment of dust particles by the action of turbulent air currents. Airborne dust may also be generated independently, by wind erosion of an exposed surface if the wind exceeds approximately 12 mph.

The air pollution impact of fugitive dust from coal ash disposal depends on the quantity and drift potential of dust particles emitted into the atmosphere. The emission rate depends on the properties of the coal ash and the activity level in the disposal process. The physical characteristics of typical ash pertaining to potential fugitive emissions are given in Table 17.

Coal ash disposal can involve wet or dry material. At present, wet methods are favored, but regulatory guidelines may encourage a trend toward dry handling. Even on dry systems, use of water and possibly dust mitigating agents is expected to be required during field operations to minimize fugitive dust.

It should be noted that the moisture content of coal ash is generally well above the level of 5% by weight, the amount required to totally mitigate emissions of fugitive dust. Therefore, it can be assumed that the emissions of fugitive dust, assuming sound disposal practice, would be quite small regardless of the disposal procedure as long as the moisture content remains large. However, airborne dust may be generated in disposal processes that allow the surface material to dry to levels below 4-5% moisture content.

Nearly 85% of the coal ash by weight (see Table 14) is less than 75 μm in particle size. Thus, disposal procedures that allow for surface exposure for extended periods of time would allow for evaporation and drying of the exposed surface particles and could cause emissions of fugitive dust. Landfill and surface mine disposal procedures are the two options that could cause increased fugitive emissions unless reasonable mitigative measures were undertaken. The regions that utilize landfill and surface mine disposal options could therefore potentially cause suspended particulate levels to increase in areas immediately bordering the sites. The extent of increased ambient concentrations depends on factors such as the surface area of the disposal site, the extent of dryness of the surface particles and the climatology of the area.

When one considers fugitive dust from coal ash disposal, it is well to keep in mind that dry soil can also cause analogous formation of fugitive dust. The difference between soil and deposited coal ash in terms of propensity to dusting is of course specific to the materials in a given locale.

The increased coal ash generation in Federal Region 6 of 58% in 1985 as a result of the National Energy Plan could cause significant site-specific particulate level increases near open disposal areas such as landfill sites. Mitigative measures such as the application of overburden, vegetative cover, and frequent watering would minimize these impacts greatly.

The Regional Ash Distribution Table indicates that in the year 2000, the National Energy Plan could cause particulate emissions from disposal operations to have the most significant increases in ash disposal in EPA Regions 6 and 3. This information by itself does not lead to the conclusion that impacts would be significant. The more important consideration at each site would be the site-specific requirements for application of available control technology.

Biological Impacts. Potential vegetation impact issues resulting from the disposal of coal ash could be of several types: vegetation loss by construction of disposal areas, effects on adjacent plant communities through disruption of local hydrology, and possible reduction in productivity due to fugitive dust. Potential positive impact issues could include enhanced surface mine reclamation and a possible increase in diversity of vegetation following reclamation of impoundments and landfills. Impact assessment has to be against the background of site-specific data and requirements for the possible application of available control and reclamation technology to minimize impacts for certain types of disposal.

Each disposal method has a different combination of potential impacts. Impoundments (lined and unlined) and landfills each require the disruption of an existing land surface and removal of any natural vegetation present. Creating impoundments or landfills may also modify the local water runoff patterns, thus affecting adjacent vegetative communities. For example, wetlands may become drier or upland areas may become wetter.

Coal ash disposal may not result in significant levels of fugitive dust, particularly with prudent design and operation of disposal methods. Impacts are likely to be minimal, but could include decreased vegetative productivity if significant dust deposits occur.

The use of surface mines as disposal sites may

Table 17. Physical properties of typical fly ashes.[a]

Property	
Specific gravity	2.5
Approximate moisture content, (% H_2O)	25.0
Particle size distribution, %	
> 2 mm	0
0.074-2 mm	11
0.002-0.074 mm (silt size)	85

[a]Source: (*4*).

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potentially have positive impacts since such use may help rehabilitate the extreme topography of surface mine pits. Coal ash is generally alkaline and contains several chemical species including calcium, magnesium and potassium, which are essential plant nutrients. Thus, coal-ash-filled areas have a reasonable potential to be successfully revegetated and to become new habitats. In some localized situations, the type of vegetation selected for reclamation use could increase diversity. For example, edge habitats could be established in forested areas.

Impacts on terrestrial vegetation in the various EPA regions will be closely related to the amount of land needed for disposal of coal ash. As indicated in the section on land-related impacts, estimated areas needed by 1985 and 2000 are relatively small. While some significant site-specific impacts are possible, the overall impact in all regions appears small.

Since many of the utilities will be located near surface water sources, the types of vegetation disrupted will include a variety of plant communities. Specific studies for proposed ash disposal sites, which will most likely be required for disposal permits, can ensure that rare or endangered species will not be affected. Some sites will have only limited natural vegetation because of prior agricultural or industrial use.

All types of impacts are similar, with or without NEP. The NEP would have the effect of increasing the land area required for ash disposal by about 9% by 1985 and 12% by 2000. The increase in area of natural vegetation that is disturbed under NEP will be dependent on the specific disposal sites selected.

The major impacts of the disposal of coal ash on terrestrial wildlife will result from the loss of potential habitat and, in some cases, from enhancement of habitat associated with reclamation. The loss of vegetation could result in the local reduction of the carrying capacity for some forms of terrestrial wildlife. Recognizing that site-specific impacts are often overriding, the magnitude of the potential incremental impact on a regional basis is likely to be small since the incremental land area used for the disposal of ash in each EPA region under NEP is small.

Another potential impact exists from the chemical constituents of coal ash. A relatively large percentage of the composition of coal ash consists of relatively inert materials (e.g., silica, alumina, ferric oxide). These materials are relatively nontoxic to terrestrial wildlife. Moreover, the solubility of coal ash is relatively low. However, coal ash does have trace elements such as arsenic, cadmium, and selenium. Therefore, the contamination of surface and groundwater is a possibility. This contamination has the potential to cause chronic exposure of wildlife to low levels of trace elements of a potentially toxic nature. It is unlikely that acute or chronic toxicity effects will be significant if the RCRA framework is successfully developed and implemented.

As in other areas of potential impact, the degree of site-specific implementation of available control technology is the overriding consideration in determining the incremental impact under NEP as it relates to aquatic biota. The available regulatory framework under RCRA, if successfully implemented, should prevent ash disposal practices with important adverse biological effects. With that in mind, the major potential concerns regarding aquatic biota are discussed below to help focus future regulatory efforts. All appear to be controllable with the application of siting and structural constraints which prevent the near-field entry of ash and/or ash liquor into surface waters.

The three characteristics of coal ash which appear potentially problematic for aquatic biota are: small particle size; relatively high percentages of ferric oxide in the solid fraction; and relatively high pH and trace metal concentrations in the liquor fraction.

Other characteristics about which too little data are available to evaluate the potential for problems are radioactivity and uncombusted carbon fractions of the waste.

The small particle size of coal ash (comparable to silts) implies greater potential for adverse impacts upon aquatic biota due to ingestion and impingement than for solids composed of larger particles. This would be of concern in any situation where higher aquatic organisms (e.g., finfish) are directly exposed to ash solids with relatively high trace metal levels which, if ingested, could be stripped and made available for subsequent accumulation or toxicity in the acidic environment of the digestive tract.

Ferric oxides, reportedly comprising up to 35% of ash solids, have poorly understood impact implications in aquatic systems. However, iron oxide flocs have been associated with reported fish kills, and the presence in surface waters of large quantities of ash rich in iron oxides could be considered problematical without more definitive data about opportunities for dissolution and flocculation as specific sites.

Ash liquors can exhibit pH values greater than 9 and a few trace metal levels in excess of recommended EPA criteria for the protection of aquatic life. In the absence of adequate mixing and dilution, these factors could create toxic conditions in affected aquatic systems. It is to be noted, however, that dilution of leachates is often likely. Cadmium, which is reported to be in excess of 10 μg/l. in ash liquors, is a cumulative toxicant reported to adversely affect salmonid fishes and certain zooplankton in excess of concentrations between 0.4

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and 1.2 μg/l. and less sensitive species between 4.0 and 12.0 μg/l.

On a regional basis, the potential for any adverse coal ash disposal impacts on aquatic biota appears to be greatest in EPA Regions 6, 8, 9, and 10. These areas show significant predicted volumetric and/or percentage increases over pre-NEP conditions for both 1985 and 2000. Regions 8 and 9 could be of special concern because of the importance of sensitive cold water fisheries in numerous small streams, in contrast to the strong preponderance of warm water ecosystems in Region 6.

Health Related Impacts. The major health concerns expected to receive regulatory attention in the disposal of coal ash as described in preceding sections may occur at several levels. They are all strongly dependent on a host of variables related to disposal technique, total quantity of ash disposed of and site-specific consideration, especially proximity to population centers. Broadly, health-related impacts could be divided into three kinds: occupational, local, and remote.

Occupational impact refers to effects on the health of workers involved in the disposal operations. These would differ according to location and type of disposal. In mine reclamation and landfill, fugitive dust is one of the significant distinguishing possibilities but is expected to be controlled. Industrial accidents and spills are considered outside the scope of this study.

Local impact refers to effects on persons in the vicinity of a disposal operation. This would be largely related to the effects of fugitive dusts and, perhaps more importantly, to potential impact on local ground and surface waters.

The remote: effects comprise effects of materials, primarily trace metals, emanating from the disposal site as leachate, carried in surface and groundwater, and turning up in water supplies (streams or wells) used primarily for either human (or domestic animal) drinking water or irrigation.

The potential impacts in most areas will not come from the differences between the NEP and pre-NEP scenarios but with reference to the 1975 baseline, whichever scenario develops. The impacts would be principally site-specific. Figure 1 outlines percentage increases in various regions. Lacking further information, correspondingly higher levels of impacts could exist in these regions.

Whether the potential impacts are realized as actual impacts depends on a further set of variables including disposal methods, utilization of groundwater versus surface water for drinking purposes, the rate of groundwater passage through a fill site, the rate of leaching by surface water, the pre-existing composition of the leach water and its distribution afterwards, the absorption of ions in the soil, the method of treatment of ash and the specific characteristics of a specific disposal site. In summary, these factors relate to possible regulatory actions enabled by RCRA.

These remarks pertain to disposal of both ash and sludge and, therefore, apply to the discussion of health impacts of sludge disposal.

Because of the large matrix of variables, each varying to some degree for each site, even within a region, it is considered unrealistic to attempt a refined quantitative analysis of health effects.

Furthermore, the regulatory framework, if implemented successfully, will by definition prevent adverse impact on any drinking water supply.

One can consider a potential worst case scenario in which a water supply is postulated to contain undiluted liquor and its composition is compared to recognized standards (for drinking water), and then examine what variables exist which might alleviate any concerns so derived. This scenario ignores many attenuating factors; actual levels of all incremental dissolved material in any surface or groundwater will be a fraction of those in ash liquors. Data developed in recent work and on the recent report of the NRC Committee on Drinking Water and Health (*6*) points to this.

The limited data available for ash liquors, which are subject to further variation depending largely on coal source, suggest that for most components there would not be major cause for concern. Possible exceptions are cadmium, selenium, and some other trace elements. This water would not in any case be considered a direct source of drinking water, and any outflow from an ash disposal site would need to be monitored and diluted or otherwise treated to increase its acceptability.

In addition to water-quality related issues, ash disposal more than sludge disposal will give some concern for fugitive dust emissions. This could therefore be mitigated by site-specific factors of construction design and operational procedures. The presence of radioactive elements in coal ash has been reported, but there are not sufficient data to determine whether there is cause for concern on this subject.

FGD Sludge-Related Impacts

Projected Production and Trends

Since the likelihood is that coal ash and FGD sludge will be disposed of together, either as fly ash admixed with FGD sludge (or SO_2 and ash simultaneously removed) or in the use of ash for the treatment of sludge, we have estimated production rates

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Table 18. Regional sludge distributions—cumulative.[a]

Federal Region	1975 10^6 tons	1985 Pre-NEP, 10^6 tons	1985 NEP, 10^6 tons	1985 Δ, 10^6 tons	1985 Δ/Pre-NEP, %	2000 Pre-NEP, 10^6 tons	2000 NEP, 10^6 tons	2000 Δ, 10^6 tons	2000 ΔPre-NEP, %
1	< 0.1	4.94 (3.95)	6.13 (4.91)	1.19 (0.95)	24	21.50 (17.21)	22.68 (18.14)	1.18 (0.94)	5
2	0.2	14.82 (11.85)	18.65 (14.92)	3.83 (3.06)	26	63.98 (51.18)	67.70 (54.16)	3.72 (2.97)	6
3	1.2	18.20 (14.56)	26.45 (21.16)	8.25 (6.59)	45	60.58 (48.46)	113.76 (91.01)	53.18 (42.55)	88
4	1.7	38.74 (34.87)	46.23 (41.61)	7.49 (6.75)	19	156.53 (140.88)	199.81 (179.83)	43.28 (38.95)	28
5	3.1	51.62 (46.45)	57.72 (51.95)	6.11 (5.49)	12	187.90 (169.11)	229.07 (206.16)	41.17 (37.05)	22
6	<0.1	12.00 (9.60)	21.18 (16.94)	9.18 (7.35)	77	79.77 (63.81)	127.43 (101.95)	47.67 (38.14)	60
7	0.5	14.75 (8.86)	17.91 (10.75)	3.15 (1.89)	21	56.65 (33.99)	75.25 (45.15)	18.61 (11.17)	33
8	<0.1	1.29 (0.77)	2.15 (1.29)	0.86 (0.52)	67	3.83 (2.30)	9.59 (5.76)	5.76 (3.46)	150
9	<0.1	0.10 (0.05)	0.98 (0.59)	0.89 (0.54)	911	0.43 (0.26)	9.33 (5.59)	8.90 (5.34)	>1000
10	0.0	0.02 (0.01)	0.17 (0.11)	0.15 (0.09)	596	0.19 (0.12)	1.20 (0.72)	1.00 (0.60)	616
Total	6.8	156.48 (130.97)	197.57 (164.23)	41.10 (33.23)	26	631.36 (527.32)	855.82 (708.47)	224.47 (181.17)	36

[a]Numbers of 1000's of acre-ft are in parentheses. Numbers may not add up to the last digit due to roundoff.

Table 19. Regional sludge plus ash distributions — cumulative.[a]

Federal Region	1975, 10^6 tons	1985 Pre-NEP, 10^6 tons	1985 NEP, 10^6 tons	1985 Δ, 10^6 tons	1985 Δ/Pre-NEP, %	2000 Pre-NEP, 10^6 tons	2000 NEP, 10^6 tons	2000 Δ, 10^6 tons	2000 Δ/Pre-NEP, %
1	< 0.4	13.13 (8.05)	15.77 (9.73)	2.64 (1.68)	20	49.78 (31.35)	55.54 (34.57)	5.76 (3.22)	12
2	1.8	42.13 (25.51)	50.16 (30.68)	8.03 (5.17)	19	162.26 (100.32)	186.40 (113.52)	24.15 (13.2)	15
3	9.6	126.54 (68.73)	143.83 (79.85)	17.29 (11.11)	14	378.03 (207.19)	485.50 (276.88)	107.47 (69.69)	28
4	15.3	194.84 (112.92)	205.78 (121.39)	10.94 (8.47)	6	624.10 (374.67)	679.05 (419.45)	54.95 (44.78)	9
5	22.5	284.16 (162.72)	295.65 (170.92)	11.49 (8.2)	4	848.19 (499.26)	915.56 (549.41)	67.37 (50.16)	8
6	< 0.7	48.32 (27.76)	78.52 (45.61)	30.2 (17.85)	63	333.56 (190.71)	449.98 (263.23)	116.42 (72.52)	35
7	2.5	51.68 (27.33)	55.48 (29.54)	3.8 (2.21)	7	185.49 (98.41)	209.14 (112.10)	23.66 (13.69)	13
8	< 1.8	25.77 (13.01)	30.97 (15.7)	5.2 (2.69)	20	72.43 (36.60)	103.76 (52.85)	31.33 (16.25)	43
9	< 0.4	10.81 (5.41)	17.67 (8.94)	6.86 (3.53)	64	84.66 (42.38)	117.0 (59.43)	32.34 (17.05)	38
10	0.3	0.83 (0.42)	1.82 (0.94)	0.99 (0.52)	119	3.81 (1.93)	10.14 (5.19)	6.33 (3.21)	166
Total	55.3	798.31 (451.86)	895.65 (513.30)	97.41 (61.42)	12	2,742.31 (1,582.82)	3,212.08 (1,886.63)	469.77 (303.8)	17

[a]Numbers in parentheses are areas in 1000's of acre-ft. Numbers may not add up to the last digit due to roundoff.

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for combined fly ash and sludge as well as FGD sludge alone. Tables 13 and 14 show the projections of the cumulative quantities and volumes of dry sludge and dry sludge plus ash, respectively, by region through the years 1985 and 2000 under pre-NEP and NEP conditions. Figure 2 shows the percentage increase in combined sludge and ash in each region due to implementation of NEP.

Tables 15 and 16 outline the breakdown of industrial and utility-related generation of coal ash and FGD sludges. Industrial wastes are likely to be a major part of national waste generation. Due to a lack of baseline data, impacts specific to industrial wastes are not considered separately. The impacts discussed broadly apply to both industrial and utility waste.

These estimates were prepared based upon the annual sludge rate projections in the Annual Environment Analysis Report (5) and assumptions regarding the distribution of coal consumption by type and region (see Tables 8-10 and 12). The basis for the projections is as follows. All scrubber systems are nonregenerable; Under the pre-NEP scenario, all coal-fired utilities are required to meet standards of 0.6 lb SO_2 emission/10^6 BTU heat input for Western coal and 1.2 lb SO_2 emission/10^6 BTU heat input for all other coals. Under the NEP scenario, all new coal-fired utility boilers (and industrial boilers larger than 25 MWe) on line in 1984 and after, are required to meet BACT standards (81% removal of all sulfur from all coals burned). Sulfur and ash contents of coal given in Table 8 are after any assumed coal cleaning or processing.

In developing the cumulative figures for sludge and ash production, a linear relationship has been used between 1975 and 1985, and between 1985 and 2000 for each scenario.

It should be noted that the tonnages and volumes of sludges and sludge plus ash do not take into account the effects of any sludge treatment nor do the cumulative sludge plus ash volumes take into account variations due to simultaneous removal of ash and SO_2.

Treatment of FGD sludge or common disposal of FGD sludge and ash could utilize essentially all available coal ash in all regions except 6, 8, 9, and 10 (assuming 50/50 admixture).

The combined impact of wastes generated by industry and utilities is the focus of this paper. Baseline data are not available, as of this writing, to consider the impact of wastes from industrial boilers alone. It should be noted, however, that preliminary esti-

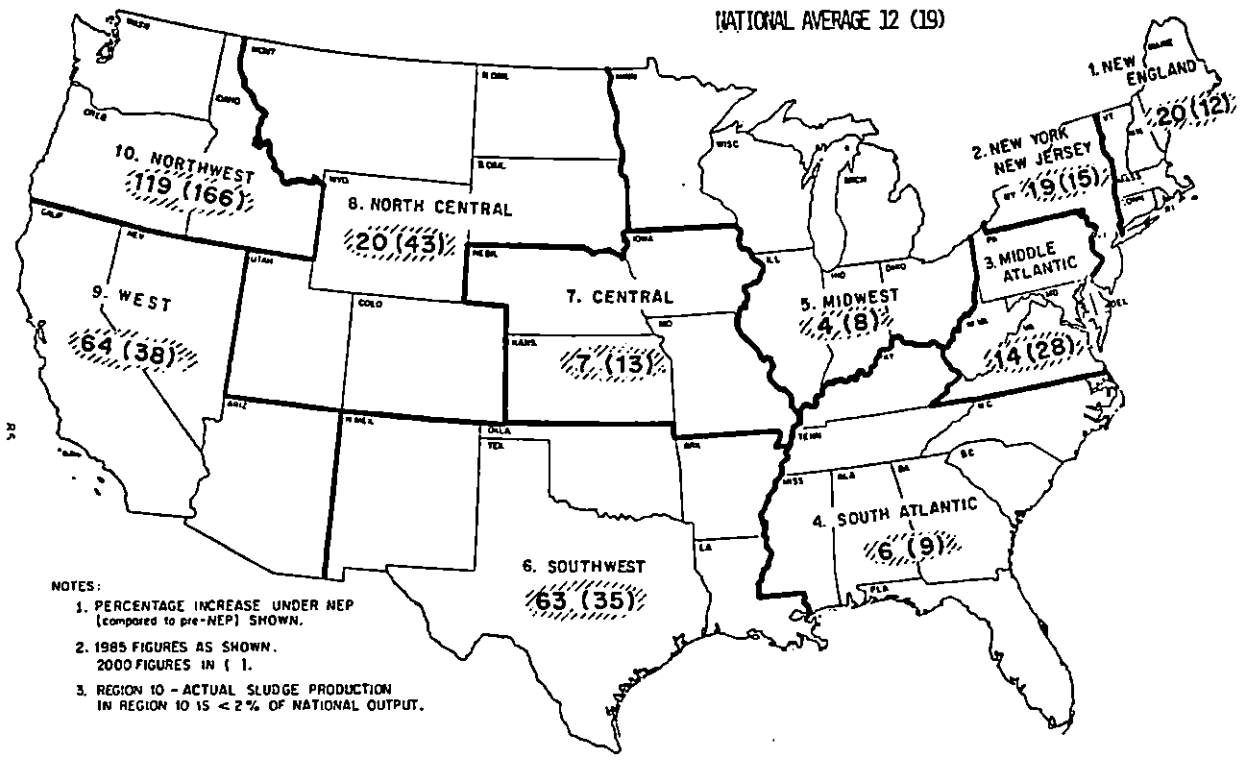

FIGURE 2. Regional FGD sludge + ash generation cumulative percentages in 1985 and 2000.

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mates indicate that, by 2000, the generation of such wastes by industry, which is presently negligible, will be a sizable percentage of the total generation of ash and FGD wastes.

Environmental Impacts

The existing regulatory framework governing disposal of ash/sludge, if successfully developed and implemented, should prevent or minimize significant adverse environmental impacts. Hence, discussion of environmental impact of ash or sludge disposal is basically an attempt to focus on potential environmental issues.

Geologic and Soils Impacts. The most direct impact of disposal would be on the geology and soils of the area. The regulatory framework under which disposal of FGD sludges and fly ash would take place has been discussed above. Because of the minor volumes of land required for disposal, incremental impacts on land (under NEP versus pre-NEP) would be minimal on a regional basis. On a site-specific basis, the degree of potential adverse impact would be related to the extent of requirements for the application of available control technology. If fully applied, such technology is believed capable of preventing significant adverse impacts.

A broader consideration is the socioeconomic impacts of incremental land use discussed next.

Land Use Planning Impacts. A typical 1000 MW plant will require 400 to 700 acres for disposal of ash and FGD sludges over a lifetime of 30 years depending upon the type of coal to be used and the region in which it is located. The 400 to 700 acres include only the excavated area (landfill or impoundment); the actual disposal area required may be much larger since land would be required for access roads, truck parking, and unloading areas, and buffer zones to screen off the disposal area. It is anticipated that in the future public pressures will result in greater attention to buffer zones in populated or recreational areas to minimize the adverse aesthetic impacts of disposal areas.

The area required for disposal of such wastes from a typical industrial boiler of 100 MW is roughly 10% of that required for a corresponding industrial plant. Cumulative wastes generated by an industrial boiler during its lifetime will require from 40 to 65 acres for the disposal area along with perhaps an additional 50 acres required for unloading areas, vehicular movement and buffer zones.

In considering land-related impacts, two perspectives are useful: baseline land requirements for waste disposal under pre-NEP by 1985 and 2000; incremental land requirements under NEP over baseline land requirements by 1985 and 2000.

Table 20. Maximum total land requirements — cumulative.

Year	Baseline under pre-NEP, acres	Total under NEP, acres	Incremental change, %
1985	18,000	21,000	12
2000	63,000	75,000	19

Preliminary estimates on maximum land requirements for disposal area proper are summarized in Table 20. These estimates are the upper limit figures for disposal area proper if all sludge is disposed on land (i.e., with no utilization or other than land disposal method). Actual land taken for this use (including access roads, buffer zones, and other areas) would be higher. Actual land requirements depend on design of disposal systems.

These land requirements may result in land use controls by local communities. Land disposal areas are usually zoned for heavy industry. This land use may not be compatible with other uses such as residential, commercial, and recreational.

Conclusions on land impacts are noted. From a regional or state land use perspective, these land requirements are not large. Regions 5, 4, 6 and 3 (in that order) are projected to require maximum total land and maximum incremental land under NEP. While individual disposals would result in a loss of land for other purposes, the impact when considered on a regional or national scale is not very large. Much of the land area required for disposal between 1985 and 2000 would result from the establishment of new utility plants and industrial boilers. It is anticipated that these "energy centers" will require a larger land area than previous facilities and hence be sited in relatively rural areas. Political and economic factors are expected to increase land use planning for such uses and place additional regulatory constraints on utilities and industry. Potentially, demand could arise to combine utility plant and disposal area into one site, reducing requirements for off-site disposal.

Water Resource-Related Impacts. The overview of national water resources was presented above and applies equally to this section. The FGD sludge may be disposed of separately, or mixed with coal ash. Two disposal regimes are considered; inland disposal (on or beneath the ground), and disposal in the oceans.

Inland Water Resource Impacts. All disposal options previously cited have the potential for impacting the water resources of a region under the conditions of pre-NEP or NEP. However, successful implementation of existing environmental regulatory statutes could preempt each of the impacts discussed below.

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The most likely form of impact would be the contamination of groundwater as a result of leaching of the sludge, either from percolation of rainwater through the sludge (in the case of landfill impoundments or surface mine disposal above the water table), or from the movement of groundwater through the disposal area (in the case of impoundment, underground mine disposal) or surface mine disposal below the water table. Wet impoundments have the potential for contributing directly to groundwater contamination as a result of seepage of the sludge liquor into the ground.

Chlorides and sulfates (primarily as calcium, sodium and magnesium salts) are the major soluble species in sludge and, in most cases, total dissolved solids (TDS) in the leachate plumes may exceed recommended drinking water standards. Soluble sulfite in leachate from sulfite-rich sludge may also be of consequence and represent an oxygen demand. However, TOS (total oxidizable sulfur) levels should be quite low in most cases. Other species present in trace levels (such as cadmium, mercury, and zinc) could also be substantially increased in waters receiving sludge leachate depending upon the relative low rates of the leachate and receiving water and their respective qualities.

Control techniques available for minimizing adverse impacts upon the water resource of an area include: sludge processing or treatment, choice of disposal method, collection and treatment of sludge leachate or runoffs, and site selection, based on hydrologic factors.

It is difficult to assess the potential impact on inland water quality as a result of the additional FGD sludge that would be generated under NEP, since several regulatory programs, including the Resource Conservation and Recovery Act of 1976, the Surface Mining Control and Reclamation Act of 1977, and the Safe Drinking Water Act, contain provisions that are intended to avoid or at least minimize the pollution of groundwater from leachates. If sludge disposal sites are designed properly and if the actual operations conform to the design expectations, one could optimistically conclude that incremental sludge disposal would have essentially no significant adverse impact on groundwater quality.

The principal concern, therefore, focuses on whether or not sufficient control measures exist for mitigating or avoiding any adverse impacts regardless of the implementation of NEP, and whether such measures can be effectively regulated to ensure compliance. In light of the existing data on sludge properties and on the effectiveness of the various control measures noted above, there appears to be adequate means for controlling the quantity of sludge leachate and, to some extent, its quality. Thus, the impacts due to the incremental sludge or sludge plus ash caused by NEP will become a site-specific question as to whether a potential disposal operation is feasible and to what extent control measures are required. Since RCRA prevents deterioration of groundwater to the extent that its potential end-use is altered, NEP conditions would have minimal impact on groundwater quality if that law is fully implemented.

Furthermore, it is not expected that surface waters would be significantly affected because of the mandates of RCRA and the Federal Water Pollution Control Act. The principal determinant of impact would be in the choice of sites appropriate for disposal within the content of local availability. Disposal sites could most likely be located in mid or lower regions of a watershed having streamflow volume that would adequately dilute any seepage of contaminated groundwater.

Oceanographic/Water Impacts. Regulatory constraints to prevent adverse impacts due to ocean disposal are available under the Marine Protection Research and Sanctuary Act. Four principal areas of potential concern, relating to FGD sludge disposal, if practiced, in the ocean water environment, are: impacts of benthic sedimentation; impacts of sludge suspended in the water column; impacts of sulfite-rich sludge; and trace contaminant impacts.

The impact of the introduction of sulfite into the ocean environment as a consequence of FGD sludge disposal is of interest because: first, sulfite has a measureable toxicity; and second, it reacts with dissolved oxygen, leading to a depletion of dissolved oxygen.

If the FGD sludge solids would dissolve instantaneously upon being diluted and dumped, and if the oxidation in real seawater would proceed as rapidly as in uncatalyzed laboratory experiments, one would expect to find severe reductions in dissolved oxygen in the vicinity of the dump. However, calcium sulfite is very insoluble and it is unlikely that complete dissolution would occur in one or a few minutes. It is likely that solids dissolution rather than oxidation would be the limiting step in the dissolution/oxidation sequence.

The anticipated initial dilution of sludge liquor by a factor of 500 could result in concentrations of some trace metals (notably mercury, zinc, selenium, cadmium, and nickel) approaching or in excess of the "minimum risk" levels recommended by the National Academy of Sciences in 1972. This range of trace contaminant levels in the solid phase of FGD sludges encompasses considerably higher concentrations than found in the sample sludge liquors. As with the liquors, values in the high range have been obtained from sludges containing fly ash. As in the

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case of sulfite, the impact potential of trace contaminants bound or adsorbed to the solid fraction of the sludge will be dependent upon critical variables such as dissolution rate and particle uptake by free-swimming organisms. Too little is known of these types of interactions over the short term to allow for a feasible prediction of quantitative impacts.

Applicable control options to reduce water-related impacts could be: the form of the sludge and its composition; disposal by dispersion; control of disposal method to concentrate sludge at the bottom; chemical treatment (e.g., adding lime and/or ash); and dumping in the deep ocean waters.

Anticipating the application of some of these control techniques, three options have been considered for ocean disposal: treated bricklike sludge in the shallow ocean; sulfate-rich sludge in the deep ocean; and treated sludge in the deep ocean.

Ocean disposal can be a significant disposal option in Regions 1 and 2. However, because of available control options and the projection that the increments in sludge and sludge plus ash, due to NEP, are small in these regions, and because ocean disposal would represent only a fraction of the sludge disposal, it is expected that there would be little impact on ocean water quality due to the implementation of NEP. Should any adverse affects be expected due to sludge disposal in the ocean, then the current regulatory disincentives to such disposal operations would preclude disposal under pre-NEP conditions. Then other means of disposing of the sludge or conversion to regnerable systems would be required.

Air Quality Impacts. Potentially important impacts, both subject to regulation under the Clean Air Act, are: fugitive dust emissions and, under some conditions, fugitive SO_2 emissions from the wastes.

SO_2 emissions could be significant if disposal is in surface or underground mines where run-off water could be acidic. However, sound control techniques would preclude release of fugitive SO_2 by such chemical destabilization methods. Except in underground mine disposal, SO_2 emissions are probably a minor factor.

The impact on air quality from FGD sludge/fly ash disposal is dependent principally on the moisture content of the material and disposal option. The high moisture content of the mixed FGD sludge/fly ash material would prevent emissions during transfer and transport to the disposal site; it is only the potential drying out of the surface particles at open pit operations which could cause fugitive emissions. Therefore, landfill and surface mine disposal operations could generate fugitive emissions due to wind erosion of the dry surface material.

Based on the regional sludge distribution table (Table 13), the major increases in sludge disposal in 1985 due to the National Energy Plan would be in EPA Regions 3 and 6. The major increases in the year 2000 are in the same two regions.

The level of increased ambient total suspended particulate (TSP) concentrations bordering a disposal site could be subject to the Prevention of Significant Deterioration (PSD) regulation in the Clean Air Act Amendment of 1977. The particulate concentration increases allowed under this regulation are 19 $\mu g/m^3$ (annual geometric mean) and 37 $\mu g/m^3$ (24 hour average, not to be exceeded more than once per year). Because the fugitive emissions from disposal operations are at ground level, the impacts near the source would be maximum and could, if controlled, exceed the PSD values. Applicants for FGD sludge disposal might be subject to PSD review. The expected ambient TSP concentration gradient from ground-level disposal sources is expected to be great, indicating that levels immediately bordering the sites could be high, but should drop off rapidly due partly to the settling rate of large particles (> 0.075 mm). The impacts on the ambient concentrations and the PSD increment would, therefore, be much lower at property line receptors if a buffer zone surrounded the disposal site. This zone may have a radius as great as 1 km for operations that have high fugitive emissions.

Terrestrial Biological Impacts. Potential impacts on vegetation from the disposal of FGD sludge are highly site-specific and similar to those resulting from disposal of coal ash. Since FGD sludges are often disposed of in combination with fly ash, impacts resulting from a combined disposal of sludge and ash are focused on. Again, site-specific application of control technology, which is available under existing regulatory mandates, would tend to minimize all potentially adverse impacts. Impact from landfills and impoundments is primarily disruption of resident vegetation on the site. Leachates may be a source of impact from landfills, surface mines and unlined impoundments used for disposal. Such leachates may have high concentrations of sodium chloride which exert osmotic stresses on plants. Plants exposed to leachates from FGD sludges and ash may or may not take up toxic amounts of heavy metals; such uptake depends on the total matrix in the soil.

Potential positive impacts from combined sludge and ash disposal include the return of surface-mined lands to a topography compatible with the surrounding area. The reclamation of surface mines, landfills and impoundments with vegetation somewhat different from the surrounding area would increase the diversity of habitats available.

Regional impacts on vegetation are a function of the additional land area required for landfill- and

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impoundment-type disposal areas. The NEP initiatives would tend to increase the land required for disposal, assuming a mix of disposal options, but the overall regional impacts in any case are not large.

The major impact on terrestrial wildlife will occur from the conversion of potential habitat. In general, loss of vegetation has the potential to reduce the carrying capacity of some areas for wildlife. The magnitude of the NEP impact will bear some direct relationship to the collective magnitude of the disposal options involving land surface area and, more importantly, to the disposal sites chosen.

Another type of potential impact of FGD sludge on terrestrial wildlife relates to the possible impacts of some of the chemical constituents in groundwater. The leachate contamination of surface waters with potentially toxic trace materials (e.g., cadmium, lead, and selenium) is a possibility. Leachate contamination may occur both with surface and underground disposal options. This presents the possibility of chronic exposure of wildlife to potentially toxic trace materials. The ingestion of plant material grown within a leachate field could also create such exposure. The amounts involved are unlikely to produce acute effects. If unregulated, they could possibly have significant chronic effects, but there is not data available to evaluate this potential.

Viewed from the regional perspective, EPA Regions 4 and 5 would have a relatively higher potential to lose habitat because of the combination of options using land surface areas. With respect to leachate contamination, those areas using lined impoundments would tend to minimize the potential effects on ground and surface waters. Consequently, the potential impact on wildlife using such waters would be minimized.

Aquatic Biological Impacts. Considerations of the site-specific application of control technology and protective regulatory framework discussed in Section 2.2.4 also apply here.

In that context, characteristics of FGD sludge and sludge/ash combinations which appear potentially problematic for aquatic biota are: the combination of small particle size and physical instability in soil-like FGD materials; relatively high concentrations of certain dissolved species in sludge leachate; the reducing capacity of untreated, sulfite-rich sludges; and the presence of relatively high concentrations of several trace metals in sludge/ash mixtures and a few metals in sludges alone.

If enough soil-like FGD sludge or soil-like sludge/ash mixture reaches the bottom of a fresh or marine surface water body to form a sediment layer, the particle size and "mudflow" characteristics of the material could form a substrate unsuitable for colonization by a diverse benthic fauna. This appears to have been the case in a shallow marine embayment where an inadvertent FGD discharge took place.

If freshwater systems should be exposed to leachate from the untreated FGD sludge, the relatively high concentrations of such dissolved solids as chlorides, sulfates, and fluorides could be problematic. Chlorides and sulfates would be of potential indirect concern as influences on salinity and the toxicity of other chemicals, while fluorides have the potential to cause health problems among populations of domestic animals (e.g., cattle) consuming fluoride-contaminated water.

There is evidence that sulfite-rich FGD sludges dissolve quickly enough to exert considerable oxygen demand. If such sludges reach surface waters with oxygen-limited environments (e.g., stratified lakes), the resident biota could suffer direct stresses due to anoxia and/or indirect stresses related to the tendency of a wide variety of contaminants to exhibit greater toxicity in oxygen-depleted environments.

Several trace metals (including mercury, cadmium, lead, nickel, iron, selenium, and zinc) have been reported in a limited number of samples of the solid and liquor fractions of FGD sludge/ash mixtures in concentrations in excess of water quality criteria recommended by the EPA for the protection of aquatic life. In some cases dilutions on the order of 10,000 to 1 would be required to achieve concentrations equivalent to minimal risk levels (e.g., for cadmium). The aquatic biological impact potential of the combined suite of trace contaminants in FGD sludge/ash mixtures is presently under study, but the area is still too poorly understood to project quantitative impact potentials or effects levels. Sludges alone appear to exhibit high concentrations of fewer metals than the sludge/ash mixtures, notably for such volatile species as mercury and selenium.

Control options involving chemical treatment of FGD sludges, especially those producing brick-like materials, seem to have the potential for reducing or eliminating the impact potentials discussed above and could play a major role in preventing adverse impacts under either a pre-NEP or NEP scenario.

On a regional basis EPA Regions 6 and 3 are predicted to experience the largest incremental sludge disposal requirements in the 1985 and 2000 scenarios. In the absence of site-specific considerations, correspondingly higher aquatic biological impact potentials could exist in these regions. Both have a variety of valued and potentially vulnerable coastal estuaries and warm-water systems, and Region 3 has a number of high-quality, cold-water fisheries in its northern portion. Regions 4 and 5 are both projected to experience large volumetric (small percentage) increments in sludge disposal. Both are largely characterized by warm-water systems gener-

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ally having somewhat greater assimilative capacities than cold-water habitats.

Health Related Impacts

The classes of regulatory constraints and health concerns from disposal of FGD sludge and fly ash are the same as those outlined for ash in Section 2.3. It must be taken into account that a major portion of FDG sludges will be disposed of in admixture with ash, which tends to raise the content of many of the trace metals but, if properly treated, reduces their availability.

As with ash, the largest changes in impacts in most areas will not come from the differences between the NEP and pre-NEP scenarios but with reference to the 1975 baseline in comparison to either scenario. The impacts would be principally site-specific. Figure 2 outlines the percentage increases in various regions. Lacking further information, correspondingly higher levels of impacts could exist in these regions.

Whether increases in tonnage result in increases in health impact is again subject to all the variables cited in connection with ash disposal.

Here again, the "worst case" discussion is based on a comparison of undiluted FGD sludge and ash liquors with recognized standards for drinking water (6). From the median values for a limited number of FGD sludge analyses, data indicate that potential problem species may include beryllium, cadmium, lead (Eastern coal only), molybdenum (Eastern, but only one analysis), selenium, and sulfate. Individual high values additionally suggest perhaps local problems with arsenic, chromium, mercury, zinc, and fluoride. These concerns, of course, are based on considering each element or ion individually without knowledge of its chemical form in the liquor, and without allowing for synergistic adverse effects or antagonistic effects, both of which are known to exist among metals. Above all, this comparison ignores attenuating factors which would lead to actual levels for all these elements in any surface or groundwater much below those given for elutriated liquor. Further problems with straight liquor compositions arise from their high dissolved solids content (i.e., salinity) which could produce osmotic effects, in addition to specific ion effects.

Prevention of any of these concerns being manifested involves site-specific consideration of all factors previously enumerated. It would appear (with careful consideration of site location, surface and groundwater relations, prudent treatment and disposal methods, and other interrelated factors including regulatory mandates discussed in this paper) that the potential health impact of the disposal of FGD sludges and ash could be brought within tolerable levels for protection of human health. Against this background, the incremental health impact on a regional basis of sludge and ash disposal due to increased coal utilization under the National Energy Plan would be well within manageable limits. Site-specific impacts in the absence of controls could be significant and require case by case evaluation.

Data Gaps and Research Needs

A number of programs have been undertaken (and are in progress) by the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Electric Power Research Institute (EPRI), and others. These efforts have provided much of the baseline information for environmental assessment. Provided these programs continue, additional data and insight permitting better environmental assessment will be possible.

The EPA Program for Control of Waste and Water Pollution from Flue Gas Cleaning (FGC) Systems is designed to evaluate, develop, demonstrate and recommend environmentally acceptable, cost-effective techniques for disposal and utilization of FGC wastes, with emphasis on Flue Gas Desulfurization (FGD) sludge, and to evaluate and demonstrate systems for maximizing power plant water reuse/recycle. The program currently consists of 19 projects, each covering one of six areas of interest: (1) environmental assessment of FGC waste disposal/utilization processes and other power plant effluents, (2) assessment of the technology of these processes and development of new technology, (3) studies of the economics of these processes, (4) development of alternative FGC waste disposal methods, (5) development of new FGC waste utilization methods, and (6) development of methods for improving overall power plant water use. The environmental assessment efforts include FGC waste characterization studies; laboratory and pilot field studies of disposal techniques for chemically treated FGD sludges; characterization of coal pile drainage, coal ash, and other power plant effluents; and studies of attenuation of FGC waste leachate by soils.

Programs undertaken by others also focus on many of the above areas of interest.

Against this background of ongoing work, three major sectors exist where some additional information from new programs may be required.

Data gaps on disposal or utilization will not be fully covered by existing programs. Some potential questions are:

- Are there polycyclic aromatic hydrocarbons in coal ash or sludge?

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- What are the radionuclides in ash or sludge, and do they appear in liquors or elutriates?
- What are the amounts of the several trace metals in ash and sludge, including antimony, molybdenum and boron? (More data are needed.)
- What are the biological and health effects of mixtures of trace metals (in the form found in liquors), such as zinc, copper, lead, mercury, cadmium or nickel in combination with selenium in particular, but also in other combinations? (Useful studies should be performed.)
- What is the uptake of potentially toxic materials by vegetation adjacent to disposal areas? (Further work is needed.)
- What are the levels of concentration of heavy metals and other potentially toxic materials in vegetation and surface water that may produce chronic health problems for wildlife?
- How does leachate move in-ground aquifers? (Further work is needed.)
- What are the socioeconomic impacts of disposal of ash and sludges (including criteria) on land use?

One key result of NEP would be to accelerate the production of wastes by industries. Generation of wastes is expected to grow rapidly between now and 2000. But the proportion generated by industry is anticipated to grow even faster and will be accelerated further by NEP initiatives. Conservation measures under NEP do not reduce quantity of total wastes.

Thus the generation of coal ash and FGD wastes will be somewhat shifted from large utility plants to a mix of utility plants and small (25 to 200 MWe) industrial units. The technological, environmental and socioeconomic impact of this shift is probably the key factor in FGD waste disposal. Programs focusing on developing baseline data and information to regulate and guide this shift would be desirable.

Advanced combustion techniques like fluid bed combustion are anticipated to be in significant commercial use by 2000. Potentially lesser environmental impact will be one of the principal reasons to consider advanced combustion techniques. But then additional baseline data would be required on problems associated with such wastes. This would require completion of current programs in this field and probably some new programs.

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Joint Exhibit 5

TVA
Tennessee Valley Authority
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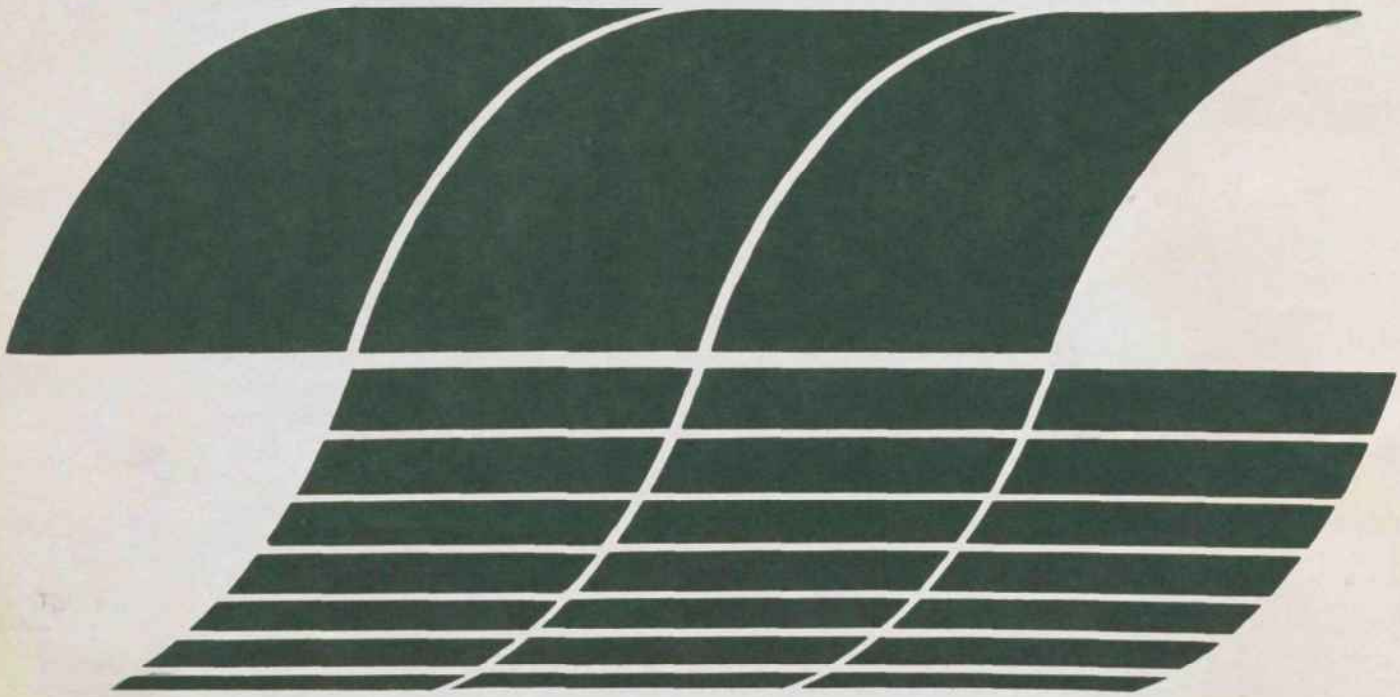
Chattanooga, TN 37401
EDT-111

EPA
United States Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park NC 27711
EPA-600/7-80-066
March 1980

Effects of Coal-ash Leachate on Ground Water Quality

Interagency Energy/Environment R&D Program Report



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March 1980

Effects of Coal-ash Leachate on Ground Water Quality

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EPA Interagency Agreement No. D5-E721
Program Element No. INE624A

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ABSTRACT

The four objectives of this research are: (1) to develop a methodology for the field collection of coal-ash leachate; (2) chemically characterize ash leachates from fossil-fueled power plants using different coal sources; (3) determine the characteristics of the hydrogeochemical environment in which the leachate occurs; and (4) determine the attenuation of coal-ash leachate by various soil types.

Groundwater monitoring wells were installed around the ash ponds at two TVA coal-fired steam plants. Continuous soil-core samples were collected and analyzed for physical and chemical parameters. Groundwater samples were collected and analyzed periodically. Ash leachate was percolated through different clays and soil types in the laboratory to study attenuation rates. Results indicate that:

1. Coal-ash leachate is a highly variable solution, but characteristically is high in dissolved solids, boron, iron, calcium, aluminum, and sulfate. Ash leachate can be acidic, with pH values as low as 2 measured. Ash leachate is a chemically reducing solution.

2. The different coal sources associated with this study produced ash leachate with similar characteristics.

3. The use of an inert gas lift pump proved an effective means of collecting anoxic groundwater samples while minimizing oxidation.

4. Differences were found in the characteristics of leachate samples obtained by extracting the interstitial soil water and samples collected from monitoring wells. Interstitial water samples contained higher concentrations of metals and were more acidic than well samples.

5. The flux of metals from coal-ash leachate was found negligible when compared to the mass of metals discharged by the ash pond surface overflow (even though concentrations in the ground water were highest) because the surface discharge was much greater than the groundwater flow.

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SECTION 1

INTRODUCTION

The increasing use of coal for power generation will result in an increasing potential for adverse environmental impacts. Realizing the importance of knowing what impacts power generating facilities may have on the environment and anticipating the forthcoming Federal regulations applying to solid waste disposal (Resource Conservation and Recovery Act, P.L. 94-580), the Tennessee Valley Authority (TVA) in conjunction with the Environmental Protection Agency (EPA) initiated a study to characterize the various effluents associated with coal-fired generating facilities. As a part of that study, entitled "Characterization of Effluents from Coal-Fired Utility Boilers," the impact of coal-ash leachate on groundwater quality at two TVA fossil-fueled power plants was investigated.

TVA's coal-fired generating system produces approximately 650 tons of coal ash for every 1000 megawatts generated. During 1977, TVA's 12 coal-fired power plants produced approximately 6.7 million tons of ash. The ash consists of various proportions of fly ash and bottom ash depending on the methods of firing and ash collection systems used at the plants. Once collected, the ash is sluiced with raw river water to nearby settling ponds. After settling, overflow from the settling pond is discharged to adjacent receiving streams in compliance with the EPA National Pollutant Discharge Elimination System permit.

Ash leachate is generated by the infiltration of ponded sluicing water into the settled ash, and its subsequent percolation through the ash where it eventually acquires the characteristics of ash leachate. The dry disposal of coal-ash, or ash ponds that are no longer inundated, such as a filled pond, can generate ash leachate with water from direct precipitation and/or rainfall runoff. Once the leachate is generated and has entered the subsurface environment below the deposited ash, its chemical characteristics can be affected by various attenuation phenomena. This report presents the results of a field and laboratory project performed to characterize coal-ash leachate and its attenuation by selected soil types at two TVA power plants. The major objectives of the project were to: (1) develop a methodology for the field collection of coal-ash leachate, (2) chemically characterize ash leachate from fossil-fueled power plants using different coal sources, (3) determine the characteristics of the hydrogeochemical environment in which the leachate occurs, and (4) determine the attenuation of coal-ash leachate by various soil types.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Results of the ash pond leachate investigation indicate:

1. Coal-ash leachate is a highly variable solution, but characteristically is high in dissolved solids, boron, iron, calcium, aluminum, and sulfate.

2. Several constituents in ash leachate were found to exceed EPA's criteria for drinking water. These include cadmium, chromium, iron, manganese, and lead. Dissolved solids and pH also did not meet these criterion.

3. Ash leachate can be acidic, with pH values as low as 2.0 measured. This acidity was found at two steam plants even though one generated an alkaline ash.

4. Ash leachate is a chemically reduced solution.

5. The different coal sources associated with this study produced ash leachate with similar characteristics. However, the acidic ash at one plant produced higher concentrations of metals in the leachate than the alkaline ash at another plant.

6. The use of an inert gas lift pump provides a means of collecting anoxic groundwater samples while minimizing oxidation.

7. Differences found in the characteristics of leachate samples obtained by extracting the interstitial soil water and those of samples from monitoring wells include: (a) interstitial water samples were more acidic than well samples, (b) interstitial water samples contained higher concentrations of metals than well samples and, (c) the collection of interstitial water samples by compressing soil samples is a time consuming and costly technique relative to the collection of water samples via monitoring wells. Further investigation into groundwater and leachate sampling techniques and their effects on sample integrity is needed to ensure accurate evaluations of leachate impacts.

8. Coal-ash leachate migration and/or attenuation in subsoils cannot be accurately determined by analyzing total soil samples for leachate constituents. Fractionization and analysis of specific particle sizes may be necessary to reduce the large variation associated with total soil sample analysis.

9. The mass of metals in the ash pond leachate entering adjacent surface water was found negligible when compared to the mass discharged by the ash pond surface overflow (even though concentrations in the ground water were higher) because surface flows were much larger.

10. Soils containing a large percentage of clay provide a better medium for attenuating metals from ash leachate than soils with more sand.

11. The anoxic leachate attenuation system, developed during this investigation, is a viable approach for studying leachate attenuation by soils under anoxic conditions.

12. Further work on the speciation chemistry of coal-ash leachate needs to be performed to determine if toxic metal species are present.

SECTION 3

LITERATURE REVIEW

The solubilization of ions from coal ash during the percolation of water through ash disposal areas and their potential for groundwater contamination, have long been recognized. In a study conducted during 1951 and 1952 by Merz and Snead,[1] the leaching of soluble salts and alkaline compounds from incinerator ash dumps was investigated. Their studies indicated that salts and alkaline compounds would leach from ash during the percolation of water from direct precipitation and/or groundwater movement through the ash; however, the leaching rate would be very low. The study also found that chlorides, nitrates, and sulfates were the most readily leached anions, and sodium and potassium were the most readily leached cations. Calcium and magnesium were found to leach, but very slowly. A limited number of leachate samples were also analyzed for copper, aluminum, lithium, manganese, vanadium, barium, boron, and strontium. Only boron and strontium were found in quantities above one milligram per liter.

In a much later report, Rohrman[2] discussed a comprehensive ash study which involved 12 fossil-fueled power plants. One of the major findings of this study was that all the ponded ash sluice waters contained boron and phosphorus, and data was presented showing that many of the elements in coal ash were present in the oxide form. In one of the first studies to determine the major chemical elements of coal-ash leachate, O'Connor, et al.,[3] mixed 50 grams of fly ash of different ages with 500 milliliters of demineralized water and analyzed the liquid for extracted solutes. This study indicated that the coal-ash extract could be characterized as an alkaline solution of calcium sulfate. The pH of the extracts ranged from 7.5 to 11.1, calcium ranged from 27 to 288 mg/l, and sulfate from 45 to 600 mg/l. An additional finding was that the pH of the extract decreased with increasing age of the ash, but a reason for this is unknown. As a further part of this study, coal ash was placed into columns and subjected to repeated elutions with demineralized water. In this experiment, the highest concentrations of solids were observed during the first elutions and most of the readily soluble constituents were eluted with the first three liters of elutant. Calcium and sulfate were found to be the most abundant ions in all the elutants. Between pH 10.0 and 11.5, calcium was equal to the total hardness. At a pH below 10.0, calcium accounted for approximately half the hardness, indicating the solubilization of other hardness-producing ions.

In a study by Weeter, et al.,[4] 500 grams each of fly ash and bottom ash were mixed with two liters of distilled water for 48 hours. The liquid of this mixture was then analyzed for the extracted solutes. The results of their analysis is presented in Table 1. The calcium and sulfate concentrations in fly ash samples ranged from 400 to 600 mg/l and from 1300 to 2000 mg/l, respectively, somewhat higher concentrations than those found by O'Connor, et al. However, in the O'Connor study a smaller concentration of ash was used in the mixing experiment. The concentration of solutes in a water-ash mixture has been shown by Weeter to be dependent on ash concentration. Batch mixing studies performed by Weeter indicated that the supernatant concentrations of sulfate, alkalinity, calcium, and iron increase with increasing fly ash loading, and steady-state concentrations for these constituents were found to occur within a mixing time of one hour. This indicates that the most readily soluble constituents in coal ash are loosely bound to sites on the surface of the ash particle.

TABLE 1. CHEMICAL CHARACTERISTICS OF COAL-ASH SHAKER TEST SUPERNATANT[a]
(after Weeter, et al.)

Parameter	Fly ash[b]	Bottom ash[b]
Iron	0.1-1.8	0.05-0.15
Potassium	33-112	0.4-6.6
Calcium	400-600	8-135
Magnesium	1-19	0.8-7.1
Titanium	Trace	0.1
Arsenic	0.01	0.01-0.8
Boron	3-10	0.1-0.2
Aluminum	1.5-6.8	0.05-0.5
Sodium	15-90	0.8-7.8
Sulfate	1300-2000	12-60
Phosphate	0.1-0.6	0.1-0.5
Silica	3-40	1-2

[a]500 grams of ash with 2 liters of distilled water; shaken for 48 hours.
[b]Values in mg/l.

In batch shake tests similar to those performed by Weeter, Theis and Wirth[5] mixed various weights of fly ash that were collected from different plants with one liter of distilled water and determined the equilibrium pH of the supernatant. Their experiments indicated that equilibrium pH levels were achieved with an ash concentration of 1 to 2 grams per liter. They also discovered that some ashes induced alkaline conditions in the supernatant, while others produced acidic conditions. An analysis of the supernatant for trace metals showed that the highest concentrations were present in the acidic ash mixture, indicating increased solubilization as would be expected with the depressed pH.

In addition to changes in the pH and metals concentrations, changes in the dissolved oxygen concentration resulting from the addition of fly ash, have been found. In Figures 1 and 2, from Theis,[6] it can readily be seen that after mixing fly ash with water the original dissolved oxygen concentration is depressed, and the pH either increased or decreased. The decreased dissolved oxygen concentration may be a result of oxygen depletion by a sulfite ion oxidation reaction, and may be expressed by:

$$SO_3^{-2} + 1/2\ O_2 \rightarrow SO_4^{-2}$$

The rate of this reaction is normally very slow:[7] however, the catalytic effects of metal ions in this reaction are well known, and the reaction rate may also be affected by certain organic compounds. Increases in pH are likely a result of the solubilization of calcium oxide (lime) present on the surface of the ash particles. Upon mixing with water, calcium oxide becomes hydrated as follows:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

In distilled water partial dissociation of the hydrated lime would cause an increase in pH. In an actual coal ash disposal area, water mixed with ash would contain alkalinity and hardness. Under these conditions, an increase in pH would result from the establishment of the following equilibriums:

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad \text{hydrated lime formation} \qquad (1)$$

$$Ca(HCO_3)_2 \rightarrow Ca^{+2} + 2HCO_3^- \qquad (2)$$

$$HCO_3^- \rightleftarrows CO_3^{-2} + H^+ \qquad (3)$$

$$CO_3^{-2} + H_2O \rightleftarrows HCO_3^- + OH^- \qquad (4)$$

Equations 3 and 4 effectuate the increase in pH by removing hydrogen ions in equation 3 and increasing hydroxide ions in equation 4. These reactions, along with others, were utilized by Chu[8] in a study to demonstrate the efficacy of lime-soda ash softening of ash pond water for closed-cycle water reuse in power plants.

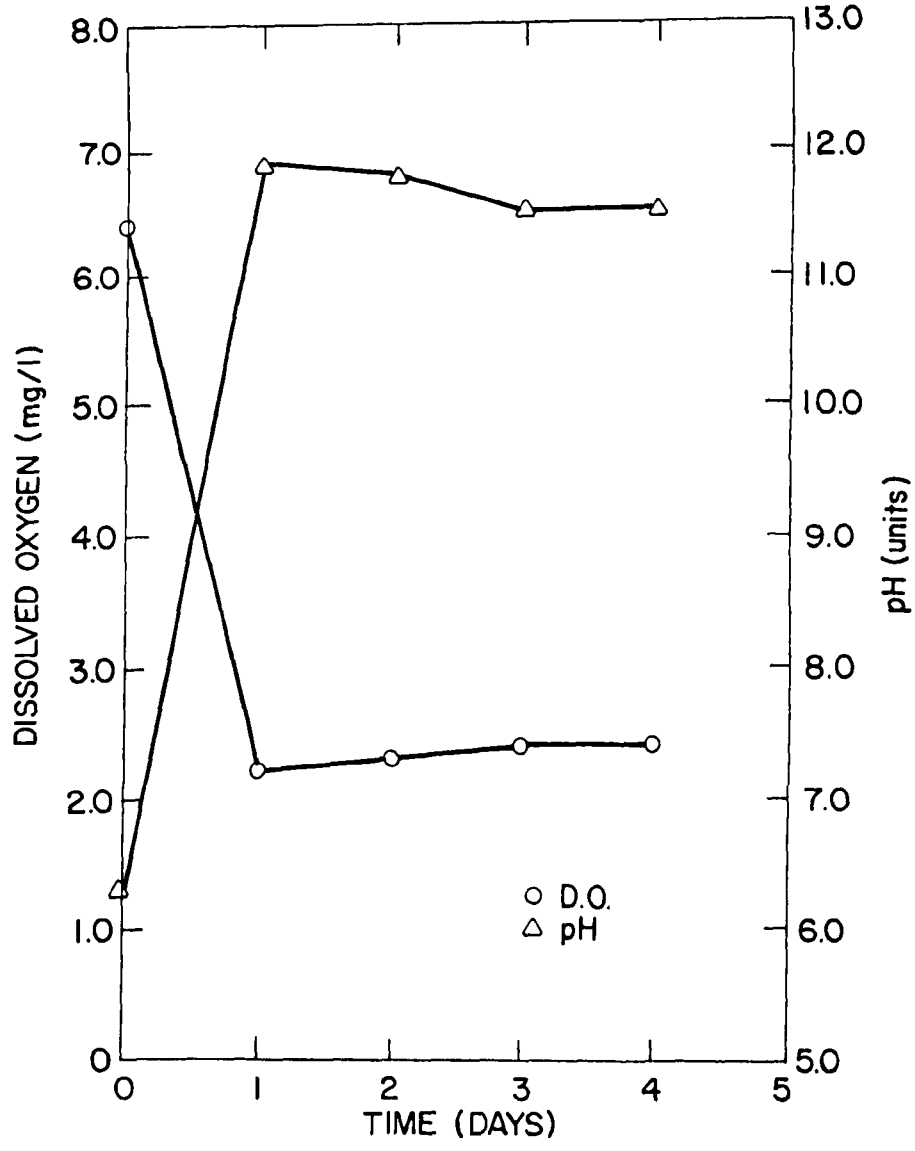


Figure 1. Effects of fly ash with lime on pH and dissolved oxygen of distilled water (after Theis).

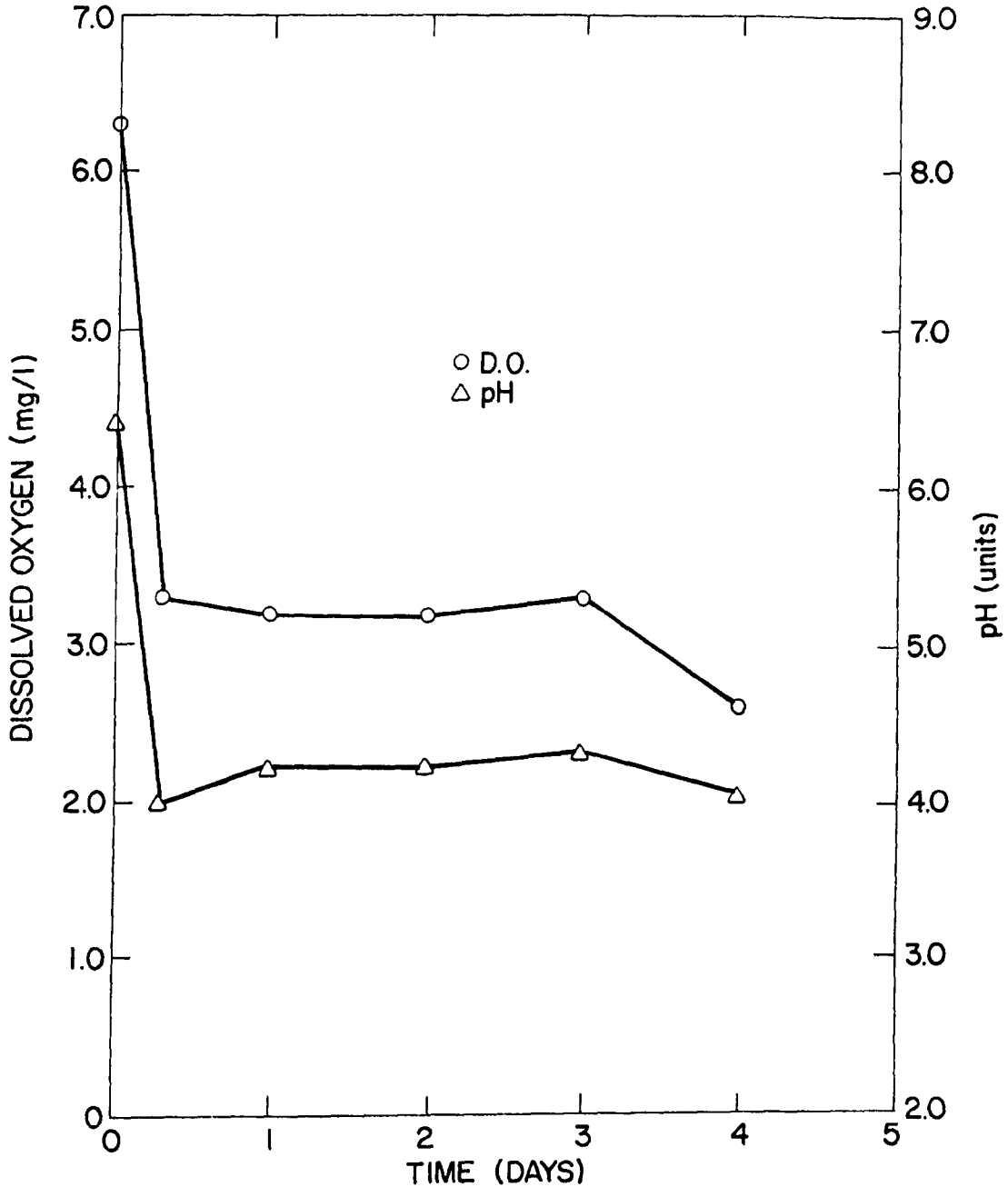


Figure 2. Effects of fly ash with lime on pH and dissolved oxygen of distilled water (after Theis).

Certain ashes may contain high concentrations of transition metal oxides, concurrent with low quantities of lime. Under these circumstances the acidic character of the transition metals, especially iron, can cause decreases in solution pH. In addition, salts of metal ions show varying degrees of acidity when dissolved in water; hydrolysis of these ions effectuates acidic conditions. For example:

$$Fe(H_2O)_5\ OH^{+2} + H_2O \rightleftarrows Fe(H_2O)_4(OH)_2^{+} + H_3O^{+} \qquad (7)$$

Decreased solution pH could present a potential water quality problem if a portion of the metals associated with coal ash were present on the surface of the ash particle where they could be easily solubilized. The sorption properties of fly ash were also investigated by Theis, and his findings indicated that surface coatings of amorphous iron, manganese, or aluminum oxides could provide a sorptive medium for trace metals.

Reed, et al.,[9] performed mixing studies using various concentrations of fly ash. From these studies he concluded that equilibrium concentrations were established within 20 minutes of contact. He also noted that the equilibrium concentrations achieved under his batch study were considerably lower than concentrations found by Burnett,[10] during a column percolation study in which fly ash from the same location was used.

In another column study performed by Brown,[11] distilled water was percolated through plastic columns filled with coal ash. Successive volumes of the percolate were then analyzed for various elements. The concentrations found in the percolate by Brown were considerably higher than concentrations found by previous investigators using batch mixing techniques. Column percolation studies tend to allow greater contact time and higher ash-to-water ratios than batch tests. These investigations indicate that column studies may be a more accurate method of predicting actual coal-ash leachate quality.

Harriger, et al.,[12] in one of the few recent studies to characterize coal-ash leachate by analyzing groundwater samples, reported highly variable concentrations of calcium, sulfate, alkalinity, iron, and magnesium in groundwater samples collected in an ash disposal area, and much higher values overall as compared to samples collected away from the ash disposal area. Some of their values are presented in Table 2 for comparison with values obtained in laboratory studies using batch and column techniques.

TABLE 2. COMPARISON OF COAL ASH LEACHATE OBTAINED BY DIFFERENT TECHNIQUES

Parameter	Mixed batch extraction[a]	Column elution extraction[b]	Leachate well sample[c]
Calcium, mg/l	20-280	490	91-660
Sulfate, mg/l	18-740	39,000	345-4000
Alkalinity, mg/l as $CaCO_3$	42-190	390	56,000-985,500
Iron, mg/l	0.03-0.1	0.1	0.04-10.4
Magnesium, mg/l	1-19	80	2.6-16.8
Arsenic, mg/l	0.01	0.13	0.01-0.19

[a] Weeter (see references).

[b] Brown (see references).

[c] Harriger (see references).

SECTION 4

DESCRIPTION OF ASH DISPOSAL AREAS

This section describes the coal-ash disposal areas at plants J and L, and provides some detailed information regarding coal use and ash generation. In addition, the geological stratigraphy beneath both disposal areas is described.

PLANT J

Plant J is a coal-fired power generating facility located on a peninsula formed by two reaches of the Clinch and Emory Rivers in eastern Tennessee. The facility was put into full operation in December 1955, and has a rated power generating capacity of 1700 megawatts. The plant utilizes coal produced in eastern Tennessee and eastern Kentucky which has an average of 2.0 percent sulfur and 19 percent ash. During 1972 the plant consumed 3.9 million metric tons of coal, and generated 711,682 metric tons of ash. The ash consisted of 560,002 metric tons of fly ash, and 151,680 metric tons of furnace bottom ash. The fly ash is collected by mechanical collectors and electrostatic precipitators installed in series, with an overall efficiency of 98 percent. The bottom ash is collected in hoppers located at the bottom of the furnace. The ashes required 30,112 million liters of raw river water to sluice it from the collection systems at the plant to a nearby ash settling pond for disposal.

The original coal-ash disposal area at plant J (ash pond A) consisted of a 242,800 m^2 settling pond. This pond was completely filled with ash by 1972 and is no longer in use. The current disposal pond has an area of approximately 594,900 $m.^2$ The pond is situated adjacent to the Emory River (see Figure 3) with the pond retainer dike separating the pond and river. The pond overflow is discharged over a weir into a small embayment of Watts Bar Reservoir.

The thickness of the ash in plant J's disposal area ranges from 0.5 meters near the pond's overflow weir to 14 meters in the original 242,800 m^2 pond. The whole disposal area is underlain by (1) a clay-silt stratum immediately below the ash ranging in thickness from 2.4 to 6.1 meters, (2) a deeper alluvial sand stratum ranging in thickness from 1.5 to 3.6 meters, and (3) low permeability shale.[13] The thickness of the shale is not accurately known.

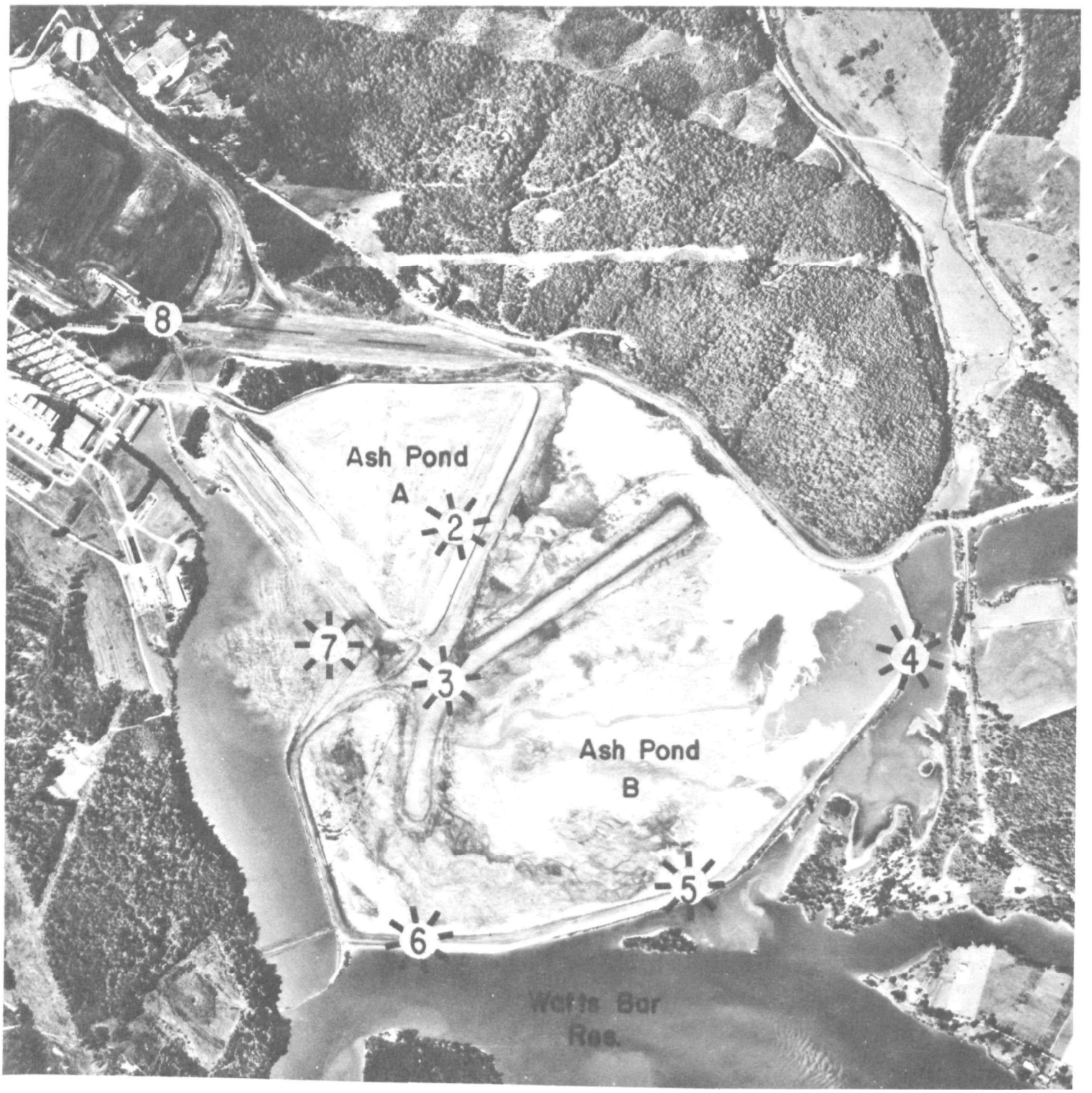


Figure 3. Plant J - ground water sampling well locations.

The ash pond dike itself is composed of a variety of materials with varying compositions, mostly silty clay, but deposits of ash are present. The height of the dike from the original ground surface to the top of the dike was approximately 4.5 meters.

PLANT L

Plant L began commercial operation in 1952, with three coal-fired units generating about 420 megawatts. By 1975, five additional units had been added bringing the total full load generating capacity of the plant to about 1965 megawatts. The facility is located on the Tennessee River in northeastern Alabama. The plant burns coal obtained from areas in western Kentucky and north Alabama which averages about 2.8 percent sulfur and 16 percent ash. During 1972, the plant consumed 3.3 million metric tons of coal and produced 432,361 metric tons of ash consisting of 107,228 metric tons of bottom ash and 325,133 metric tons of fly ash. The fly ash is collected by electrostatic precipitators or mechanical collectors and the bottom ash is collected in hoppers located at the bottom of each furnace. The volume of raw river water required to sluice the ash from the collection systems to nearby ash settling ponds during 1972 was about 27,725 million liters.

Plant L originally had two principal disposal areas (see Figure 4), ponds 1 and 2. Pond 1 is no longer active or inundated and has begun to revegetate. Currently, all the ash discharged from the plant is received by pond 2. This pond is 95 percent full and acts merely as a conduit to transport the ash to pond 3, which is the latest ash pond constructed. Some settling occurs in pond 2, but it is mostly the very coarse, heavy material. Most of the ash is settled in pond 3. The total ash disposal area, including ponds 1, 2, and 3, is approximately 1,032,000 m^2.

The thickness of the ash in plant L's ash disposal area ranges up to 11 meters in depth. The greatest ash depths occur in the older ponds 1 and 2. Underlying the ash disposal areas, there are three geological formations present:[14] (1) recent deposits of river alluvium, (2) older river terrace deposits, and (3) limestone.

The material overlying the limestone bedrock in the disposal area was deposited by the Tennessee River. There is no clear-cut delineation between the alluvium and the terrace deposits. Both are composed mostly of clay and silt with some sand and gravel mixtures. In the ash disposal area, these deposits vary in thickness from 3.8 to 9.0 meters. The underlying bedrock in the area is Ordovician age limestone several hundred feet thick. Its composition is mainly shaly limestone with interbeds of purer limestone and zones of varicolored siltstone or argillite. There are numerous cavities in the limestone resulting from its dissolution by ground water.

Pond No. 3's dike material is composed of a highly compacted clay of low permeability. The thickness of the dike from its interface with the original ground surface to the top of the dike is approximately 10 meters.

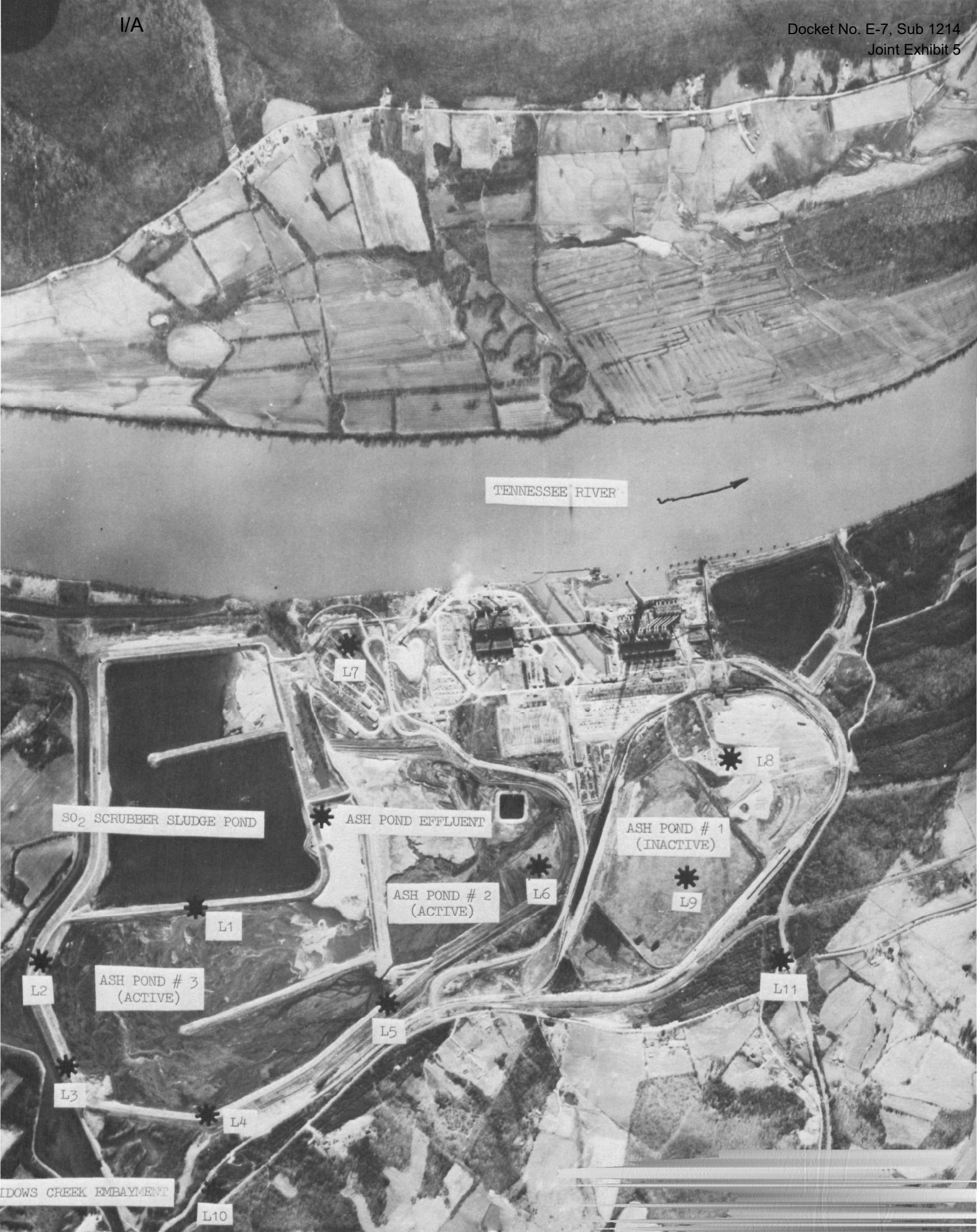


Figure 4. Plant L - ground water sampling well locations.

SECTION 5

METHODOLOGY

This section describes the methods and procedures used to obtain data on ash leachates, groundwater contamination, leachate migration, and leachate attenuation by soils. The project involved field investigations at two power plants with different coal sources and subsurface soil conditions, and a laboratory simulation of leachate attenuation using leachate collected at one of the power plants.

FIELD INVESTIGATION

Plant J - Groundwater Sampling Well Design and Installation

During March and April 1976, groundwater sampling wells were installed at eight locations in and around the ash disposal pond at plant J (see Figure 3). Two of the eight sampling sites (J1 and J8) are located hydraulically upgradient from the ash disposal area and function as background locations. Site J2 was located in an older section of the disposal area, which is no longer inundated and is presently used as an equipment storage area. Site J3 was located in an area of the active disposal pond that had recently been filled and was stable enough to support drilling equipment. Sites J4, J5, J6, and J7 were located on the peripheral retainer dike downgradient from the active disposal area and were spaced in such a manner as to intercept any lateral flow of ash leachate from the ash disposal area.

To install a sampling well, a "split-spoon" soil sampler with a diameter of 5.1 cm was first used to obtain a soil sample and then a hollow-stem auger having a 30.5 cm outside diameter and powered by a hydraulic drill was used to drill the well hole. The soil samples were collected continuously by alternating the downward movement of soil sampler and auger until an impermeable substratum was encountered. After extracting the soil from the split-spoon sampling device, the outermost layers of the soil core were cut away, so as to eliminate any contamination from the sampling device, and a portion of the residual soil sample preserved in a plastic container for later laboratory analysis. The remainder of the residual soil sample was then

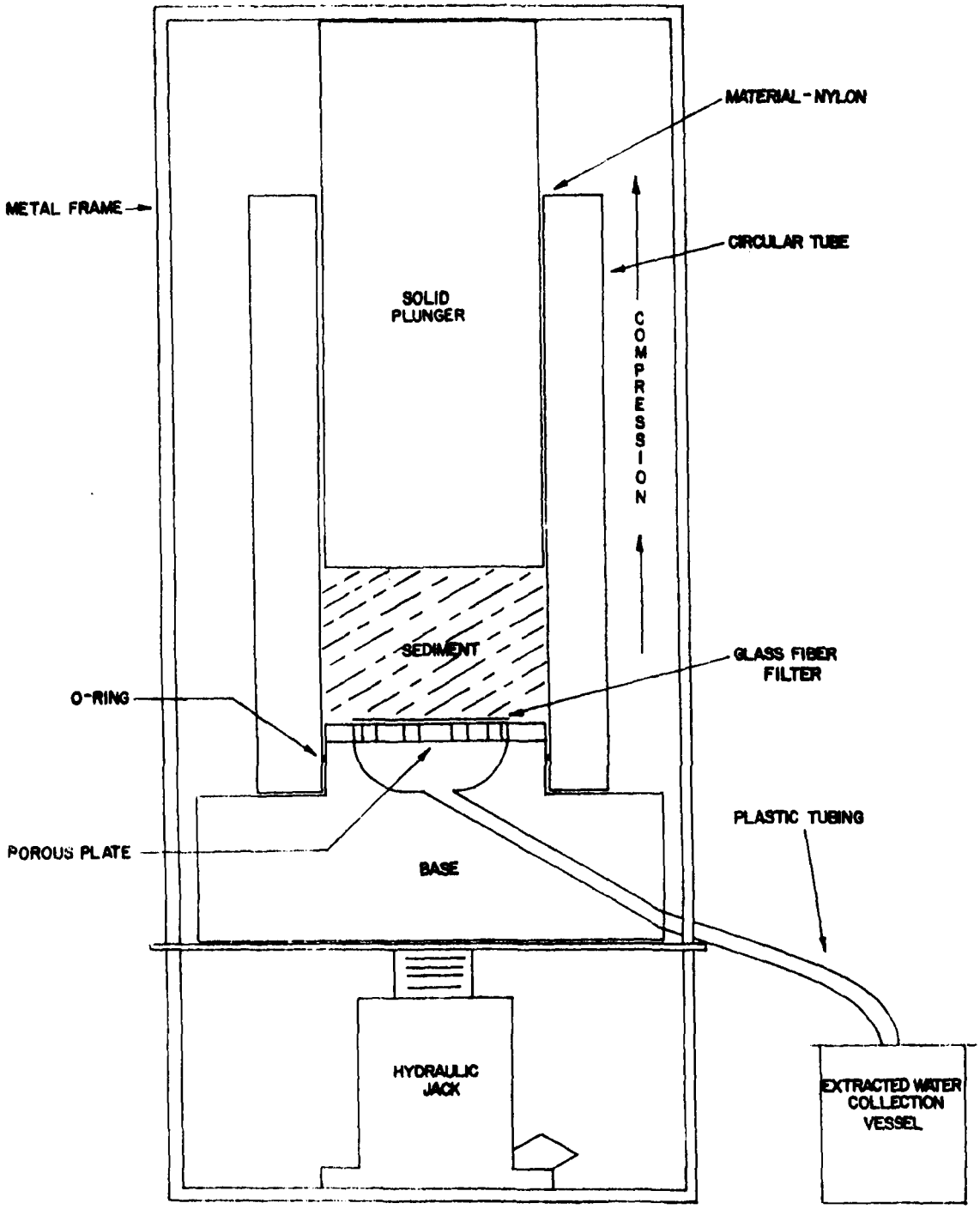


FIGURE 5. CROSS-SECTION OF INTERSTITIAL WATER EXTRACTOR

hydraulically compressed with the nylon interstitial water extraction device illustrated in Figure 5. It was necessary to perform the extraction as soon as possible because any delay could alter the composition of the interstitial water, and no technique for preservation was available. A portion of the extracted interstitial water was then immediately analyzed for pH, conductivity, sulfate, alkalinity, and hardness. The remaining water was filtered through a 0.45 micron filter pad and acidified (HNO_3) for later laboratory analysis of metals.

The interstitial water extraction device was made of inert nylon. All parts were machined to fit with little or no water loss during operation. Actually, however, after many hours of use, extracted water began to leak out between the solid plunger and its sheath (the circular tube). This was a result of sand getting between the plunger and circular tube and the subsequent scoring of each during operation. A harder material, perhaps teflon, and more precise machine work would undoubtedly correct some of this problem. Operation of the extraction device was quite simple, but required a great deal of strength for optimum results. To operate the device, the solid plunger was removed from the circular tube and glass fiber filters (usually two) placed over the porous plate. A portion of subsoil sample collected within the zone of saturation was then placed inside the circular tube. The amount of subsoil compressed at one time varied depending on its composition. Clay material often required compression of several portions of a sample in order to obtain the needed volume of water, while a larger quantity of sand could be compressed with the same result. The amount of subsoil used per compression ranged from approximately 400 to 800 grams. After placing the subsoil in the circular tube, the solid plunger was inserted and the whole extraction device installed in the metal holding frame. A three-ton hydraulic jack was then used to force the base and plunger together, compressing the subsoil and forcing the water through the glass fiber filters to the collection vessel.

The volume of interstitial water obtained in this manner ranged from 6 to 30 milliliters per compression, or, by rough estimate, 4 to 15 percent of the subsoil's moisture content.

At all locations except J1 and J8, and at selected elevations (usually upon encountering a change in strata), undisturbed soil samples were collected for laboratory determinations of horizontal and vertical permeabilities, grain size classification, moisture content, and bulk density. (The results of these determinations are presented in Table 3, and the analytical methods in appendix A.) This was normally done by offsetting from the original sampling bore hole and drilling down to the predetermined sampling depth. The undisturbed samples were collected by hydraulically pushing a cylindrical tube (a Shelby tube) having a length of 76 cm and a diameter of 8.9 cm through the desired sampling area. The Shelby tube, with sample, was then extracted from the well hole and both ends sealed with paraffin wax to prevent moisture loss.

TABLE 3. PERMEABILITY, DENSITY, GRAIN-SIZE DISTRIBUTION,* AND MOISTURE CONTENT OF SUBSOILS COLLECTED FROM ASH DISPOSAL SITE - PLANT J

Sampling Location	Depth (m)	Vertical permeability (cm/s)	Horizontal permeability (cm/s)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Density (g/cm^3)	Moisture (%)
J2	15.3	$6.3x10^{-8}$	$7.4x10^{-8}$	0	8	54	38	1.48	25.7
J3	14.1	$1.3x10^{-6}$	$7.4x10^{-5}$	3	25	63	9	1.42	24.6
J4	7.4	$2.8x10^{-7}$	$6.6x10^{-8}$	0	40	41	19	1.68	20.9
J4	9.7	$3.1x10^{-6}$	$8.8x10^{-6}$	0	80	14	6	1.60	22.6
J5	6.6	$4.0x10^{-7}$	$2.8x10^{-7}$	0	33	45	22	1.60	24.3
J6	7.4	$4.4x10^{-7}$	$2.5x10^{-6}$	0	29	51	20	1.48	26.7
J6	14.5	$1.4x10^{-6}$	$1.3x10^{-6}$	0	82	13	5	1.79	13.9
J7	12.9	$6.1x10^{-6}$	$1.4x10^{-5}$	0	69	24	7	1.45	20.7
J7	5.1	$1.7x10^{-7}$	$2.6x10^{-7}$	0	25	47	28	1.56	23.0

*Textural classification of soil fractions as per American Society for Testing and Materials designation, where: clay <0.005 mm, silt 0.005-0.074 mm, sand 0.074-4.75 mm, and gravel >4.75 mm.

After the original split-spoon sampling was completed, the void that had been produced by the action of the hollow-stem auger was cleaned out and a groundwater monitoring well installed. Each well was constructed of schedule 80 (0.64 cm wall thickness) polyvinyl chloride (PVC) pipe that had an outside diameter of 11.4 cm. The bottom 45 cm of each PVC well was perforated with 0.95 cm drill holes to allow groundwater inflow. Each PVC well was lowered to the bottom of the well hole and the annular space created between the perforated PVC pipe and the side of the well hole filled with pea gravel to some approximate height above the perforations, usually about 0.6 meters; this served to filter the inflow of solids into the well and prevent clogging. A layer of fine sand (approximately 0.3 meters thick) was placed in the annular space above the pea gravel filter. This functioned as a barrier between the pea gravel filter and a bentonite slurry placed in the annular space above the sand. The bentonite slurry extended from the top of the fine sand upwards to the surface of the water table and served to prevent water from channeling down the side of the PVC pipe. The remaining annular space above the bentonite slurry was filled with soil extracted from the original hole. At the point where the well casing entered the ground, a 0.5 meter diameter concrete apron, sloping away from the well, was constructed. This was done to further inhibit water from channeling down the side of the casing.

Fourteen wells were installed at the eight locations at plant J. Multiple wells were installed at locations J2, J3, J4, J5, J6, and J7 to enable the sampling of leachate from different substrata. Table 4 gives the depth of each well, the water table elevation at time of installation, and the type of stratum sampled.

Groundwater Sample Collection

To ensure that contamination of monitoring well samples did not occur from lowering a sampling device into the wells, groundwater samples were collected with a gas lift pump as illustrated in Figure 6. Cylinders of commercial argon or nitrogen gas containing less than 0.5 ppm oxygen were used during sample collection to minimize oxidation of the samples.

The gas cylinders were equipped with a pressure regulator and hose. With the hose attached to the Shrader valve at the well head, the regulator was adjusted to deliver 4218 to 7031 kgs/sq meter (6 to 10 psi). The gas flowed down the quarter-inch flexible tubing and into the bottom of the half-inch rigid plastic pipe, and lifted the water in the pipe to the surface where it was collected. To avoid collecting a water sample that may have set in a well for several weeks (and no longer would be representative of the surrounding ground water), at least one water volume of each well was pumped out prior to collecting a sample for analysis. After collection, water samples were preserved and shipped to the laboratory for analysis (see section 5).

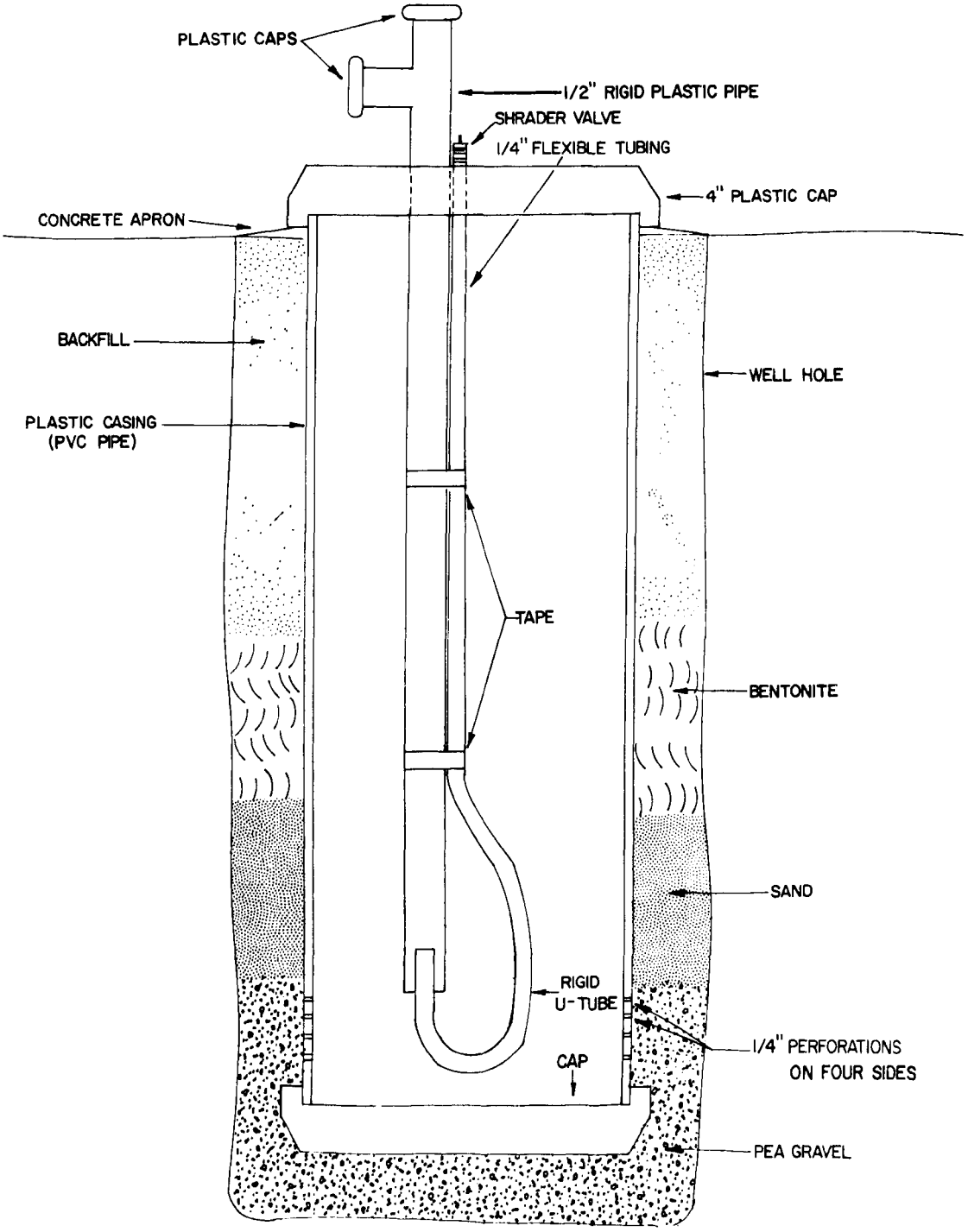


FIGURE 6. CROSS-SECTION OF GROUNDWATER SAMPLING WELL

TABLE 4. GROUNDWATER SAMPLING WELL DEPTHS, WATER TABLE ELEVATIONS, AND SUBSOIL STRATUM SAMPLED AT PLANT J

Well	Well depth (meters)	Elevation at well bottom[a]	Water table elevation[a]	Type of stratum sampled[b]
J1	8.5	224.8	231.28	Shale
J2	14.0	219.4	230.19	Silty clay
J3	12.8	216.7	227.75	Silty sand
J3A	8.2	221.4	227.81	Coal ash
J4	7.6	221.6	225.11	Sand
J4A	3.6	225.6	c	Clayey silt
J5	8.5	220.7	225.64	Sand
J5A	3.6	225.7	c	Clayey silt
J5B	8.2	221.1	c	Sand
J6	4.1	224.4	224.15	Sand
J6A	11.8	216.8	c	Clayey silt
J7	14.0	213.4	226.10	Clay
J7A	4.2	223.0	226.10	Sand
J8	7.5	226.6	230.90	Shale

[a]Elevation above mean sea level (meters).
[b]Monitoring well casing perforated within these strata.
[c]Not measured.

TABLE 5. COMPARISON OF DISSOLVED OXYGEN CONCENTRATIONS IN GROUNDWATER SAMPLES COLLECTED BY PUMPING WITH NITROGEN AND AIR AT PLANT J

Well	In situ[a] dissolved oxygen	Dissolved oxygen in sample	
		Pumped with nitrogen	Pumped with air
J2	0.5 mg/l	1.0 mg/l	20 mg/l
J3	0.2 mg/l	0.5 mg/l	8.3 mg/l
J3A	0.5 mg/l	0.2 mg/l	7.4 mg/l
J4	0.6 mg/l	0.2 mg/l	-
J4A	0.6 mg/l	0.7 mg/l	-

[a]*In situ* concentration after recovery from wasting one well water volume.

The validity of using a gas, such as nitrogen, to collect groundwater samples is supported by the data in Table 5. These data indicate that less change will occur in the dissolved oxygen concentration in the ground water by using nitrogen gas to pump the wells rather than by using air, and that the difference is quite significant.

Plant L - Groundwater Sampling

Groundwater monitoring wells were installed at 11 locations in and around the coal-ash disposal area at plant L (Figure 4). Two of the eleven locations, L10 and L11, are located hydraulically upgradient from the ash disposal area and function as background locations. Sites L6, L8, and L9 are in successively older sections of the ash disposal area and for the most part are no longer inundated. Locations L8 and L9 have some vegetative cover, while L6 is barren and partially inundated. Location L7 is hydraulically downgradient from the disposal area and L1, L2, L3, L4, and L5, are situated along the active disposal area's peripheral retainer dike.

Eighteen groundwater monitoring wells were installed at plant L. Multiple wells were installed at seven locations in order to sample different substrata. The depth of each well, the water table elevation, and the type of substratum from which water samples were collected are presented in Table 6.

Plant L's monitoring well design, and procedures for their installation, are essentially the same as described for plant J. However, at plant L, several of the monitoring wells were constructed using schedule 40 PVC pipe (0.32 cm wall thickness) with an outer diameter of 8.8 cm (3-1/2 inches). This smaller pipe proved to be easier to handle and install with no observed loss in sampling performance. Split-spoon soil sample collections, interstitial water extractions, undisturbed Shelby tube samples, and groundwater sample collection procedures at plant L are the same as described for plant J. The results of the permeability, density, grain, size distribution, and moisture content determinations on the undisturbed soil samples collected at plant L are presented in Table 7.

LABORATORY ATTENUATION STUDIES

During the project design phase, several possibilities were considered for generating, or simulating, an ash leachate in the laboratory suitable for use in an attenuation study. However, after the groundwater sampling wells were installed and leachate samples analyzed, it became apparent that the most representative water to use, and the most easily obtainable, was the actual coal-ash leachate collected in situ. The coal-ash leachate used in the laboratory attenuation studies was collected from groundwater sampling well L6A, at plant L. This well is approximately 10.6 meters deep and

TABLE 6. GROUNDWATER SAMPLING WELL DEPTHS, WATER TABLE ELEVATIONS, AND SUBSOIL STRATUM SAMPLES AT PLANT L

Well	Well depth (m)	Elevation at well bottom[a]	Water table elevation[a]	Type of stratum sampled
L1	10.67	179.72	183.22	Silt-clay
L1A	6.10	184.28	-	Silt-clay
L2	13.72	177.81	182.22	Silt-clay
L2A	6.10	185.76	186.50	Silt-clay
L3	13.41	178.13	181.51	Silt-clay
L3A	12.50	178.98	181.48	Silt-clay
L4	15.85	176.03	182.52	Silt-clay
L4A	6.10	185.44	182.60	Silt-clay
L5	15.24	175.89	183.03	Silt-clay
L5A	8.53	182.77	186.58	Silt-clay
L6	14.33	179.23	186.85	Silt-clay
L6A	10.67	182.54	186.81	Silt-clay
L7	8.84	175.04	182.10	Silt-clay
L8	11.89	179.51	187.55	Silt-clay
L9	8.53	183.13	189.08	Silt-clay
L9A	5.49	186.04	189.58	Silt-clay
L10	19.51	177.06	183.98	Silt-clay
L11	17.68	174.97	183.50	Silt-clay

[a]Elevation above mean sea level (m).

TABLE 7. PERMEABILITY, DENSITY, GRAIN-SIZE DISTRIBUTION*, AND MOISTURE CONTENT OF SUBSOILS COLLECTED FROM ASH DISPOSAL SITE - PLANT L

Sampling location	Depth (m)	Vertical permeability (cm/s)	Horizontal permeability (cm/s)	Sand (%)	Silt (%)	Clay (%)	Density (g/cm^3)	Moisture (%)
L2	13.8	$1.4x10^{-8}$	$0.2x10^{-8}$	23	48	29	1.72	19.2
L2A	5.8	$6.3x10^{-8}$	$1.7x10^{-7}$	30	18	31	1.66	18.7
L3	13.4	$6.7x10^{-8}$	$5.8x10^{-8}$	15	31	50	1.03	56.1
L3A	6.6	$6.9x10^{-9}$	$1.1x10^{-8}$	27	24	36	1.77	17.5
L3A	11.0	$2.7x10^{-8}$	$1.2x10^{-8}$	10	15	68	1.43	31.6
L4	13.4	$3.7x10^{-8}$	$5.5x10^{-8}$	14	21	43	1.28	36.5
L4	13.9	$4.4x10^{-8}$	$3.4x10^{-8}$	4	54	42	1.23	38.0
L4A	10.1	$1.9x10^{-8}$	$2.0x10^{-8}$	23	28	41	1.72	18.0
L5	8.3	$1.4x10^{-8}$	$1.7x10^{-8}$	15	34	51	1.64	23.2
L5	9.0	$4.3x10^{-8}$	$7.4x10^{-9}$	29	26	40	1.60	22.0
L6	10.7	$6.6x10^{-6}$	$5.6x10^{-6}$	54	42	4	1.45	24.3
L6	12.7	$1.2x10^{-8}$	$5.7x10^{-9}$	13	31	56	1.62	24.2
L7	8.8	$55.2x10^{-8}$	$45.0x10^{-8}$	10	65	25	1.06	57.5
L8	3.0	$5.6x10^{-8}$	$2.3x10^{-8}$	14	41	45	1.57	24.6
L8	0.8	$3.0x10^{-4}$	$1.5x10^{-4}$	37	58	1	1.18	35.2
L8	5.1	$1.9x10^{-8}$	$7.4x10^{-9}$	1	22	77	1.44	32.7
L9A	5.9	$2.0x10^{-8}$	$1.9x10^{-8}$	9	36	55	1.55	26.5
L10	16.6	$2.3x10^{-8}$	$4.7x10^{-8}$	5	15	80	1.34	37.3
L11	5.9	$6.3x10^{-8}$	$2.8x10^{-8}$	30	28	42	1.64	22.9

*Textural classification of soil fractions as per American Society for Testing and Materials designation, where: clay <0.005 mm, silt 0.005-0.074 mm, sand 0.074-4.75 mm, and gravel >4.75 mm.

terminates at the interface of the ash and the original soil. Only the bottom 45 cm of the well is perforated to allow leachate inflow. The water collected at this well has thus percolated downward through approximately 10 meters of ash. Leachate from plant L was selected because it could be transported to the laboratory the quickest.

After deciding that field collection was the optimum method for obtaining a leachate sample, there were collection problems that needed to be surmounted.

Preliminary in situ measurements indicated that anoxic conditions existed in the leachate environment, and if these conditions were not maintained during collection, transportation, and storage, alterations in the chemical characteristics of the leachate would result (simply allowing the leachate to come in contact with air would cause precipitates to form). This problem was alleviated by using argon gas to pump the leachate to the well head. At the well head, tygon tubing was connected to the 1.27 cm pipe that expelled the sample, and the other end to a 20-liter plastic receiving carboy, which was closed to the atmosphere. After wasting one well volume, the collection apparatus was purged with argon gas and then connected to the well head for sample collection. By sampling in this manner it was possible to maintain anoxic conditions in the leachate. After sample collection was completed, an argon atmosphere was maintained over the leachate in the carboy during transportation to the laboratory. Argon gas was used in place of nitrogen in the attenuation study because it contained less oxygen (<0.1 mg/l). In addition, argon is heavier than nitrogen and air and tended to form a blanket over the leachate to aid in the maintenance of anoxic conditions.

In the laboratory, the carboy was placed into a controlled temperature compartment maintained at 20°C under an atmosphere of argon. Once temperature equilibrium was established (approximately two days), attenuation studies were performed with the following materials: (1) soil taken from the ash pond dike at plant L, (2) soil taken from the ash pond dike at plant J, and (3) kaolinite. Each of these materials was homogenized and mixed with equal volumes of silica and rehomogenized prior to packing into columns. It was necessary to mix these materials with silica so that flow through the columns could be sustained. The fine clay material tended to swell and clog upon wetting, inhibiting or completely stopping the flow of leachate. The silica increased the permeability of the mixture and allowed the maintenance of flow through the column. The effect of the silica was not determined in this study, but it was assumed to be negligible because of the nonreactive nature of the silica particles, and the fact that each column had the same amount of silica, so the relative effects would be nearly the same.

Into each column (a 25-ml buret with an inside diameter of 1.2 cm), 11.64 grams of soil-silica mixture (1:1 volume ratio) was packed, at a density approximating the field conditions of 1.6 grams

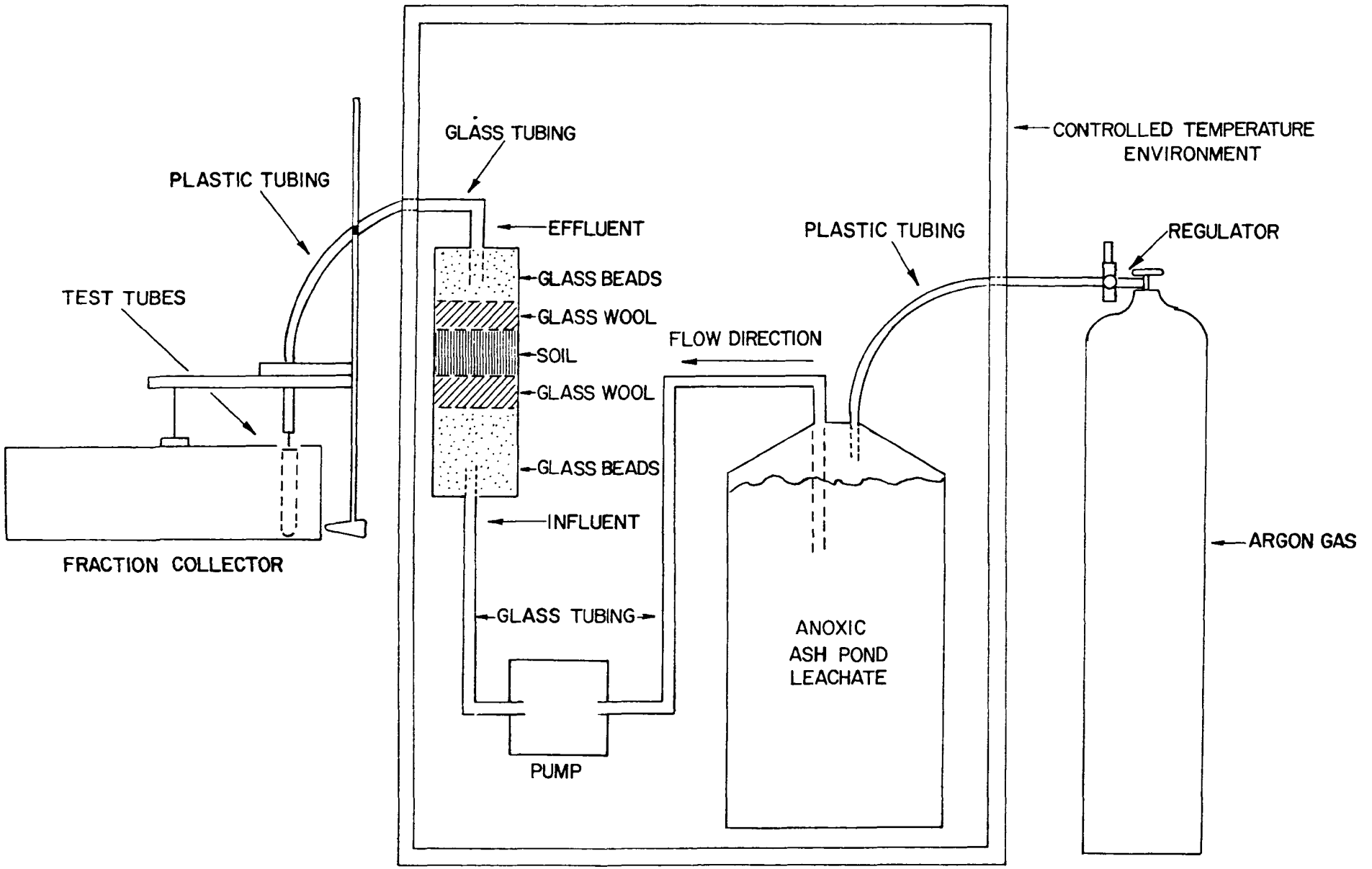


FIGURE 7. COLUMN ELUTION APPARATUS

per cubic centimeter. Both ends of the soil-silica mixture were packed with glass wool and glass beads to maintain the integrity of the soil column. The column was set up in a controlled temperature chamber (see Figure 7) to maintain 20°C. The leachate was pumped from the plastic carboy with a low flow, teflon-coated pump, up through the soil column to allow air to escape and ensure saturation. The effluent from the column was then collected in glass test tubes predosed with 0.1 ml nitric acid. Effluent flow was adjusted as needed to approximately 0.1 ml per minute. Sample collection was accomplished by photoelectrical measurements of the column effluent volume, coupled with a rotating automatic fraction collector. Effluent samples were collected during the three attenuation studies until the calcium exchange capacity of each soil-silica mixture was theoretically exceeded (this was estimated from calculation). The effluent from each column was collected in 30 ml test tubes which were composited to make up 6 effluent samples per column. After compositing, the samples were analyzed for the constituents listed in Table 8. Procedures for these analyses are given in appendix A. In addition, each of the soils and clays were subjected to powder X-ray diffraction analysis for their relative amounts of montmorillite, kaolinite, illite, and quartz. Each was also analyzed for the constituents listed in Table 8 (see appendix A for description of soil procedure).

TABLE 8. CONSTITUENTS ANALYZED IN COLUMN ATTENUATION STUDIES

Calcium	Copper
Magnesium	Chromium
Sodium	Zinc
Potassium	Nickel
Iron	Cadmium
Manganese	Lead
Sulfate	Aluminum
Barium	Beryllium
Mercury	Selenium

SECTION 6

COAL ASH LEACHATE FIELD INVESTIGATIONS

In this section, the results of analyses performed on soil core, interstitial water, and groundwater samples collected at plants J and L are presented.

SOIL CORE ANALYSES

The split-spoon soil cores collected at plants J and L, as described in the section on Methodology, were analyzed in the laboratory for the chemical constituents listed in Table 9. The analytical procedures used in these analysis are described in appendix B.

TABLE 9. CHEMICAL ANALYSIS PERFORMED ON SPLIT-SPOON SOIL CORES

Aluminum	Calcium	Iron	Lead
Arsenic	Cadmium	Magnesium	Selenium
Barium	Chromium	Mercury	Sulfate
Beryllium	Copper	Nickel	Zinc

At nearly all sampling locations at plants J and L, soil-core samples were taken from ground surface to bedrock at various vertical intervals depending on the type of substratum encountered. The purpose for analyzing these vertical strata profiles for the constituents in Table 9 was to determine the extent of leachate migration downward and away from the ash disposal area by comparing the vertical and horizontal distribution of constituents in the substrata. In addition, the concentration differentials between various strata were used to compare their relative capacities for attenuating ash leachate.

The data presented in Tables 10 and 11 are a result of the chemical analyses performed on the soil cores collected at plants J and L, respectively.

TABLE 10. SOIL-CORE ANALYSIS AT PLANT J[a]

Sampling location	Depth (m)	Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
J1	0.7	Clay-silt	160	11	130	-	1,200	< 1	30	20	30,000	< 0.1	-	25	18	< 2	81	57
	1.3	Clay-silt	140	-	130	-	1,600	< 1	26	31	21,000	< 0.1	-	28	14	-	49	55
	1.9	Clay-silt	160	11	240	-	4,100	< 1	29	30	26,000	< 0.1	-	39	18	-	130	60
	2.5	Clay-silt	150	-	180	-	4,200	< 1	31	28	22,000	< 0.1	-	39	21	< 2	28	64
	3.2	Clay-silt	64	-	140	-	3,300	< 1	9	16	14,000	< 0.1	-	25	81	-	40	38
	3.7	Clay-silt	160	-	140	-	3,900	< 1	37	28	27,000	< 0.1	-	45	19	-	46	96
	4.0	Clay-silt	120	< 4	120	-	4,800	< 1	32	29	21,000	< 0.1	-	40	22	< 2	71	46
J2	1.3	Ash	60	48	130	-	2,200	< 1	10	24	8,300	< 0.1	-	15	< 5	2	2,500	21
	3.3	Ash	56	-	100	-	3,700	< 1	31	25	6,300	< 0.1	-	15	7	-	500	23
	5.7	Ash	83	-	140	-	2,400	< 1	20	30	13,000	< 0.1	-	13	7	-	240	20
	8.1	Ash	470	-	110	-	2,000	< 1	12	21	13,000	< 0.1	-	11	9	-	230	13
	13.5	Clay-silt	83	-	130	-	1,200	< 1	7	16	9,000	< 0.1	-	13	22	< 2	120	43
	14.0	Clay-silt	21,000	12	260	-	5,200	..	22	31	13,000	-	1,600	22	22	< 1	67	27
	14.1	Clay-silt	620	-	130	-	1,000	< 1	13	9	3,800	< 0.1	-	< 5	20	-	79	32
	14.6	Clay-silt	9,400	-	130	< 1	970	< 1	16	17	5,300	-	940	9	35	-	120	40
	15.0	Clay-silt	79	-	89	-	1,000	< 1	17	16	30,000	< 0.1	-	14	32	-	120	48
	15.5	Clay-silt	2,200	-	39	-	510	-	6	4	8,400	-	300	< 5	14	-	320	12
	16.0	Sand	420	-	37	-	1,000	< 1	11	11	10,000	< 0.1	-	12	21	-	72	31
	16.4	Sand	3,900	-	74	< 1	350	< 1	10	8	4,700	-	590	6	38	-	110	83
	16.9	Sand	240	-	42	-	300	< 1	7	11	25,000	< 0.1	-	6	9	-	120	20
	17.3	Sand	1,000	-	-	-	460	-	9	< 2	2,900	-	140	< 5	7	< 1	-	8
	17.8	Sand	360	-	47	-	400	< 1	9	16	3,800	< 0.1	-	5	< 5	< 2	130	140
J3	2.2	Ash	4,900	-	79	< 1	1,200	< 1	6	23	4,900	0.7	290	6	15	< 2	3,600	5
	3.2	Ash	44,000	-	470	4	3,700	3	47	72	30,000	0.52	3,000	56	69	-	590	90
	4.4	Ash	20,000	-	31	-	4,600	-[b]	23	37	14,000	< 0.1	1,400	20	21	-	470	24
	10.2	Clay-silt	8,000	6	91	-	1,000	-[b]	11	14	13,000	< 0.1	720	12	29	-	< 4	39
	11.0	Sand	4,200	22	53	< 0.1	550	< 1	6	6	19,000	< 0.1	340	< 5	11	-	< 4	12
	11.1	Sand	4,500	-	77	< 1	520	< 1	6	6	5,000	-	650	7	5	-	84	22
	11.5	Sand	-	-	-	-	-	-	-	-	-	< 0.1	-	-	-	-	-	-
	12.1	Sand	2,300	-	30	-	770	-	< 5	2	2,200	-	430	< 5	7	-	< 4	13
	13.4	Sand	2,700	-	45	-	800	-	< 5	12	3,200	< 0.1	650	< 5	10	-	< 4	19
	14.1	Sand	2,900	-	32	< 1	300	< 1	6	2	1,800	0.27	460	5	< 5	< 2	60	16
	14.5	Sand	-	-	-	-	290	-	-	-	-	-	360	-	-	-	-	-
	14.9	Sand	6,900	-	86	< 1	870	1	13	8	8,900	0.28	2,400	16	8	< 2	350	32
	15.0	Shale	16,000	-	180	2	16,000	2	35	16	20,000	0.20	8,600	39	13	< 2	170	67

TABLE 10 (continued)[a]

Sampling location	Depth (m)	Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
J4	1.7	Clay-silt	4,100	60	75	-	12,000	-	8	3	34,000	0.93	280	13	17	-	14,000	2
	3.5	Clay-silt	5,100	-	46	-	1,200	-	6	<2	8,300	<0.1	370	5	15	-	<4	10
	5.0	Clay-silt	11,000	-	54	<1	160	2	12	7	21,000	0.3	460	6	28	22	1,800	23
	6.5	Clay-silt	6,300	<4	23	-	440	-	11	<2	25,000	<0.1	420	5	13	-	800	13
	8.0	Sand	3,900	-	54	<1	160	<1	<5	<1	3,700	-	300	<5	7	-	130	12
	9.6	Sand	1,300	-	12	-	400	-	<5	<2	2,200	<0.1	190	<5	3	-	<4	2
	11.1	Shale	11,000	-	140	3	970	2	30	18	41,000	0.28	2,900	53	54	<2	180	86
J5	3.9	Clay-silt	12,000	-	32	1	330	1	10	8	14,000	0.23	600	8	26	<2	340	30
	7.6	Clay-silt	7,000	-	36	<1	160	<1	7	6	14,000	-	350	7	21	-	5,600	17
	10.0	Clay-silt	3,800	-	16	-	420	-	9	<2	13,000	<0.1	230	<5	11	-	<4	9
	11.8	Sand	4,300	-	32	<1	260	1	<5	4	1,900	0.55	380	5	<5	<2	150	16
	12.2	Shale	20,000	-	180	1	1,800	1	35	29	16,000	-	6,800	46	8	-	400	94
	12.3	Shale	17,000	-	190	1	1,800	1	34	24	23,000	-	8,700	58	11	-	130	86
J6	1.9	Ash	8,900	-	160	<1	1,400	2	16	32	38,000	1.2	410	18	25	<2	3,300	9
	4.8	Clay-silt	11,000	-	28	<1	480	1.0	13	10	18,000	-	520	8	19	-	100	26
	8.2	Clay-silt	5,900	-	80	-	600	-	14	<2	11,000	<0.1	800	10	12	-	<4	24
	9.6	Clay-silt	-	-	-	-	460	-	-	-	-	-	800	-	-	-	-	-
	11.5	Clay-silt	3,800	-	45	1	390	2	10	8	9,500	0.17	540	5	<5	<2	34	21
	12.8	Clay-silt	6,300	-	78	-	910	-	20	<2	12,000	<0.1	930	10	14	-	<4	26
	14.1	Sand	1,700	-	46	<1	1,500	<1	<5	2	1,800	0.48	390	5	<5	<2	170	15

[a]Values in µg/g.

[b]Not analyzed.

TABLE 11. SOIL-CORE ANALYSES AT PLANT L[a]

Sampling location	Depth (m)	Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
J7	0.7	Clay-silt	14,000	-	220	1	4,100	<1	31	22	21,000	0.37	6,400	42	15	<2	140	59
	1.6	Clay-silt	14,000	-	300	1	15,000	<1	31	22	19,000	0.37	6,600	42	15	<2	240	59
	2.5	Clay-silt	16,000	-	280	-	22,000	-	51	21	29,000	<0.1	6,700	43	24	-	490	71
	3.5	Clay-silt	12,000	-	190	-	14,000	-	33	17	26,000	<0.1	5,000	44	20	-	290	48
	4.5	Clay-silt	12,000	-	57	<1	1,000	<1	12	9	17,000	-	1,100	5	30	-	350	25
	5.0	Clay-silt	14,000	-	58	-	1,500	-	12	8	25,000	<0.1	110	12	17	-	470	35
	6.8	Shad	5,100	-	31	<1	150	<1	10	2	18,000	-	500	<5	24	-	120	19
	7.9	Sand	6,200	-	25	-	470	-	26	10	8,900	<0.1	120	9	16	-	<4	29
	8.8	Sand	5,900	-	29	-	550	-	11	6	8,400	<0.1	960	10	13	-	<4	18
	10.0	Sand	2,200	-	<10	<1	120	<1	<5	<1	22,000	0.23	250	<5	19	<2	37	18
	11.2	Sand	2,700	-	15	-	240	-	8	6	2,300	<0.1	370	<5	6	-	76	9
	11.8	Sand	1,300	-	<10	<1	160	<1	<5	2	1,800	0.15	250	<5	17	<2	93	8
	13.4	Shale	1,500	-	430	2	2,300	1	39	4	21,000	1.1	6,100	57	29	<2	7,000	77
J8	3.3	Shale	17,000	-	100	2	21,000	2	35	68	18,000	0.27	5,200	70	33	<2	7,000	70
	4.0	Shale	18,000	-	110	1	4,100	2	43	12	21,000	-	7,000	41	24	-	3,600	67
	4.8	Shale	15,000	-	200	-	4,600	-	42	4	27,000	<0.1	7,300	45	17	-	200	77
	6.3	Shale	18,000	-	310	1	11,000	1	46	42	22,000	-	8,500	43	28	-	160	76
	7.8	Shale	12,000	-	200	-	7,100	-	32	14	22,000	<0.1	6,000	34	10	1	180	51
	9.2	Shale	18,000	-	180	1	4,200	1	44	27	24,000	0.28	8,600	51	22	<2	93	74

TABLE 11. SOIL-CORE ANALYSES AT PLANT L[a]

Sampling location	Depth (m)	Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
L1	2.4	Silty clay	13,000	<1	100	<1	82,000	<1	26	19	31,000	<0.1	1,800	13	28	<1	60	20
	4.3	Silty clay	17,000	<1	80	1	2,400	<1	23	17	28,000	0.2	820	7	15	<1	8	20
	6.7	Silty clay	15,000	<1	80	<1	1,200	<1	26	15	19,000	0.1	620	8	20	<1	50	25
	7.3	Silty clay	16,000	<1	70	2	2,000	<1	26	9	30,000	-	950	6	20	-	60	22
	9.1	Silty clay	16,000	3	110	1	89,000	<1	26	16	30,000	0.1	4,000	26	24	<1	60	48
	10.4	Silty clay	18,000	<1	80	1	5,400	<1	29	24	29,000	-	4,600	25	15	-	10	70
	11.6	Silty clay	10,000	<1	80	<1	93,000	<1	22	20	17,000	-	5,300	28	16	-	410	52
L2	2.1	Silty clay	10,000	<1	80	<1	2,200	<1	36	13	29,000	0.2	970	12	21	<1	100	38
	6.7	Silty clay	17,000	<1	100	2	1,200	<1	48	18	29,000	0.2	900	10	21	<1	46	42
	10.4	Silty clay	20,000	1	20	<1	730	<1	33	13	29,000	0.1	440	8	14	<1	8	19
	11.0	Silty clay	15,000	<1	120	2	2,400	<1	28	10	16,000	-	2,000	16	20	-	80	42
	12.8	Silty clay	12,000	<1	80	1	2,000	<1	20	6	12,000	0.2	1,400	9	18	<1	60	29
	13.5	Silty clay	11,000	<1	50	<1	2,400	<1	18	4	6,200	-	990	8	14	-	30	39
	13.6	Silty clay	3,800	<1	190	<1	160,000	<1	16	18	39,000	-	3,200	32	25	-	20	28
L3	3.7	Silty clay	15,000	<1	170	1	7,900	<1	45	10	52,000	<0.1	2,300	28	24	<1	26	70
	6.7	Silty clay	10,000	<1	40	1	380	<1	25	6	11,000	0.2	710	8	10	<1	60	26
	9.5	Silty clay	14,000	<1	40	<1	350	<1	34	8	23,000	<0.1	760	8	24	<1	60	27
	10.1	Silty clay	19,000	<1	120	<1	2,400	<1	32	10	19,000	-	3,300	13	23	-	160	24
	11.9	Silty clay	19,000	5	100	3	2,600	<1	36	22	97,000	-	3,900	48	31	-	60	78
	13.7	Silty clay	14,000	<1	80	1	240,000	<1	27	13	8,600	-	15,000	34	22	-	34	42
	14.9	Silty clay	26,000	<1	110	3	4,600	<1	48	32	49,000	0.1	12,000	57	41	<1	28	90
L4	3.7	Silty clay	16,000	7	80	1	1,800	<1	38	6	22,000	0.2	2,000	10	14	<1	1,000	30
	6.7	Silty clay	13,000	<1	60	<1	610	<1	39	7	23,000	<0.1	1,600	10	14	<1	60	36
	9.7	Silty clay	11,000	<1	100	<1	2,300	<1	26	8	30,000	0.2	1,500	12	15	<1	90	35
	9.8	Silty clay	10,000	<1	60	1	800	<1	12	10	11,000	-	1,000	7	12	-	300	39
	10.8	Silty clay	11,000	<1	40	<1	650	<1	15	4	6,100	0.1	400	<5	7	<1	20	18
	12.8	Silty clay	11,000	<1	80	1	1,200	<1	22	20	18,000	-	1,400	32	31	-	8	97
	14.6	Silty clay	13,000	<1	60	2	12,000	<1	27	9	14,000	-	8,400	18	14	-	20	40
	15.9	Silty clay	17,000	<1	40	1	1,600	<1	26	8	29,000	<0.1	1,600	11	18	<1	8	25

TABLE 11 (continued)

Sampling location	Depth (m)	Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
L5	2.1	Silty clay	12,000	9	140	2	3,800	<1	34	8	26,000	0.2	2,000	11	18	<1	180	34
	5.2	Silty clay	11,000	<1	80	<1	900	<1	33	9	25,000	<0.1	1,700	10	16	<1	10	42
	6.7	Silty clay	17,000	1	60	<1	620	<1	34	8	30,000	0.2	1,300	10	21	<1	60	26
	8.2	Silty clay	18,000	<1	40	<1	420	<1	30	7	25,000	-	1,600	7	17	-	26	24
	10.1	Silty clay	10,000	<1	50	1	350	<1	31	14	30,000	-	1,500	10	18	-	10	25
	11.9	Silty clay	10,000	<1	20	<1	570	<1	28	18	30,000	0.2	1,600	10	16	<1	12	26
	15.2	Silty clay	12,000	1.0	60	<1	32,000	<1	29	13	34,000	-	3,200	13	19	-	19	58
L6	0.9	Ash	11,000	5	140	2	14,000	<1	32	27	13,000	<0.1	1,300	42	25	2	3,700	91
	1.5	Ash	15,000	3	110	2	13,000	<1	24	34	11,000	<0.1	1,000	41	31	2	5,500	120
	2.1	Ash	14,000	<1	200	1	7,300	<1	26	34	65,000	0.2	1,100	31	11	<1	60	73
	3.7	Ash	10,000	2	220	1	5,500	<1	26	18	65,000	0.2	660	34	16	<1	200	57
	5.2	Ash	14,000	1	140	<1	3,800	<1	19	18	35,000	0.2	740	24	10	<1	360	34
	6.7	Ash	15,000	4	240	2	13,000	2	45	20	51,000	0.2	1,300	29	23	1	940	130
	8.2	Ash	12,000	5	140	2	8,700	<1	21	13	53,000	<0.1	680	24	8	<1	190	77
	8.8	Ash	15,000	4	220	1	10,000	2	42	35	48,000	<0.1	1,200	29	24	<1	190	140
	10.1	Silty clay	15,000	<1	140	2	4,800	<1	28	20	50,000	<0.01	640	28	8	<1	200	52
	10.7	Silty clay	22,000	<1	90	1	1,400	<1	36	9	40,000	0.1	980	11	17	<1	34	47
	11.3	Silty clay	18,000	<1	80	<1	610	<1	29	9	32,000	-	790	8	18	-	60	24
	11.9	Silty clay	14,000	<1	120	<1	1,800	<1	34	4	28,000	0.1	920	14	16	<1	8	19
	12.5	Silty clay	19,000	1	260	1	3,200	<1	42	14	39,000	-	160	13	32	-	64	33
	13.1	Silty clay	20,000	<1	80	2	3,800	<1	34	8	49,000	0.2	1,900	11	28	<1	60	32
	13.7	Silty clay	25,000	<1	100	2	3,800	<1	37	14	41,000	-	2,800	18	21	-	26	55
	14.2	Silty clay	17,000	<1	170	1	8,500	<1	40	13	44,000	0.1	2,700	20	31	<1	60	64
L7	0.9	Silty clay	17,000	<1	90	2	5,900	<1	31	15	27,000	<0.1	2,800	11	18	<1	80	56
	2.4	Silty clay	22,000	<1	190	2	5,000	<1	29	35	31,000	-	3,100	21	23	-	60	130
	3.7	Silty clay	22,000	<1	230	2	2,300	<1	32	13	44,000	0.1	3,000	23	23	<1	120	83
	5.2	Silty clay	18,000	<1	160	2	2,500	<1	32	20	34,000	-	2,800	18	25	-	26	74
	6.7	Silty clay	10,000	<1	90	1	1,200	<1	17	9	16,000	-	1,300	8	9	-	60	36
	8.2	Silty clay	18,000	<3	160	2	8,000	<1	28	14	36,000	0.1	6,500	37	37	<1	28	85

TABLE 11 (continued)

Sampling location	Depth (m)	Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
L8	0.9	Ash	12,000	<1	180	2	6,500	<1	37	21	60,000	<0.1	1,400	28	11	<1	700	47
	1.5	Ash	15,000	<1	320	2	7,600	<1	29	24	34,000	0.3	1,200	21	16	<1	3,400	45
	2.1	Ash	5,500	<1	180	<1	2,200	<1	21	12	46,000	0.1	640	16	13	<1	280	17
	2.7	Silty clay	13,000	<1	40	<1	830	<1	36	12	42,000	0.1	600	10	47	<1	360	49
	3.4	Silty clay	16,000	<1	40	1	740	<1	42	12	40,000	-	700	7	26	-	1,200	38
	5.2	Silty clay	15,000	14	40	1	1,000	<1	61	20	52,000	0.2	710	7	26	<1	100	79
	7.6	Silty clay	13,000	<1	160	2	53,000	<1	27	17	34,000	-	3,600	28	22	-	60	54
	10.1	Silty clay	12,000	<1	90	2	3,600	<1	29	25	33,000	-	1,600	16	27	-	100	67
	11.9	Silty clay	10,000	3	140	2	5,500	<1	19	5	63,000	0.1	2,800	18	14	<1	120	57
L9	0.9	Ash	10,000	<1	140	1	4,800	2	38	24	37,000	0.2	760	24	10	<1	50	93
	1.8	Ash	12,000	<1	200	2	5,200	<1	33	27	38,000	0.2	960	19	12	<1	36	42
	2.7	Silty clay	13,000	<1	300	2	8,500	<1	42	23	63,000	0.2	1,800	20	15	<1	60	31
	3.7	Silty clay	5,600	1	260	2	4,900	<1	21	28	21,000	0.2	860	10	14	<1	160	25
	4.6	Silty clay	7,000	20	270	3	5,800	<1	27	19	46,000	0.4	880	21	14	<1	240	39
	5.5	Silty clay	6,300	<1	90	1	1,300	<1	17	17	13,000	0.1	840	6	20	<1	180	49
	6.1	Silty clay	11,000	<1	50	2	430	<1	34	8	22,000	-	690	<5	15	-	60	18
	7.9	Silty clay	15,000	<1	120	3	4,200	<1	33	33	55,000	0.4	1,600	27	44	<1	80	48
	10.5	Silty clay	15,000	<1	160	3	8,000	<1	41	31	40,000	-	3,300	32	21	-	60	77
L10	2.1	Silty clay	11,000	11	40	<1	200	<1	45	12	37,000	0.1	330	7	15	<1	12	29
	5.2	Silty clay	4,500	<1	30	<1	170	<1	26	6	20,000	-	120	<5	14	-	60	13
	8.2	Silty clay	4,100	<1	20	<1	270	<1	17	9	13,000	-	160	<5	17	-	8	18
	12.8	Silty clay	11,000	24	20	1	330	<1	37	24	32,000	0.2	340	13	16	<1	60	66
	17.4	Silty clay	10,000	16	10	2	320	<1	39	26	41,000	0.2	400	23	22	<1	8	91
	20.4	Silty clay	13,000	<1	20	<1	360	<1	37	28	34,000	-	530	18	26	-	8	45
L11	3.7	Silty clay	9,900	<1	40	<1	380	<1	51	21	50,000	0.2	290	12	8	<1	8	24
	6.7	Silty clay	10,000	<1	40	<1	360	<1	37	16	40,000	-	760	9	23	-	60	22
	9.8	Silty clay	13,000	<1	40	1	650	<1	46	22	36,000	0.4	1,400	13	17	<1	60	48
	12.8	Silty clay	3,100	1	10	<1	490	<1	33	7	19,000	-	210	<5	14	-	8	16
	17.4	Silty clay	3,900	<1	80	1	830	<1	33	20	32,000	0.2	940	37	19	<1	10	41

[a]Values in μg/g.

The most notable characteristic about the data from plant J (Table 10) is that the concentrations of most constituents are highly variable, both within and between sampling locations. The concentration of mercury, with two exceptions, was found to be below 1.0 µg/g. At sampling locations J1 and J8, the least variability (in terms of absolute differences) in concentrations was observed for most constituents. This is not surprising since both these locations were hydraulically upgradient from the ash disposal area and have homogeneous stratum types throughout their vertical profiles, albeit different from one another. The variable nature of the data is further illustrated in Table 12. This table gives the ranges of concentrations in each soil type measured at locations J2 through J7 combined, and also the ranges within each location. These data indicate that the more variable values are associated with the clay-silt, ash, and shale materials, while the sand contained a narrower range of concentrations. Locations J1 and J8 were omitted from the soil type comparisons because of their previously mentioned homogeneity. However, in the bottom portion of Table 12, where ranges of values are given for each sampling location, the lower variability at locations J1 and J8 relative to other locations is again indicated. At sampling locations J2 through J7, the magnitude of the variability is dependent on the constituent under consideration. For example, location J2 has the widest range of aluminum values, location J4 has the widest range of calcium values, and location J7 has the widest range of chromium concentrations.

The data from plant L (Table 11), although not nearly as variable as plant J's, exhibits some variability, both within and between, sampling locations. Beryllium, cadmium, and selenium values, like plant J's data, are less than or near their analytical detection limits, while concentrations of mercury were all measured below 0.5 µg/g. However, unlike the data from plant J, the two hydraulically upgradient sampling locations at plant L (L10 and L11) are no less variable than sampling locations downgradient from the ash disposal area. It should be noted that the strata types present at plant L consisted mostly of a homogeneous silty-clay material throughout the vertical profile. The variation in plant L's soil core concentrations is also illustrated in Table 13, where the range of concentration in each stratum measured and the ranges within each location are given.

The data in this table indicate that, except for selenium, sulfate, and zinc, the highest constituent concentrations are associated with the silty-clay material. At the bottom of Table 13, the range in concentration within each sampling location indicates that, unlike the control locations at plant J, plant L's upgradient control locations (L10 and L11) are nearly as variable as the sampling locations downgradient from the ash disposal area. Several parameters (iron, copper, chromium, zinc, lead, and nickel) actually demonstrate higher maximum concentrations in the control locations than several of the hydraulically downgradient locations.

TABLE 12. RANGES OF CONCENTRATIONS WITH EACH SOIL TYPE AND AT EACH SAMPLING LOCATION FOR THE SOIL CORE SAMPLES ANALYZED FROM PLANT J[a]

Soil type	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
Clay-silt	64-21,000	<4-60	16-300	<1-1.0	160-12,000	<1-2.0	6-37	<2-31	8300-34,000	<0.1-0.93	110-6700	<5-45	<5-81	<1-22	4-1400	2-96
Sand	240-6900	22	<10-86	<1-<0.1	120-1500	<1-1.0	<5-26	<1-16	1800-25,000	<0.1-0.55	120-2400	<5-16	<5-38	<2	<4-350	2-140
Shale	1500-20,000	-	100-430	1.0-3.0	970-21,000	1.0-2.0	30-46	4-68	16,000-41,000	<0.1-1.1	2900-8700	39-70	8-33	1.0-<2	93-7000	51-94
Ash	56-44,000	48	31-470	<1-4.0	1200-4600	<1-3.0	6-47	21-72	4900-38,000	<0.1-1.2	290-3000	6-56	<5-69	<2-2.0	230-3600	5-90
Sampling locations																
J1	64-160	<4-11	120-240	-	1200-4800	<1	9-37	16-31	14,000-30,000	<0.1	-	25-45	14-81	<2	28-130	38-96
J2	56-21,000	12-48	37-260	<1	300-5200	<1	6-31	<2-31	2900-30,000	<0.1	140-1600	<5-22	<5-38	<1-<2	67-2500	8-140
J3	2300-44,000	6-22	30-470	<0.1-4.0	290-16,000	<1-3.0	<5-47	2-72	1800-30,000	<0.1-0.7	290-8600	<5-56	<5-69	<2	<4-3600	5-90
J4	1300-11,000	<4-60	12-140	<1-3.0	160-12,000	<1-2.0	<5-30	<1-18	2200-41,000	<0.1-0.93	190-2900	<5-53	3-54	<2-22	<4-14,000	2-86
J5	3800-20,000	-	16-190	<1-1.0	160-1800	<1-1.0	<5-35	<2-29	1900-23,000	<0.1-0.55	230-8700	<5-58	<5-26	<2	<4-5600	9-94
J6	1700-11,000	-	28-160	<1-1.0	390-1500	<1-2.0	<5-20	<2-32	1800-38,000	<0.1-1.2	390-930	5-18	<5-25	<2	<4-3300	9-26
J7	1300-16,000	-	<10-430	<1-2.0	120-22,000	<1-1.0	<5-51	<1-22	1800-29,000	<0.1-1.1	110-6700	<5-57	6-30	<2	<4-7000	8-77
J8	12,000-18,000	-	100-310	1-2	4100-21,000	1.0-2.0	32-46	4-68	18,000-27,000	<0.1-0.28	5200-8600	34-70	10-33	1-<2	93-7000	51-77

[a]Values in μg/g.

TABLE 13. RANGES OF CONCENTRATIONS WITHIN EACH STRATA AT EACH SAMPLING LOCATION FOR THE SOIL CORE SAMPLES ANALYZED FROM PLANT L[a]

Strata	Al	As	Ba	Be	Ca	Cd	Cr	Cu	Fe	Hg	Mg	Ni	Pb	Se	SO_4	Zn
Ash	5,500-15,000	<1-5	110-240	<1-2	2200-14,000	<1-2	19-45	13-35	11,000-65,000	<0.1-0.3	640-1400	16-42	8-31	<1-2	36-5500	17-140
Silty clay	3,100-26,000	<1-24	10-300	<1-3	320-240,000	<1	12-51	4-35	6,100-97,000	<0.1-0.4	120-15,000	<5-57	7-47	<1	8-3400	13-130
Sampling location																
L1	13,000-18,000	<1-3	70-110	<1-2	1200-93,000	<1	22-29	9-24	17,000-31,000	<1-0.2	620-5300	6-28	15-28	<1	8-410	20-70
L2	3,800-20,000	<1-1	20-190	<1-2	730-160,000	<1	18-48	4-18	6,200-39,000	0.1-0.2	440-3200	8-32	14-25	<1	8-100	19-42
L3	10,000-26,000	<1-5	40-170	<1-3	350-240,000	<1	25-48	6-22	8,600-97,000	<1-0.2	710-15,000	8-57	10-41	<1	26-260	26-90
L4	10,000-17,000	<1-7	40-100	<1-2	610-12,000	<1	12-39	4-20	6,100-30,000	<1-0.2	400-8400	<5-32	7-31	<1	8-1000	18-97
L5	10,000-18,000	<1-9	20-140	<1-2	350-32,000	<1	28-34	7-18	25,000-34,000	<1-0.2	1300-3200	7-13	16-21	<1	10-180	24-58
L6	10,000-25,000	<1-5	80-260	<1-2	610-14,000	<1-2	19-45	4-35	11,000-65,000	<0.1-0.2	160-2800	8-42	8-32	<1-2	8-5500	19-140
L7	10,000-22,000	<1-<3	90-230	<1-2	1200-8000	<1	17-32	9-35	16,000-44,000	<1	1300-6500	8-37	9-37	<1	26-120	36-130
L8	5,500-16,000	<1-14	40-320	<1-2	740-53,000	<1	19-42	5-25	33,000-63,000	<0.01-0.3	600-3600	7-28	11-47	<1	60-3400	17-79
L9	5,600-15,000	<1-20	50-300	1-3	430-8500	<1-2	17-42	8-33	13,000-63,000	0.2-0.4	690-3300	<5-32	10-44	<1	36-240	18-93
L10	4,100-13,000	<1-24	10-40	<1-2	170-360	<1	17-45	6-28	13,000-41,000	0.1-0.2	120-530	<5-23	14-26	<1	8-60	13-91
L11	3,100-13,000	<1-1	10-80	<1-1	360-830	<1	33-51	7-22	19,000-50,000	0.2-0.4	210-1400	<5-37	8-23	<1	8-60	16-48

[a]Values in ug/g.

TABLE 14. CONCENTRATIONS IN ASH SAMPLES COLLECTED FROM ASH DISPOSAL AREAS - PLANTS J AND L[a]

	Plant J		Plant L	
Constituent	Mean	Range	Mean	Range
Aluminum	9,938.4	56-44,000	12,346.2	5,500-15,000
Arsenic	48	48	2.3	<1.0-5
Barium	151.4	79-470	186.9	110-320
Beryllium	2.5	<1.0-4	1.5	<1.0-2
Calcium	2,828.6	1,200-4,600	7,815.4	2,200-14,000
Cadmium	1.3	<1.0-3	1.2	<1.0-2
Chromium	21.3	6-47	30.2	19-45
Copper	33.1	21-72	23.6	12-35
Iron	12,785.7	4,900-30,000	42,769.2	11,000-65,000
Magnesium	1,563.3	290-3,000	995.4	640-1,800
Mercury	0.3	<0.1-0.7	0.2	<0.1-0.3
Nickel	19.4	6-56	27.8	16-42
Lead	19.0	<5-69	16.2	8-31
Selenium	2.0	<2-2	1.2	<1.0-2
Sulfate	1,161.4	230-3,600	1,200.5	36-5,500
Zinc	28.0	5-90	74.3	17-140

[a]Values in mg/L.

The mean concentrations and range of values for the constituents listed in Table 9 were calculated for all ash samples collected at plants J and L. At plant J, ash samples were collected over various vertical intervals at sampling locations J2 and J3, and at plant L sampling locations L6, L8, and L9. The results of these calculations indicate (Table 14) that the mean concentrations of aluminum, barium, calcium, chromium, iron, nickel, sulfate, and zinc are highest in ash from plant L. Plant J, however, had the higher mean concentrations of arsenic, beryllium, cadmium, copper, mercury, lead, selenium, and magnesium. There are a multitude of reasons why the above elements would be partitioned as they are between the two plants; different coal sources, methods of firing the coal, and ash collection systems are the major reasons related to plant operations. The sample collection is undoubtedly another factor to consider. The age of the ash sample and its particle size characteristics may also affect concentrations within the sample. The longer coal ash has been exposed to the leaching process the more opportunity for the dissolution of ions, and at least one investigator[15] has shown that smaller ash particles contain higher concentrations of certain elements.

The variable nature of the constituents measured in the soil cores from plants J and L, precluded the use of this data for determining the extent of leachate migration. The natural variation of soils resulting from spatial differences in mineralogy, organic content, and soil particle sizes makes the effects of leachate on constituent concentrations in the soil difficult or impossible to define. Determining differences in the attenuation capacity of the various substrata also suffers because the highly variable soil makes results ambiguous. In order to utilize soil core data to determine the magnitude of leachate migration, some means of eliminating or minimizing the natural variation will be needed. One approach may be to analyze only a certain particle size fraction of a sample for a contaminant. Another might be to separate the various components of a soil sample, such as organic and inorganic, and analyze separately. There are many approaches which might be considered, but the measurement of constituents in total soil samples, as this investigation indicates, does not appear to be a viable one.

INTERSTITIAL WATER ANALYSIS

During the collection of soil core samples from plants J and L, certain cores were selected for extraction and analysis of their interstitial water (the extraction methodology is given in section 4). The basis for selecting which cores were to be extracted was the apparent moisture content of the core and the density of the material under consideration. Both of these factors were evaluated in the field, based on field soil testing techniques, previous experience, and intuition. In all, 23 soil-core extractions were analyzed from plant J, and seven at plant L. The fewer number of samples extracted

TABLE 15. ANALYSIS OF EXTRACTED INTERSTITIAL WATER FROM PLANT J

	Well locations											
	J3	J3	J4	J4	J4	J4	J4	J5	J5	J5	J6	J6
Depth, m	13.4	14.1	5.0	6.5	8.0	9.6	11.1	6.7	8.4	11.8	5.0	6.5
Strata	Sand	Sand	Clay-silt	Clay-silt	Clay-silt	Clay-silt	Sand	Clay-silt	Sand	Sand	Clay-silt	Clay-silt
Aluminum, mg/L	3.2	3.15	180	190	60	< 0.2	5.2	15	62	8.0	-	5.5
Barium, mg/L	< 0.1	-	< 0.1	< 0.1	< 0.1	< 0.1	1.3	-	-	-	-	-
Beryllium, mg/L	-	-	-	-	< 0.01	-	-	-	-	-	-	-
Calcium, mg/L	56	15.5	470	680	350	130	170	270	310	87	-	31
Cadmium, mg/L	-	< 0.001	-	-	-	-	-	0.002	0.005	0 003	-	-
Chromium, mg/L	< 0.01	0.008	0.04	0.05	0.06	< 0.01	< 0.01	0.02	0.7	0.02	< 0.001	0.011
Copper, mg/L	0.3	0.02	0.2	0.3	0.3	< 0.1	< 0.1	0.20	0.27	0.63	0.2	0.08
Iron, mg/L	15	0.82	3300	2400	1200	1.0	120	1000	1000	10	38	10
Magnesium, mg/L	14	-	200	220	91	33	31	-	-	-	-	-
Mercury, mg/L	-	< 0.01	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.01	< 0.01	< 0.02	-
Nickel, mg/L	< 0.5	< 0.05	0.9	< 0.5	0.8	< 0.5	< 0.5	0.35	0.5	0.2	< 0.5	< 0.5
Lead, mg/L	-	< 0.006	0.76	0.58	0.42	0.09	0.11	0.019	0.017	0.12	< 0.05	0.066
Selenium, mg/L	-	< 0.05	-	-	-	-	-	< 0.10	< 0.05	< 0.05	-	-
Sulfate, mg/L	-	-	6800	4800	2300	380	680	-	-	-	100	-
Zinc, mg/L	0.7	0.02	4.3	3.5	4.8	5.8	0.6	1.3	2.6	2.1	5.1	1.4
pH, std. units	7.3	8.0	4.3	4.2	4.3	6.0	6.8	2.6	1.8	1.9	2.4	2.4
Conductivity, $\mu mhos/cm^2$	-	-	-	-	-	-	-	4000	3700	6000	900	1700

TABLE 15 (continued)

	Well locations										
	J6	J6	J6	J7	J7	J7	J7	J7	J7	J7	J7
Depth, m	8.2	11.5	12.8	1.6	4.5	5.0	6.8	7.9	8.8	10	11.2
Strata	Clay-silt	Clay-silt	Clay-silt	Clay-silt	Clay-silt	Clay-silt	Clay-silt and sand	Clay-silt and sand	Clay-silt and sand	Clay-silt and sand	Clay-silt and sand
Aluminum, mg/L	2.5	6.4	9.1	1.15	3.5	2.8	3.6	8.4	8.1	23	11
Barium, mg/L	< 0.1	-	< 0.1	-	< 0.1	1.9	-	< 0.1	1.8	-	2.3
Beryllium, mg/L	-	-	-	-	-	-	-	-	-	-	-
Calcium, mg/L	62	78	130	420	660	510	37	51	58	59.5	73
Cadmium, mg/L	0.006	0.006	-	< 0.001	-	0.002	0.004	-	-	0.005	0.003
Chromium, mg/L	< 0.001	0.015	0.01	< 0.001	< 0.01	0.003	0.005	< 0.01	0.02	0.09	0.021
Copper, mg/L	< 0.1	0.07	< 0.1	0.01	< 0.1	0.3	0.06	0.2	0.2	0.03	< 0.1
Iron, mg/L	38	25	64	1.4	0.8	50	2.7	8.1	5.2	92	85
Magnesium, mg/L	12	-	19	-	63	41	-	20	32	-	15
Mercury, mg/L	< 0.02	< 0.01	< 0.02	< 0.01	< 0.02	< 0.02	-	< 0.02	< 0.02	< 0.01	< 0.01
Nickel, mg/L	< 0.5	< 0.05	< 0.5	0.11	< 0.5	< 0.5	0.09	< 0.05	< 0.05	0.12	< 0.5
Lead, mg/L	0.07	0.018	-	< 0.002	-	0.004	0.016	16	-	0.07	0.035
Selenium, mg/L	< 0.05	< 0.05	-	< 0.02	-	< 0.10	< 0.05	-	-	< 0.05	< 0.05
Sulfate, mg/L	260	-	< 100	-	1500	-	-	100	230	-	-
Zinc, mg/L	0.5	0.53	2.2	0.03	5.0	2.6	0.38	0.9	2.5	0.43	1.7
pH, std. units	7.1	2.3	2.7	7.2	6.8	1.7	1.7	1.5	1.4	2.1	2.2
Conductivity, $\mu mhos/cm^2$	575	2200	2100	2750	1950	2700	1200	4500	20,000	9500	3550

TABLE 16. ANALYSIS OF EXTRACTED INTERSTITIAL WATER FROM PLANT L

Constituents	Sampling locations						
	L3	L6	L6	L6	L6	L7	L8
Depth, meters	15.0	8.0	8.8	10.0	10.6	8.2	0.9
Strata	Silt-clay	Ash	Ash	Ash	Ash	Silt-clay	Ash
Aluminum, mg/l	2.2	8.4	8.6	2.0	8.2	7.7	4.1
Barium, mg/l	0.400	0.600	0.600	0.500	0.600	0.600	0.200
Beryllium, mg/l	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Calcium, mg/l	96	220	280	320	210	200	170
Cadmium, mg/l	0.010	0.080	0.040	0.020	0.010	0.020	0.020
Chromium, mg/l	<0.050	0.110	0.050	<0.050	0.060	<0.050	<0.050
Copper, mg/l	<0.010	0.110	0.090	0.020	0.060	0.070	0.030
Iron, mg/l	1.9	9.5	6.3	8.8	19	8.9	3.5
Mercury, mg/l	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Magnesium, mg/l	21	3.8	6.3	16	12	14	9.8
Manganese, mg/l	0.140	0.550	0.450	1.6	1.2	3.5	0.580
Nickel, mg/l	<0.050	0.100	0.070	0.120	0.090	0.080	0.090
Lead, mg/l	0.050	0.050	0.050	0.050	0.120	0.100	0.050
Zinc, mg/l	0.070	1.8	0.620	0.690	0.640	0.400	0.330
pH, standard units	7.5	3.5	3.6	6.5	4.1	2.9	3.4
Conductivity, µmhos/cm	880	1180	1130	1040	3000	6400	1650
Alkalinity, mg/l as $CaCO_3$	320	-	-	-	-	-	-
Sulfate, mg/l	100	900	900	920	600	500	860

at plant L was because the compacted nature of the soils precluded the extraction of enough water for laboratory analysis. In Tables 15 and 16, the results of analyses on the interstitial waters from plants J and L, respectively, are presented. The dashes that appear in these tables indicate analyses were not performed because an insufficient amount of extracted water was available to accommodate the analytical evaluation. The minimum detection limits shown for the same elements are also a result of insufficient sample volume.

One of the most striking features about the data in Tables 15 and 16 is the low pH values observed. At plant J, 16 of the 23 pH measurements were less than 5.0, and 13 of the values were below 3.0. At plant L, five of the seven measurements for pH were below 5.0, and one less than 3.0. The data do not, however, indicate any trends in pH, such as with depth or stratum type. In addition, the constituent concentrations in these tables do not always track with variations in pH, as would be expected from solubility relationships. For example, iron concentrations at sampling location J7 (Table 15) are not inversely proportional to pH, and zinc concentrations at location J4 demonstrate similar behavior. The solubilities of the elements in Tables 15 and 16 in relation to other matrices in which they were measured are obviously a factor to consider and this subject is discussed later in the report.

GROUNDWATER ANALYSIS

In Tables 17 and 18, the results of the laboratory analysis performed on groundwater samples collected from the wells at plant J and L, respectively, are presented. Samples were collected from all sampling locations at plant J, except J1, on July 2, 1976, and from all locations except J3 and J3A on March 9, 1977. These sample omissions were a result of sampling well malfunctions. Groundwater samples were collected from all sampling locations at plant L, on February 22, 1977.

For comparative purposes, the EPA's domestic water supply criteria[16] are also listed in Tables 17 and 18. Although these criteria are not applicable to leachate from solid waste disposal sites, they are used here, and elsewhere in this report, as a screening process to identify water quality constituents that may deserve environmental consideration. Of the constituents measured in samples from plant J, five were found to exceed EPA's criteria for iron, manganese, lead, dissolved solids (as sulfate), and pH. Samples from all wells except J1, a background well, exceeded the criterion for iron; samples from all wells in the March collection exceeded the manganese criterion; and the criterion for dissolved solids was exceeded in March at locations J4, J4A, J5A, J7A, and J8. Lead exceeded the criterion in July at locations J6, and the pH was not within the criterion at wells J3, J4, J5B, J6, J6A, and J7.

At plant L, the data indicate that the criterion for iron was exceeded in samples analyzed from wells, L3A, L6A, L7, L8A, and L9A. Dissolved solids, as sulfate, exceeded the criterion in samples from

TABLE 17. ANALYSIS OF GROUNDWATER SAMPLES COLLECTED FROM SAMPLING WELLS AT PLANT J - JULY 2, 1976

Parameter	J2	J3	J3A	J4	J4A	J5	J5A	J6	J6A	J7	J8	DWSC[a]
					July 2, 1976							
Aluminum, mg/L	0.8	2.0	520	5.2	170	2.3	40	2.3	85	7.2	5.4	b
Beryllium, mg/L	< 0.01	< 0.01	0.07	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	b
Cadmium, mg/L	< 0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.001	0.003	< 0.001	0.001	0.01
Calcium, mg/L	92	27	280	36	420	100	400	160	85	39	360	b
Chromium, mg/L	< 0.005	< 0.005	< 0.005	0.01	< 0.005	< 0.005	< 0.005	0.006	< 0.005	0.012	0.012	0.05
Copper, mg/L	0.04	0.08	1.4	0.06	0.18	0.04	0.09	0.06	0.07	0.04	0.07	1.0
Iron, mg/L	10	9.3	2000	6.8	680	98	640	12	200	5.6	13	0.3
Lead, mg/L	< 0.01	0.011	0.044	0.043	< 0.01	< 0.01	< 0.01	0.042	0.089	0.011	0.026	0.05
Mercury, mg/L	< 0.0002	< 0.0002	0.0029	< 0.0002	0.0006	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.002
Nickel, mg/L	< 0.05	< 0.05	0.82	< 0.05	0.31	< 0.05	0.18	0.06	0.07	< 0.05	< 0.05	b
Selenium, mg/L	< 0.001	< 0.001	0.005	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.01
Dissolved solids, total, mg/L	450	150	680	210	-	590	8100	530	270	190	1800	250
Zinc, mg/L	0.04	0.09	1.3	0.2	2.1	0.08	0.41	0.05	0.19	0.03	0.08	5.0
pH, standard units	6.6	9.5	8.9	9.5	7.1	8.2	8.1	10	9.2	9.7	8.0	5.9

TABLE 17 (continued)

Parameter	J1	J2	J4	J4A	J5	J5A	J5B	J6	J6A	J7A	J8	DWSC[a]
						March 9, 1977						
Aluminum, mg/L	0.3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.4	< 0.2	< 0.2	< 0.2	< 0.2	[b]
Arsenic, mg/L	< 0.004	0.026	< 0.004	< 0.004	< 0.004	0.006	< 0.004	< 0.004	< 0.004	< 0.002	< 0.002	0.05
Boron, mg/L	0.16	5.6	0.2	0.26	0.09	0.61	0.13	0.2	0.2	2.0	0.16	[b]
Barium, mg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	1.0
Beryllium, mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	[b]
Calcium, mg/L	62	110	110	410	19	260	18	110	100	520	360	[b]
Cadmium, mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.01
Chromium, mg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.05
Copper, mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.02	< 0.01	< 0.01	< 0.01	< 0.01	1.0
Iron, mg/L	< 0.05	16	< 0.05	420	0.57	2200	3.7	1.6	77.0	7.0	0.24	0.3
Mercury, mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.002
Magnesium, mg/L	17	42	16	120	12	100	10	15	18	96	70	[b]
Manganese, mg/L	0.13	4.6	0.64	44	0.24	63	4.5	3.5	7.3	18	2.2	0.05
Nickel, mg/L	< 0.05	< 0.05	< 0.05	0.08	< 0.05	0.06	< 0.05	< 0.05	< 0.05	0.08	< 0.05	[b]
Lead, mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.04	< 0.01	< 0.01	< 0.01	< 0.01	0.05
Selenium, mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.01
Sulfate, mg/L	68	65	310	2100	30	3400	130	120	150	1700	890	250
Sulfide, mg/L	0.08	< 0.02	< 0.02	0.07	< 0.02	0.13	< 0.02	< 0.02	< 0.02	0.03	< 0.02	[b]
Dissolved solids, total, mg/L	410	1400	900	4000	210	4900	390	950	1200	3400	2700	250
Volatile solids, total, mg/L	10	70	40	570	10	500	50	50	70	250	120	[b]
Zinc, mg/L	< 0.02	< 0.01	< 0.01	< 0.01	< 0.01	0.05	0.2	< 0.01	0.02	0.01	0.02	5.0
pH, standard units	7.5	7.1	6.8	6.6	7.0	6.5	3.3	7.4	6.9	7.0	7.6	5.9
Oxidation reduction potential, MV	+130	-135	-70	-100	-130	-110	+200	-100	-160	-110	+150	[b]
Conductivity, μmhos/cm^2	470	790	510	2200	180	2900	360	520	680	1900	1460	[b]
Alkalinity, mg/L as $CaCO_3$	192	390	-	-	81	108	-	237	320	320	295	[b]
Water table elevation, m	230.48	228.55	224.79	224.03	224.70	223.75	221.16	220.19	224.36	225.13	228.22	[b]

[a] Domestic Water Supply Criteria, EPA, 1976.

[b] Not analyzed.

TABLE 18. ANALYSIS OF GROUNDWATER SAMPLES COLLECTED FEBRUARY 22, 1977, FROM SAMPLING WELLS AT PLANT L

Parameter	L1	L2	L2A	L3	L3A	L4	L5	L6	L6A	L7	L8	L8A	L9	L9A	L10	L11	DWSC[a]
Aluminum, mg/L	0.8	0.5	<0.2	0.3	0.2	0.4	<0.2	<0.2	<0.2	2.3	<0.2	11	<0.2	<0.2	<0.02	<0.02	[b]
Arsenic, mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-	0.01	-	0.005	<0.002	0.019	<0.002	0.035	<0.002	<0.002	0.05
Boron, mg/L	0.15	0.35	0.23	0.2	0.21	0.16	0.24	0.44	8.1	0.31	2.3	20	0.76	6.1	0.16	0.08	[b]
Beryllium, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.04	<0.01	<0.01	<0.01	<0.01	<0.01	[b]
Calcium, mg/L	55	81	64	64	120	39	50	110	190	100	270	520	120	180	7.3	27	[b]
Cadmium, mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01
Chromium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.05
Copper, mg/L	<0.01	<0.01	0.04	0.04	0.01	0.02	<0.01	<0.01	0.02	<0.01	0.02	0.03	<0.01	<0.01	0.04	<0.01	1.0
Iron, mg/L	<0.05	<0.05	<0.05	0.06	0.34	0.26	0.13	0.23	13	0.44	0.22	380.0	<0.05	0.87	0.08	<0.05	0.3
Mercury, mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002
Magnesium, mg/L	4.4	7.1	6.1	15	29	9.0	7.9	25	11	14	40	91	30	20	1.3	12	[b]
Manganese, mg/L	0.75	0.45	2.9	0.69	1.9	0.47	0.29	0.85	5.6	7.1	2.2	4.7	0.87	1.0	0.22	0.74	0.05
Nickel, mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	[b]
Lead, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.05
Selenium, mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01
Sulfate, mg/L	8.0	10	79	22	39	3.0	10	68	170	8.0	490	2500	21	450	47	13	250
Sulfide, mg/L	0.33	0.04	0.04	0.1	0.2	0.16	0.2	0.44	0.11	0.07	0.16	0.06	0.04	0.16	0.14	0.04	[b]
Dissolved solids, total, mg/L	190	180	290	180	250	150	150	330	400	450	1000	3700	270	920	160	150	250
Zinc, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.21	<0.01	<0.01	<0.01	0.11	5.0
pH, standard units	7.7	7.8	7.7	8.0	7.9	7.4	8.0	7.4	7.5	8.5	7.2	4.4	7.6	7.5	6.0	7.2	5.9
Oxidation reduction potential, MV	+70	+390	+390	+120	+130	+130	+60	+130	+10	+110	+150	+340	+370	_	+180	+360	[b]
Conductivity, μmhos/cm2	280	325	530	350	680	280	350	720	930	790	1080	2450	740	250	220	250	[b]
Alkalinity, mg/L as $CaCO_3$	198	230	246	235	425	132	165	350	416	185	225	-	490	149	57.2	98.5	[b]
Water table elevation, m	183.21	182.20	185.34	181.41	181.44	182.54	183.02	186.83	186.77	181.03	187.38	189.45	189.06	189.55	180.29	183.51	[b]

[a] Domestic Water Supply Criteria, EPA, 1976.

[b] Not analyzed.

wells L8, L8A, and L9A. The pH in well L8A was not within the criterion, and manganese exceeded the criterion in all wells sampled, including the background wells.

The data also indicate that pH values measured in samples collected from the sampling wells (Tables 17 and 18) were generally higher than values obtained from the extracted interstitial water samples (Tables 14 and 15). Samples from the wells were generally neutral to alkaline, with only two depressed pH values observed (wells L8A and J5B), while the pH of the interstitial water was generally very acidic (a pH of 1.4 was measured), but ranged to alkaline. Although the methods of collection differ between the interstitial water and the well water, it was possible to compare samples collected by both methods from the same location and depth. These comparisons are given in Table 19, along with the soil core sample concentrations for the same locations and depth. The table shows that in all cases where measurable quantities of a constituent were found the concentration in the interstitial water sample was greater than that found in the well sample. This comparison indicates that the measurement of interstitial water may be a more accurate method of determining groundwater contamination by leachates than utilizing groundwater monitoring wells of the design used in this study. However, more research is needed to economize and standardize this technique. Specific reactions and chemistry of selected constituents in Table 19 are discussed below.

Aluminum

In aqueous systems, aluminum is strongly influenced by its tendency to form soluble complexes with fluoride, hydroxide, sulfate, phosphate, and some organic ligands; its solubility is affected by the concentrations of these ligands.[17] The solubility of aluminum, as a function of pH, in a hydroxide equilibrium environment, is illustrated in Figure 8. On the alkaline side of the curve, the main species present is monovalent $AL(OH)_4^{-1}$, while under acidic conditions the main species is the trivalent form Al^{+3}. However, in aqueous solutions such as the interstitial water in Table 19, other complexing ligands in addition to hydroxide may alter the solubility of aluminum through complexation. For example, the concentration of sulfate in an interstitial water sample collected from location J4 was measured at 2300 mg/l, with a pH of 4.3. Roberson and Hem[18] studied the solubility of aluminum in the presence of different concentrations of sulfate and at different pH's, and Figure 9 illustrates the solubility of microcrystalline gibbsite ($Al(OH)_3$) as a function of sulfate concentrations over the ranges of pH from their studies. Using the data from location J4, at 2300 mg/l sulfate and a pH of 4.3, the relationship presented in Figure 9 indicates that approximately 270 mg/l of aluminum could be soluble in the interstitial water sample. In addition, using values from location J4 at 310 mg/l sulfate and a pH of 6.8 for the well water sample, 0.04 mg/l of soluble aluminum could be present in the well water according

TABLE 19. COMPARISON OF CONCENTRATIONS MEASURED IN GROUNDWATER SAMPLING WELLS, EXTRACTED INTERSTITIAL WATER, AND SOLID SUBSTRATUM MATERIAL, PLANTS J AND L

	Sampling location and site								
	Location J3 (13.4 m)			Location J4 (8.0 m)			Location J5 (8.4 m)		
Constituent	Groundwater sampling wells	Extracted interstitial water	Solid substratum material	Groundwater sampling wells	Extracted interstitial water	Solid substratum material	Groundwater sampling wells	Extracted interstitial water	Solid substratum material
pH, standard units	9.5	7.3	-	6.8	4.3	-	7.0	1.8	-
Alkalinity, mg/L as $CaCO_3$	-	-	-	-	-	-	81	-	-
Oxidation reduction potential, MV	-	-	-	-70	-	-	-130	-	-
Dissolved solids, total, mg/L	150	-	-	900	-	-	210	-	-
Volatile solids, total, mg/L	-	-	-	40	-	-	10	-	-
Aluminum, mg/L	2.0	3.2	2700	< 0.2	60	3900	< 0.2	62	7000
Arsenic, mg/L	-	-	-	< 0.004	-	-	< 0.004	-	-
Boron, mg/L	-	-	-	0.2	-	-	0.09	-	-
Barium, mg/L	-	< 0.1	45	< 0.1	< 0.1	54	< 0.1	-	36
Beryllium, mg/L	< 0.01	-	-	< 0.01	< 0.01	< 1.0	< 0.01	-	< 1.0
Calcium, mg/L	27	56	800	110	350	160	19	310	160
Cadmium, mg/L	< 0.001	-	-	< 0.001	-	< 1.0	< 0.001	0.005	< 1.0
Chromium, mg/L	< 0.005	< 0.01	< 5.0	< 0.005	0.06	< 5.0	< 0.005	0.7	7.0
Copper, mg/L	0.08	0.3	12	< 0.01	0.3	< 1.0	< 0.01	0.27	6.0
Iron, mg/L	9.3	15	3200	< 0.05	1200	3700	0.57	1000	14,000
Mercury, mg/L	< 0.0002	-	< 0.1	< 0.002	< 0.02	-	< 0.002	< 0.01	-
Magnesium, mg/L	-	14	650	16	91	300	12	-	350
Manganese, mg/L	-	-	-	0.64	-	-	0.24	-	-
Nickel, mg/L	< 0.05	< 0.5	< 5.0	< 0.05	0.8	< 5.0	< 0.05	0.5	7.0
Lead, mg/L	0.011	-	10	< 0.01	0.42	7.0	< 0.01	0.017	21
Selenium, mg/L	< 0.001	-	-	< 0.001	-	-	< 0.001	< 0.05	-
Sulfate, mg/L	-	-	< 4.0	310	2300	130	30	-	5600
Sulfide, mg/L	-	-	-	< 0.01	-	-	< 0.02	-	-
Zinc, mg/L	0.09	0.7	19	< 0.01	4.8	12	< 0.01	1.3	17

TABLE 19 (continued)

Constituent	Sampling location and site: Location L3 (15.0 m) Groundwater sampling wells	Location L3 (15.0 m) Extracted interstitial water	Location L3 (15.0 m) Solid substratum material	Location L6 (10.6 m) Groundwater sampling wells	Location L6 (10.6 m) Extracted interstitial water	Location L6 (10.6 m) Solid substratum material	Location L7 (8.8 m) Groundwater sampling wells	Location L7 (8.8 m) Extracted interstitial water	Location L7 (8.8 m) Solid substratum material
pH, standard units	8.0	7.5	-	7.5	4.1	-	8.5	2.9	-
Alkalinity, mg/L as $CaCO_3$	235	320	-	930	-	-	185	-	-
Oxidation reduction potential, MV	+120	-	-	+10	-	-	+110	-	-
Dissolved solids, total, mg/L	180	-	-	400	-	-	450	-	-
Volatile solids, total, mg/L	-	-	-	-	-	-	-	-	-
Aluminum, mg/L	0.3	2.2	26,000	< 0.2	8.2	22,000	2.3	7.7	18,000
Arsenic, mg/L	< 0.002	-	< 1.0	-	-	< 1.0	0.005	-	< 3.0
Boron, mg/L	0.2	-	-	8.1	-	-	0.31	-	-
Barium, mg/L	-	0.4	110	-	0.6	90	-	0.6	160
Beryllium, mg/L	< 0.01	< 0.01	3.0	< 0.01	< 0.01	1.0	< 0.01	< 0.01	2.0
Calcium, mg/L	64	96	4600	190	210	1400	100	200	8000
Cadmium, mg/L	< 0.001	0.01	< 1.0	< 0.001	0.01	< 1.0	< 0.001	0.02	< 1.0
Chromium, mg/L	< 0.005	< 0.05	48	< 0.005	0.06	36	< 0.005	< 0.05	28
Copper, mg/L	0.04	< 0.01	32	0.02	0.06	9.0	< 0.01	0.07	14
Iron, mg/L	0.06	1.9	49,000	13	19	40,000	0.44	8.9	36,000
Mercury, mg/L	< 0.002	< 0.004	0.1	< 0.002	< 0.004	0.1	< 0.002	< 0.004	0.1
Magnesium, mg/L	15	21	12,000	11	12	980	14	14	6500
Manganese, mg/L	0.69	0.14	-	5.6	1.2	-	7.1	3.5	-
Nickel, mg/L	< 0.05	< 0.05	57	< 0.05	0.09	11	< 0.05	0.08	37
Lead, mg/L	< 0.01	< 0.05	41	< 0.01	0.12	17	< 0.01	0.1	37
Selenium, mg/L	< 0.001	-	< 1.0	< 0.001	-	< 1.0	< 0.001	-	< 1.0
Sulfate, mg/L	22	100	28	170	600	34	8.0	-	28
Sulfide, mg/L	0.1	-	-	0.11	-	-	0.07	-	-
Zinc, mg/L	< 0.01	0.07	90	< 0.01	0.64	47	< 0.01	0.4	85

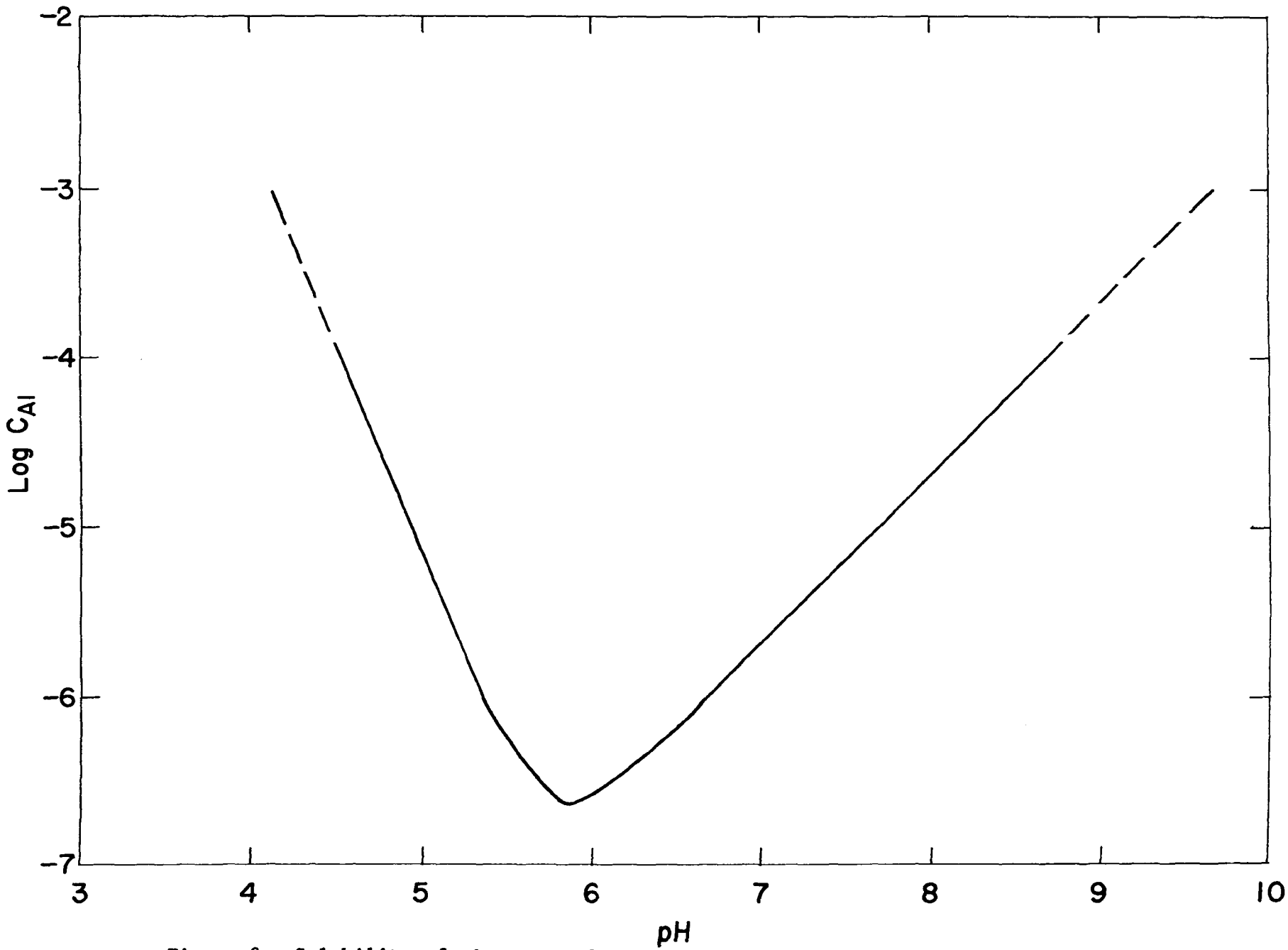
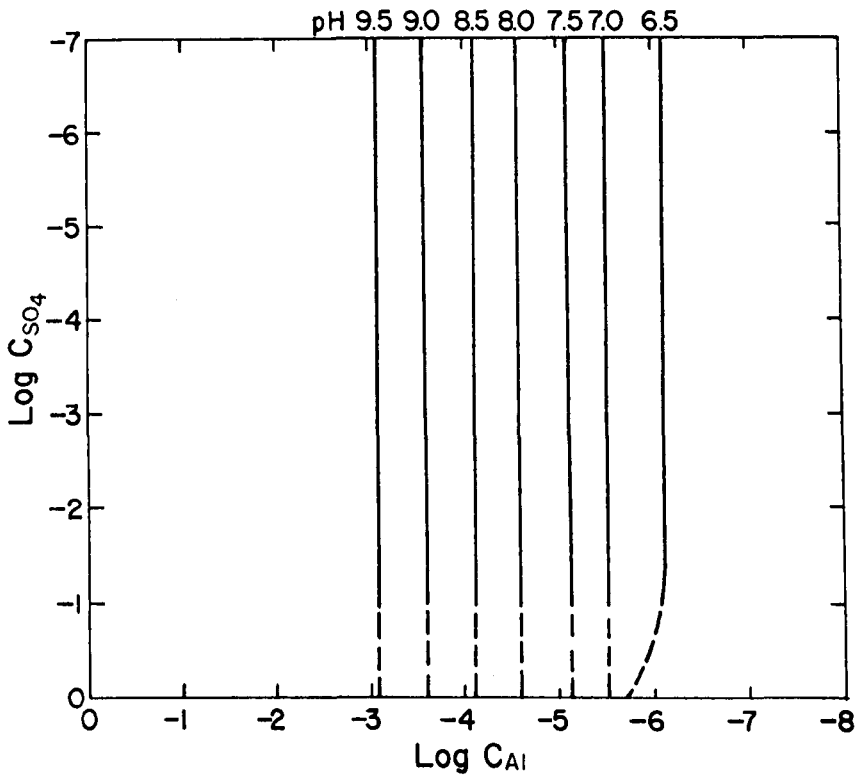


Figure 8. Solubility of microcrystalle gibbsite as a function of pH, at 25° C., and 1 atmosphere total pressure (from Roberson and Hem, 1969).



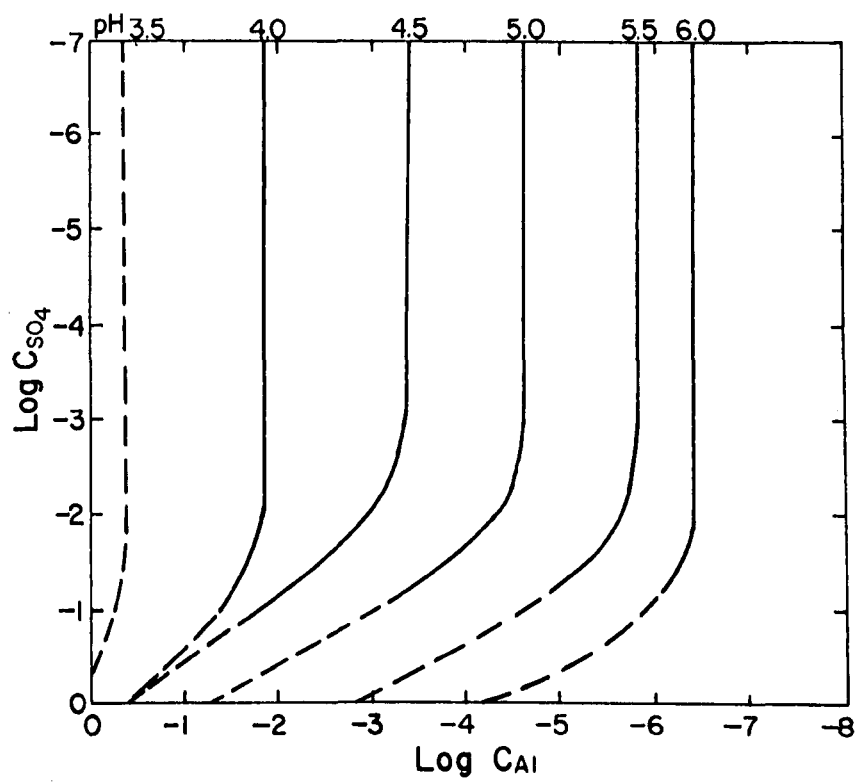


Figure 9. Solubility of microcrystalline gibbsite as a function of sulfate concentration. Ionic strength 0.10 for 25°C, and 1 atmosphere total pressure (from Roberson and Hem, 1969).

to the relationship expressed in Figure 9. From Table 19, the concentrations of aluminum actually measured in the interstitial and well water samples at location J4, are 60 and <0.20 mg/l respectively. The concentration of aluminum in the well water sample may agree with the value predicted from Figure 9, but it cannot be verified because the detectable limit is higher than the predicted value. The concentration of aluminum in the interstitial water sample (60 mg/l), however, is 4.5 times less than the predicted value (270 mg/l). It might be postulated that 60 mg/l was all the aluminum available for solubilization; however, a return to Table 19, location J4, shows that 3900 µg/g of aluminum was present in the (soil) substratum. The soil moisture content was approximately 20 percent (see Table 3), and if all the aluminum were to dissolve, calculations indicate that a 624 mg/l aluminum solution would result--more than enough to meet the predicted value.

Thus, it appears that other factors besides the sulfate concentrations affected the solubility of aluminum in the interstitial water samples from location J4. The type of matrix in which the aluminum is chemically bound, incomplete soil-water contact, and competition with other metal ions for the sulfate ligand are factors which might affect aluminum solubility. Further analysis of the data indicates that competition for the sulfate ligand may indeed be the limiting factor. The competition for the sulfate ligand by other metal ions, such as magnesium, calcium, barium, and lead, may force the hydroxide solubility to be limiting for aluminum. The following calculations tend to verify this point:

$$\{Al^{+3}\}\{OH^{-1}\}^3 = K_{so} = 10^{-32} \quad (1)$$

$$\{H^{+}\}\{OH^{-}\} = 10^{-14} \quad (2)$$

$$\{Al^{+3}\}_{apparent} = 2.2 \times 10^{-3} \text{ moles/liter} \quad (3)$$

$$pH = -\log \{H^{+}\} = 4.3 \quad (4)$$

$$\{OH^{-}\} = 10^{-14}/\{H^{+}\} \quad (5)$$

$$\{OH^{-}\} = 10^{-14}/5.0 \times 10^{-5}$$

$$\{OH^{-}\}_{apparent} = 1.99 \times 10^{-10}$$

Substitution of 3 and 5 into 1 yields:

$$\{Al^{+3}\}_{apparent} \{OH^{-}\}^3_{apparent} = 1.7 \times 10^{-32} \quad (6)$$

The calculated solubility (6), using the measured values of aluminum and pH from Table 19, is close to the theoretical solubility constant (1). These data suggest that the system is in equilibrium and it is the hydroxide solubility that is controlling the aluminum concentration in the interstitial water and, as stated earlier, the predominate form at a pH of 4.3 would be Al^{+3}.

It should be pointed out that the characteristics of the samples from location J4 are not necessarily indicative of all locations at plant J or L. For example, at location J3 (Table 19), the aluminum concentration in both the interstitial water and well water exceeds its hydroxide solubility ($K_{apparent} = 9.4 \times 10^{-25}$ and $K_{apparent} = 2.3 \times 10^{-18}$ respectively) indicating either the occurrence of complexation or the presence of a system not in equilibrium, while for location L6, calculations indicate the concentration of aluminum in the interstitial water has not reached the limit imposed by the hydroxide solubility constant ($K_{apparent} = 6.0 \times 10^{-34}$), even though the concentration is higher than at location J3. This suggests that the acidic conditions (pH 4.1) at location L6 are allowing more aluminum in solution, but not enough is present to attain maximum equilibrium concentrations.

It should be noted that the simplistic approach used in the equilibrium discussions herein minimizes the effects of ionic strength, temperature, and medium on K_{so}.

Iron

There are two oxidation states in which iron normally occurs, the ferrous form (Fe^{+2}), and the ferric form (Fe^{+3}). Under oxidizing conditions and near neutral pH (5 to 8), iron is precipitated as the highly insoluble ($K_{SO} = 6.0 \times 10^{-38}$) ferric hydroxide, $Fe(OH)_3$. The solubility of iron is dependent on pH and oxidation-reduction potential (Eh). Its chemical behavior is also influenced by its ability to form complex ions with sulfides, sulfates, oxides, hydroxides, chlorides, fluorides, carbonates, phosphates, and organic material. The ferrous form (Fe^{+3}) forms weaker complexes than the ferric, and forms few stable inorganic complexes. It is the predominate oxidation state in reducing and/or acidic environments.[19]

Figure 10 illustrates the relationships between pH and Eh that define the conditions under which specific ionic species of iron dominate. This is known as an Eh-pH, or stability field, diagram. Specific areas where species dominate are delineated by thermodynamic computations, in which the Nernst equation is the fundamental relationship that establishes the dividing line between oxidized and reduced species. A thorough discussion of Eh-pH diagrams is given by Garrels,[20] where this familiar form of the Nernst equation is utilized.

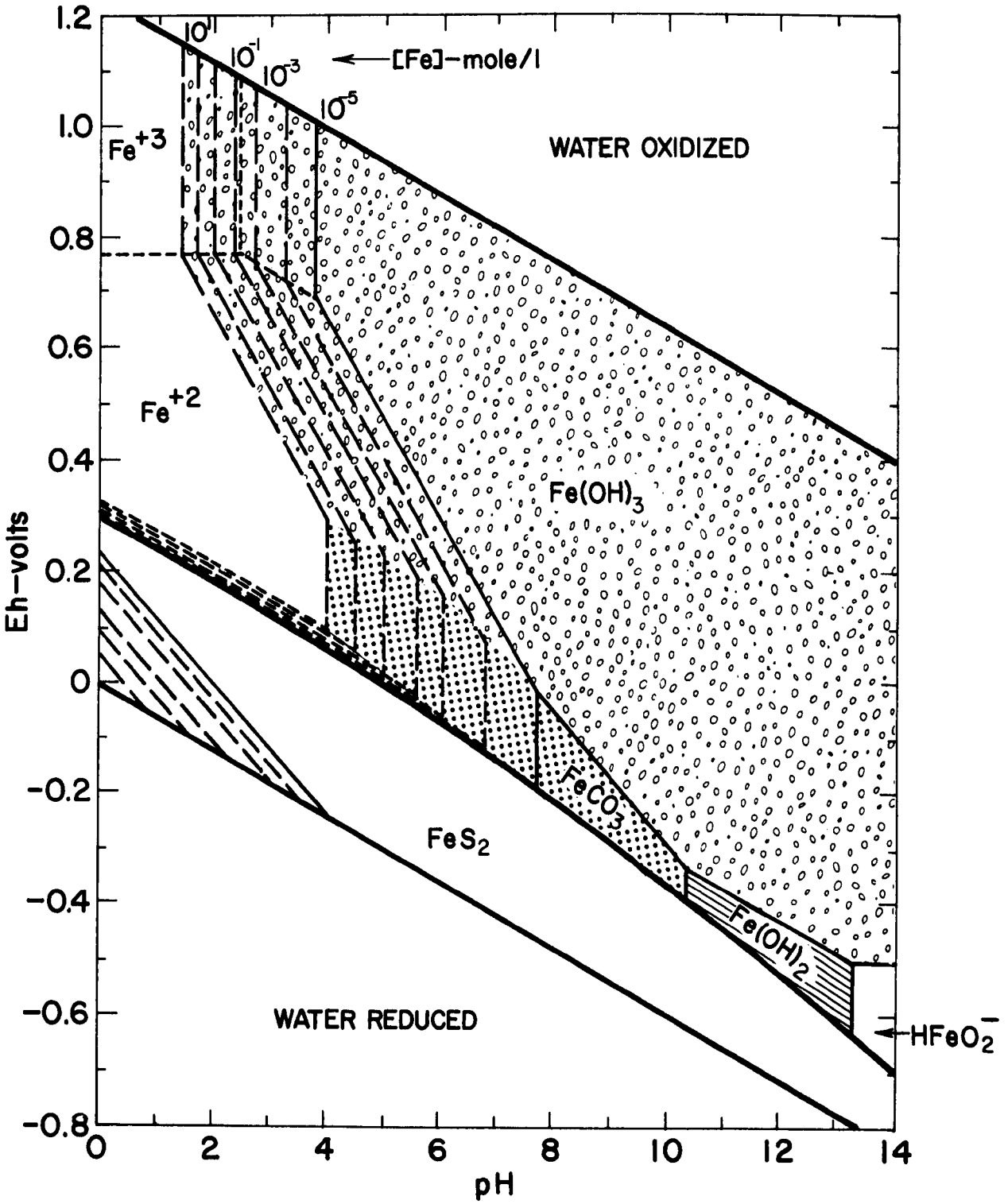


Figure 10. Solubility of iron in relation to pH and Eh at 25° C., and 1 atm. Total dissolved sulfur 10^{-4} M: bicarbonate species 10^{-2} M (Hem, 1960) (7)

$$Eh = E^{o} + \frac{RT}{nF} \ln \{\frac{ox}{red}\}$$

Where:

Eh = oxidation reduction potential

E^{o} = standard oxidation potential for half-cell reaction

R = universal gas constant (1.987 calories/degree mole)

T = temperature in degrees Kelvin

n = number of electrons involved in chemical reaction

F = Faraday constant (96,484 coulombs)

{ox} = activity of oxidized ions

{red} = activity of reduced ions

This equation can be used with thermodynamic data to generate the stability field diagrams of the type illustrated in Figure 10, for any of the various metal equilibriums one would care to examine. They were not presented for all the metal ions measured during this study because the variable nature of the data, both between and within sampling locations, would require a voluminous exposition.

As Figure 10 indicates, ferrous iron (Fe^{+2}) can be produced by the oxidation of pyrite (FeS_2), reduction of ferric species (Fe^{+3}), dissolution of ferrous hydroxide ($Fe(OH)_2$), or dissolution of siderite ($FeCO_3$). Additionally, the kinetics and formation of intermediate species may affect the formation of ferrous iron. The FeS_2 equilibrium is a feasible condition because of the high concentration of sulfate present in several of the sampling wells, the low pH values of the interstitial water, and the presence of pyrite (FeS_2) in coal. In Figure 11, the stability fields for five different sulfur species are illustrated. The dotted line indicates the ferrous-ferric boundary and demonstrates that sulfate is the predominate form of sulfur stable in the ferric region.

At a pH less than about 8.0, and under reducing conditions, the H_2S and S^{o} forms predominate. Oxidation of H_2S will produce the S^{o} form, which upon further oxidation, forms SO_4^{-2}. The H_2S form has the notorious "rotten egg" odor, which was noticeable during the collection of water samples from several of the wells at both plants. This qualitative analysis indicates the potential presence of a reducing environment in the ground water at certain sampling locations. It was most noticeable in samples collected from wells downgradient from the ash disposal areas, and least, if at all, in the upgradient or background wells. In addition, the odoriferous wells upon inspection were found to have a black deposit (possibly FeS) on the 1.27 cm rigid PVC pipe installed inside the well. This deposit was most concentrated at the interface of the groundwater surface with the atmosphere and may be a result of

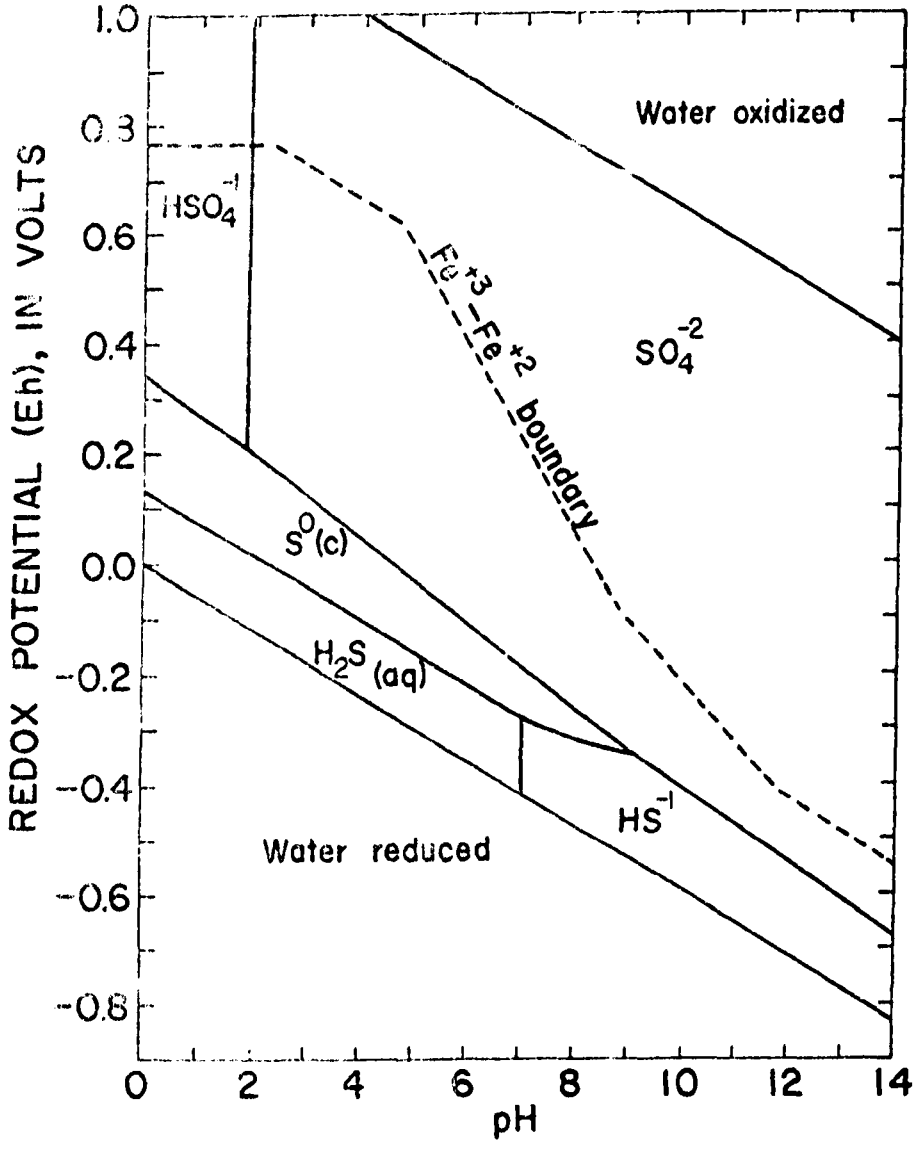


Figure 11. Fields of stability of sulfur species likely to occur in natural water (Hem, 1960)(2)

oxidation within the well casing. Solubility product calculations were performed for the FeS, $K_{so} = 2.6 \times 10^{-22}$ equilibrium, using iron and sulfide data from Tables 17 and 18. The calculations indicated that concentrations of iron and sulfide in samples from three locations at plant J (J5A, J4A, and J7A) exceeded the solubility product for FeS, and at plant L, wells L3, L3A, L4, L5, L6, L6A, L7, L8, L8A, L9A, and L10 exceeded the FeS solubility. The water sampled from these wells was thus unstable (not at equilibrium) with regard to the ferrous sulfide equilibrium, and precipitation of FeS could be expected, which may account for the black deposits on the aforementioned PVC pipe.

A potentially important aspect of the speciation chemistry of iron-sulfate equilibrium, as it relates to coal-ash leachate, is the oxidation of pyrite present in the ash disposal area. In a study by Cox, et al,[21] to characterize the runoff from coal storage piles, the production of ferrous iron and acidity from pyrite oxidation was shown to be the major factor effectuating the solubilization of iron. The oxidation of pyrite results in the production of ferrous iron and acidity via the following reactions:

$$2\ FeS_2 + 7O_2 + 2\ H_2O \rightarrow 2\ Fe^{+2} + 4H^{+} + 4\ SO_4^{-2} \qquad (1)$$

$$4\ Fe^{+2} + O_2 + 4H^{+} \rightarrow 4\ Fe^{+3} + 2H_2O \qquad (2)$$

At this stage the ferric iron can either hydrolyze to form insoluble ferric hydroxide,

$$Fe^{+3} + 3\ H_2O \rightarrow Fe(OH)_3 + 3H^{+}, \qquad (3)$$

or oxidize pyrite directly producing more ferrous iron and acidity:

$$FeS_2 + 14\ Fe^{+3} + 8\ H_2O \rightarrow 15\ Fe^{+2} + 2\ SO_4^{-2} + 16\ H^{+} \qquad (4)$$

The speciation chemistry of the iron-sulfate equilibrium is a complex process, and may be worthy of further study in relation to ash pond leachate due to its potential for decreasing pH and subsequent solubilization of trace metals.

Copper, Lead, Zinc, and Other Metals

At pH values below 7.3, the predominate form of soluble copper is Cu^{+2}, while at higher values $CuOH^{+}$ is most prevalent. Copper is strongly complexed with inorganic ligands such as carbonates, hydroxides, and

chlorides and with organic matter. The low pH values observed in the interstitial water samples indicate the Cu^{+2} form would prevail, while at the higher pH values in the well samples it would precipitate as $Cu(OH)_2$ or $Cu_2(OH)_2CO_3$. In solution at the higher pH values, it could be in the form of $Cu(OH)_4^{=}$, or $CuO_2^{=}$.

Solubility calculations were performed for the copper equilibriums CuS, $CuCO_3$, and $Cu(OH)_2$ using data in Tables 17 and 18 and the stability constants listed in Table 20. The calculations indicated that all well water samples that contained measurable amounts of copper and sulfide were unstable (nonequilibrium) with regard to Cu^{+2}. The solubility limiting equilibrium was found to be CuS as the following calculation, using the data from location L6A, demonstrates:

$\{Cu^{+2}\}$ = 0.02 mg/l = 3.1×10^{-7} mole/liter

$\{S^{=}\}$ = 0.11 mg/l = 3.4×10^{-6} mole/liter

$\{CO_3^{=}\}$ = 1.62 mg/l = 2.7×10^{-5} mole/liter

$\{OH^{-}\}$ = 3.1×10^{-7} mole/liter

Sulfide solubility:

$\{Cu^{+2}\}\{S^{=}\} = 1.0 \times 10^{-12}$ — exceeds solubility product, system unstable, precipitation occurring

Hydroxide solubility:

$\{Cu^{+2}\}\{OH^{-}\}^2 = 2.9 \times 10^{-20}$ — equal to solubility product, system stable, in equilibruim

Carbonate solubility:

$\{Cu^{+2}\}\{CO_3^{=}\} = 8.3 \times 10^{-12}$ — less than solubility product, system unstable, available Cu^{+2}

The calculations indicate that the water sample from L6A is in equilibrium with regard to $Cu(OH)_2$ and not at equilibrium with regard to $CuCO_3$. Above a pH of approximately 7.5 such as at many of the sampling locations at plants J and L, the $Cu(OH)_2$ solubility is exceeded and precipitation occurs.

In waters with pH values below 6.0, the predominate ionic species of lead is the divalent Pb^{+2} form. The solubility of lead can be influenced by complexation with hydroxides, chlorides, and organic material.

In association with sulfates, carbonates, or phosphate anions under alkaline conditions, soluble compounds will readily be formed resulting in the precipitation of lead. Solubility calculations for the PbS equilibrium, $K_{so} = 7.0 \times 10^{-29}$, using data from Tables 17 and 18, indicate that the water sample collected from sampling well L9A at plant L is chemically unstable with regard to the PbS equilibrium, $K_{apparent} = 7.2 \times 10^{-13}$, and precipitation is occurring.

Where:

K_{so} = solubility product at equilibrium

$K_{apparent}$ = solubility product of the measured solution

TABLE 20. SOLUBILITY PRODUCT CONSTANTS FOR IRON, ALUMINUM, COPPER, LEAD, AND ZINC COMPOUNDS

Compound	Solubility product[a]
FeS	2.6×10^{-22}
$Fe(OH)_2$	5.0×10^{-15}
$Fe(OH)_3$	6.0×10^{-38}
$FeCO_3$	2.0×10^{-11}
$Al(OH)_3$	1.0×10^{-32}
Cus	7.9×10^{-37}
$Cu(OH)_2$	1.5×10^{-20}
$CuCO_3$	2.3×10^{-10}
PbS	7.0×10^{-29}
$Pb(OH)_2$	1.5×10^{-17}
$PbCO_3$	7.2×10^{-14}
ZnS	7.9×10^{-26}
$Zn(OH)_2$	5.0×10^{-17}
$ZnCO_3$	2.0×10^{-11}

[a]Adapted from: Sillen, L. G., and A. E. Martell, "Stability Constants of Metal-Ion Complexes." London: The Chemical Society, Burlington House, W. E. (1964).

Generally, the dominating ionic zinc species in solutions of low pH (<7.0) is Zn^{+2}, with the anionic forms $Zn(OH)_3^{-1}$ and $Zn(OH)_4^{-2}$ being the soluble species at high pH (11.0).[23] The carbonate is the most soluble form, $K_{so} = 2.0 \times 10^{-11}$, with the hydroxide following at $K_{so} = 5.0 \times 10^{-17}$. The least soluble zinc compound is the ZnS form with $K_{so} = 7.9 \times 10^{-26}$. Solubility calculations, again using the data in Tables 17 and 18, indicate that in the well samples where measurable zinc and sulfide concentrations were found (L4, L8A, L11, J5A, and J7A), unstable conditions ($K_{apparent} > K_{so}$) with regard to zinc solubility were present, and precipitation was occurring. With measured pH values less than 11, no hydroxo-zinc complexing would be expected; thus, any dissolved zinc species measured in the sampling wells would be predominately the divalent Zn^{+2}.

The concentrations of beryllium, cadmium, chromium, mercury, and selenium measured in the sampling wells at plants J and L, as Tables 17 and 18 indicate, were all less than or near their analytical detection limits. This contrasts with interstitial water analysis in Tables 15 and 16, where concentrations of cadmium, chromium, and mercury were present in measurable quantities.

Arsenic was present in measurable quantities in samples collected from wells J2, J5A, L6, L7, L8A, and L9A. Boron was present in all well samples collected from plants J and L, on March 9 and February 22, respectively. In addition, the concentration of boron in samples from wells J2, J7A, L6A, L8, L8A, L9, and L9A were found to exceed the EPA's quality criteria for water[16] of 0.750 mg/l for irrigation (at one location, L8A, by more than 26 times).

As a result of the comparisons between the data listed in Tables 15, 16, 17, 18, and 19, the solubility calculations that were made using these data, and observations made from the selected Eh-pH diagrams, several trends have become apparent. First, in general these data indicate that the concentrations of metals in the interstitial water samples were higher than concentrations measured for the same constituents in samples taken from the sampling wells; second, interstitial water samples tended to have lower pH values than well samples, perhaps indicating a more reducing environment in the former; third, the predominate form of iron, copper, zinc, and lead ions present in solution was as the divalent species, while aluminum was in the trivalent form; and fourth, the metal-sulfide equilibrium played a dominant role in controlling the solubility of metals (with the exception of aluminum, which was limited by the hydroxide solubility due to its +3 valence state).

SECTION 7

HYDROLOGY

The ash disposal areas at plants J and L are located adjacent to reservoirs in which the water levels in winter are drawn down several feet for flood control. As a result, groundwater discharge to the river is greatest during this period. During the late spring and summer months the reservoir levels are higher, with minor daily variations in elevation. The higher reservoir levels during this time reduce the water table gradient toward the river, resulting in a decreased rate of groundwater discharge to the reservoir.

Although seasonal variations in groundwater flow beneath the ash disposal areas at both plants occur, the net groundwater movement is to the adjacent reservoir. In Figures 12 and 13, water table elevations in the sampling wells at plants J and L, measured respectively on March 9 and February 22, 1977, are plotted along with the average elevation of the associated reservoir levels observed in 1977 (far right horizontal axis). The sampling locations are plotted on the graph from left to right in order of decreasing distance from the river. An estimated line of best fit through the points (dashed line) indicates a riverward gradient and thus, the net direction of groundwater flow at the two disposal areas is toward the river.

Figure 14, is a geologic section and water table profile of the ash pond area at plant J, showing the water table gradient toward the river. The figure also shows a condition that may be common to ash disposal areas where the perimeter dike is constructed of a low permeable material. Subsurface water might be impounded behind the closed perimeter dike continuous with the pond's bottom, both of low permeability (which is the current design). After raising the dike several times to accommodate additional ash, a large bowl with low permeability sides would result. Water in the bottom of this bowl would tend to be passed around by ambient groundwater flows and mixing would be minimal. Static water in this zone would undoubtedly be of poorer quality than water merely passing through coal ash once, acquiring some characteristics of ash leachate, and then flowing on to mix with unaffected ground or surface waters or acted on by attenuation dynamics of the surrounding subsoils. The water in the dead space of the bowl would have a prolonged ash contact time, allowing for maximum dissolution of ions and the formation

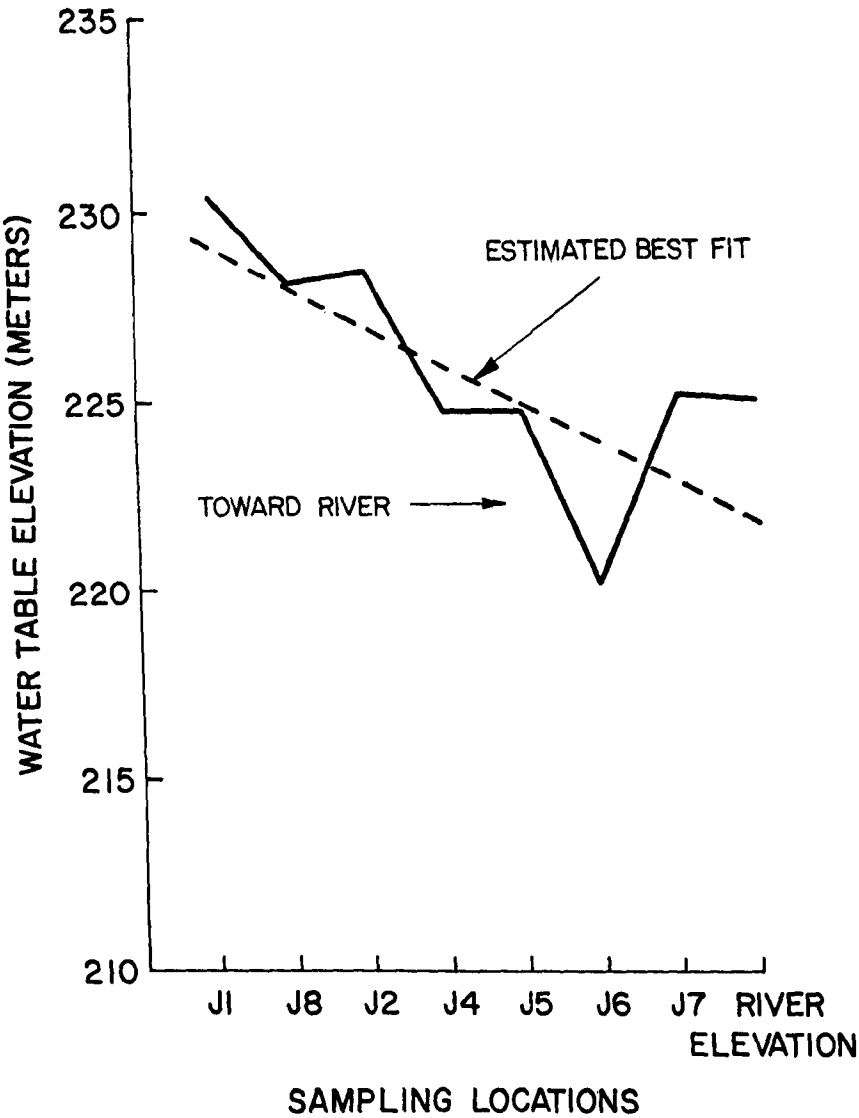


Figure 12. Groundwater table elevation in sampling wells at plant J, March 9, 1977

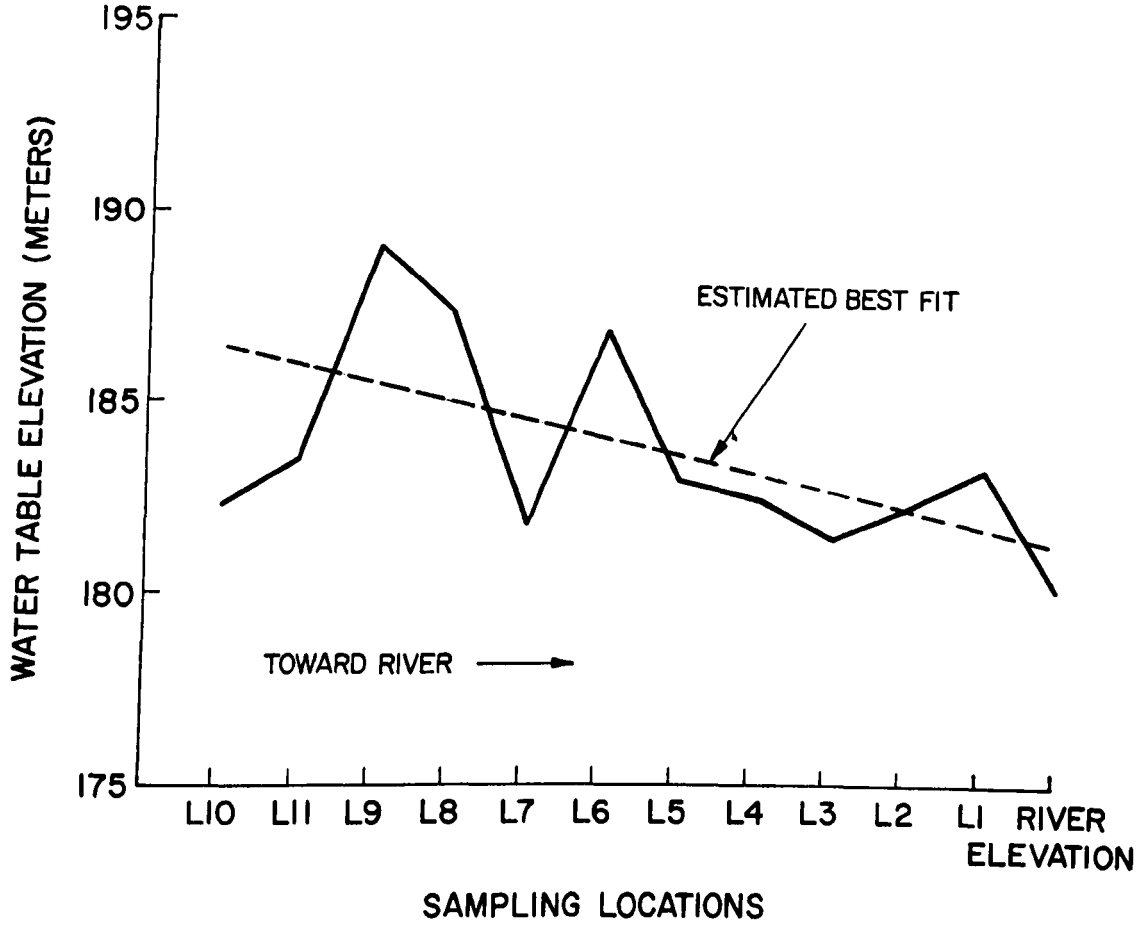


Figure 13. Groundwater table elevation in sampling wells at plant L, February 22, 1977

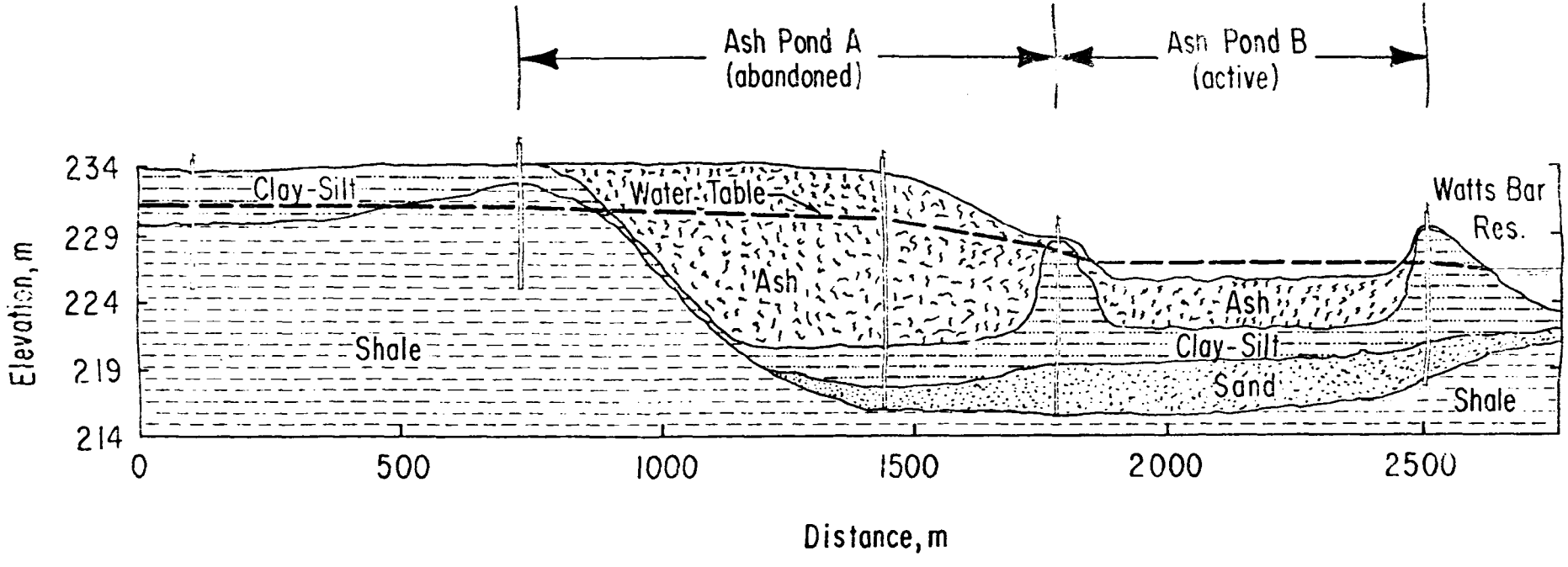


Figure 14. Cross section of ash disposal area at plant J.

of an acidic, highly reducing environment. The potential impact of a hidden condition such as this on local groundwater quality may warrant determination of whether the phenomenon exists.

In Figure 13, the water table elevations in the abandoned ash ponds at plant L (locations L8 and L9), are higher than the surrounding water table elevations, including the background locations. This is the type of data that would indicate a leachate bowl. Inflows into the bowl would not be able to equilibrate with the surrounding water table if the bowl's sides and bottom were of low permeability (permeability of the soil below the deposited ash at locations L8 and L9, averages 10^{-8} cm/sec), and the water level inside the bowl would tend to rise above the ambient groundwater table. The phenomena is speculative at this point; more data would be required for confirmation.

The permeability of the ash pond dike and subsoil beneath the ash at plant J, was measured in the laboratory in both the vertical and horizontal directions. The vertical permeabilities ranged from 6.3 x 10^{-8} to 1.3 x 10^{-6} cm/sec (see Table 3), while horizontal permeabilities ranged from 7.4 x 10^{-8} to 7.4 x 10^{-5} cm/sec. Subsoil samples with lower permeabilities contained larger fractions of clay,* while samples with higher permeabilities contained larger fractions of sand (Table 3). The density of the soils ranged from 1.42 to 1.79 g/cm^3. Sample density increased with sand content. Moisture content of plant J soils ranged from 13.9 to 25.7 percent. Generally, the soil samples from plant J, consisting mostly of sand with a moderate moisture content, were of moderate permeability and medium to high density.

At plant L, vertical permeabilities ranged from 6.9 x 10^{-9} to 3.0 x 10^{-4} cm/sec, and horizontal permeabilities ranged from 5.7 x 10^{-9} to 1.5 x 10^{-4} cm/sec (see Table 7). The sample with 10^{-4} cm/sec permeability was an ash sample collected at location L8. In general, soil samples from plant L having the lowest permeability also contained a large percentage of clay, while the higher permeable samples contained more sand (with the exception of L8, which was ash at 0.8 meters). The densities of the soil material at plant L ranged from 1.03 to 1.77 g/cm^3; moisture ranged from 17.5 to 57.5 percent. Soil samples from plant L, consisting mostly of highly compacted silty clay, were generally of low permeability and high moisture content.

Figure 15 shows an idealized cross section of the ash pond dike at plant J; the superimposed values are mean horizontal permeabilities (K) as measured on samples of the clay-silt and sand strata collected at locations J4, J5, and J6. The permeabilities of both strata were

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*Textural classification of soil fractions as per American Society for Testing and Materials designation, where: clay <0.005 mm, silt 0.005 to 0.074 mm, sand 0.074 to 4.75 mm, and gravel >4.75.[24]

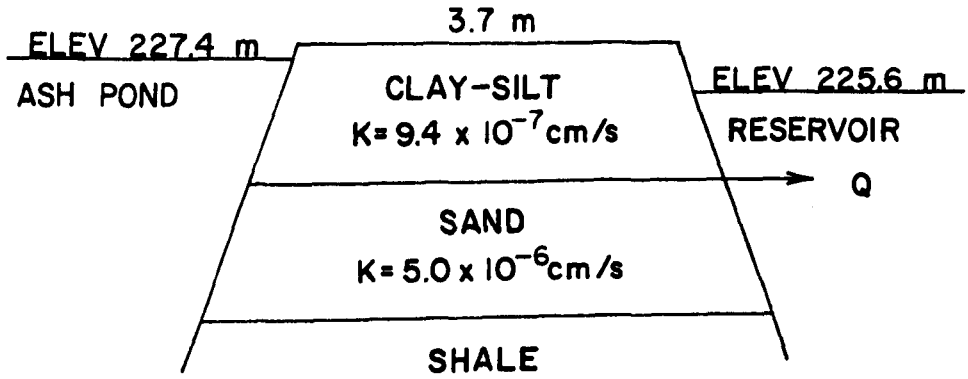


Figure 15. Cross section of the clay-silt and sand strata at plant J, showing mean horizontal permeabilities (K) for locations J4, J5, and J6.

very low, with the permeability of clay-silt stratum being the lower of the two. Using a modification of Darcy's law, the flow through a discrete saturated substratum, such as the clay-silt substratum, is:

$$Q = TIW \quad (5)$$

Where: T = coefficient of transmissibility, volume per unit time per unit length of stratum width

I = hydraulic gradient, unitless

W = width of the vertical section through which the flow occurs, unit length

and,

$$T = Km \quad (6)$$

Where: K = average coefficient of permeability from top to bottom of stratum, volume per unit time

m = thickness of stratum, unit length

For example, in the clay-silt stratum at locations J4, J5, and J6, the average horizontal coefficient of permeability (from Table 3) was 9.4×10^{-7} cm/sec, and the average thickness of the stratum was 9.8 meters. Conversion of the coefficient of permeability to liters per day gives 0.83 liters per day, per square meter. Substitution into equation 6 produces a coefficient of transmissibility of 7.9 liters per meter of stratum width for the clay-silt stratum. The width of the vertical section through which the flow occurs (W) corresponds to the linear length of the ash pond dike adjacent to the reservoir, and was measured to be approximately 1718 meters. The hydraulic gradient (I) of the water table was 0.5. Substituting into equation 5:

$$Q = (7.95 \frac{\text{liters}}{\text{day-m}})(0.5)(1718 \text{ m})$$

$$Q = 6824 \text{ liters per day (1803 gallons per day)}$$

gives the total groundwater flow passing through this cross-sectional area of the clay-silt stratum. A similar calculation for the sand stratum, where the average permeability was 5.0×10^{-6} cm/sec and the average stratum thickness for locations J4, J5, and J6 was 2.5 meters, indicates a total flow through this stratum of 9265 liters per day. Combining the flows through the clay-silt and sand strata gives a total flow through both strata of 16,090 liters per day. This compares to a surface discharge from the ash disposal pond at plant J, of from 59.4

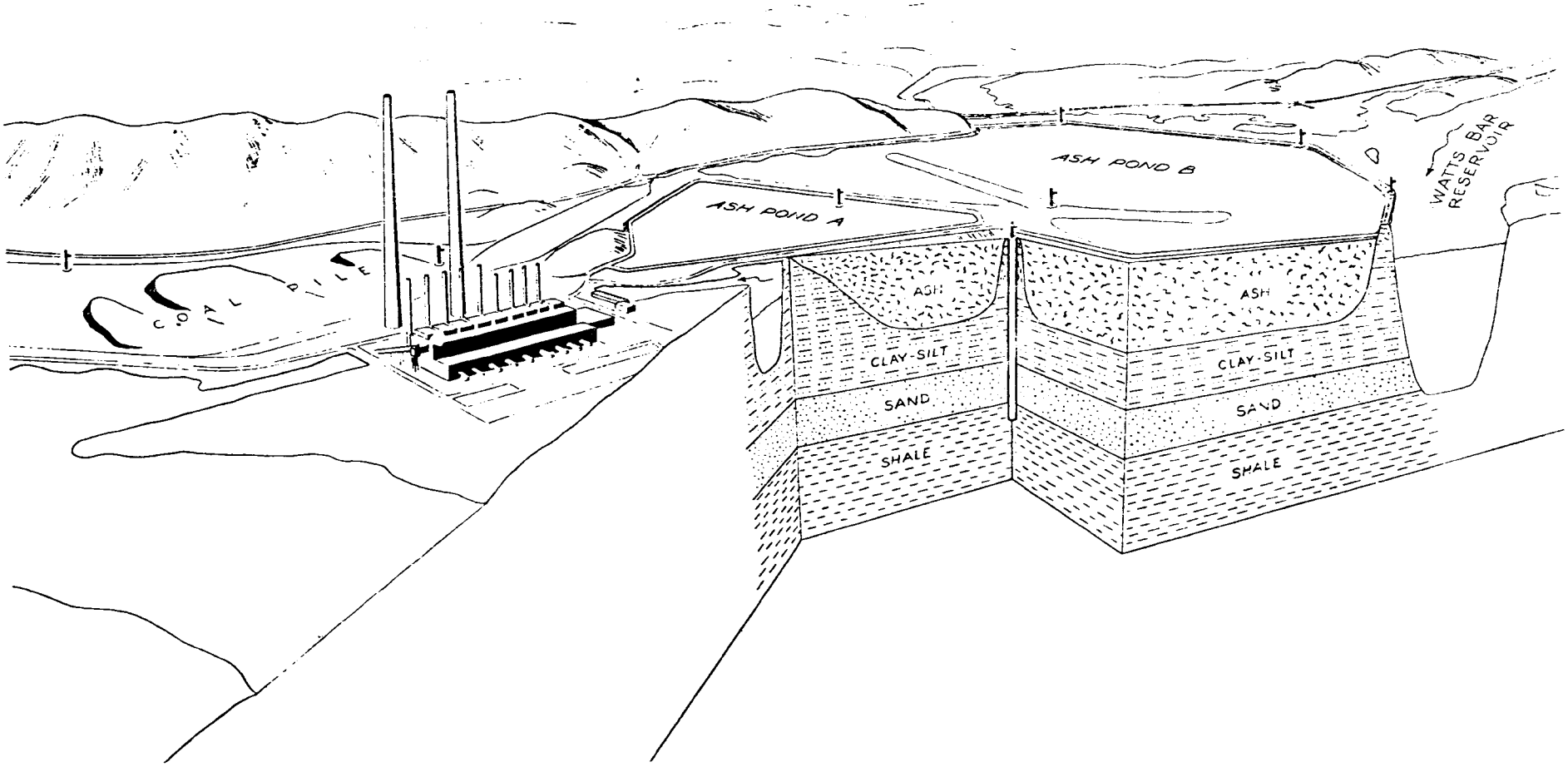


Figure 16. Cross section of substratum below plant J's ash disposal area.

TABLE 21. FLUX OF SELECTED CONSTITUENTS THROUGH SUBSTRATA AT PLANT J

Constituent	Concentration in clay-silt mg/l	Clay-silt flux g/24 hr.	Concentration in sand mg/l	Sand flux g/24 hr.	Total ground water flux g/24 hr.	Concentration in ash pond discharge mg/l	Ash pond discharge flux g/24 hr.
Aluminum	98	671	3.2	30	701	1.4	142,088
Calcium	301	2054	98	914	2968	22.5	2,283,567
Cadmium	<0.002	0.013	0.001	9.26	9.27	0.0015	152
Chromium	<0.005	0.034	0.007	0.064	0.098	<0.005	-
Copper	0.113	0.773	0.053	0.494	1.26	0.06	6089
Iron	506	3457	38.9	360	3817	2.35	238,505
Magnesium	79.3	541	14.3	132	673	3.1	314,624
Nickel	0.18	1.27	0.05	0.494	1.76	<0.05	-
Lead	0.036	0.247	0.032	0.293	0.540	<0.01	-
Sulfate	1883	12,851	153	1420	14,271	88.5	8,982,033
Zinc	0.90	6.14	0.110	1.02	7.16	0.05	5074

to 16.2 million liters per day during 1976. It should be noted that the flow (Q) is dependent on the hydraulic gradient (I), while transmissibility (T) and width (W) remain constant. The hydraulic gradient fluctuates with time according to the elevation of the adjacent reservoir, subsequently increasing or decreasing subsurface discharge.

Figure 16 shows a cross section of the ash pond and substrata at plant J and illustrates the spatial relationships between the ash, clay-silt, sand, and shale materials. The total flux of aluminum, calcium, cadmium, chromium, copper, iron, magnesium, nickel, lead, sulfate, and zinc were calculated for the combined flows in the clay-silt and sand strata illustrated in Figure 16 (detailed vertical profiles of the substratum at plants J and L are presented in appendix B). These fluxes are compared (see Table 21) to the total mass of the same constituents discharged from the ash pond's surface effluent. The fluxes in the groundwater were obtained by averaging the concentrations measured (Table 17) at locations J4A, J5A, and J6A for the clay-silt flux, and J4, J5, and J6, for the sand flux. The product of the average concentrations and the clay-silt and sand flows calculated above, gives the 24-hour flux in each strata. The summation of these two fluxes provides the total groundwater flux of each constituent. These calculations were made assuming concentration homogeneity within each stratum, and disregarding attenuation processes. The mass constituent discharged from the ash pond via the surface effluent was determined by averaging the concentrations measured in two samples collected during 1976, and multiplying this value by the average 1976 daily effluent discharge.

Comparison of the columns in Table 21 shows that the total flux of aluminum, calcium, copper, iron, magnesium, nickel, and zinc was greatest in the clay-silt stratum, while in the sand stratum cadmium, chromium, lead, and sulfate flux were greatest. Comparison of the total flux through both strata with the total mass from the ash pond surface discharge shows that the flux through both strata combined was a small percentage (less than 1 percent) of the total mass discharged from the ash pond surface effluent. Albeit, with the exception of copper, constituent concentrations were higher in the groundwater than in the ash pond discharge. The significant factor effectuating the total mass in the ash pond surface discharge as compared to the groundwater flux was flow. Flow from the ash pond during 1976 averaged 1.0×10^8 liters per day, whereas, the calculated total flow through the combined clay-silt and sand strata was 16,909 liters per day--only 0.016 percent of the ash pond discharge.

The physical measurements of the predominantly clay-silt substrata necessary to quantify groundwater flow at plant L, were not made because the large area involved would have required numerous and costly

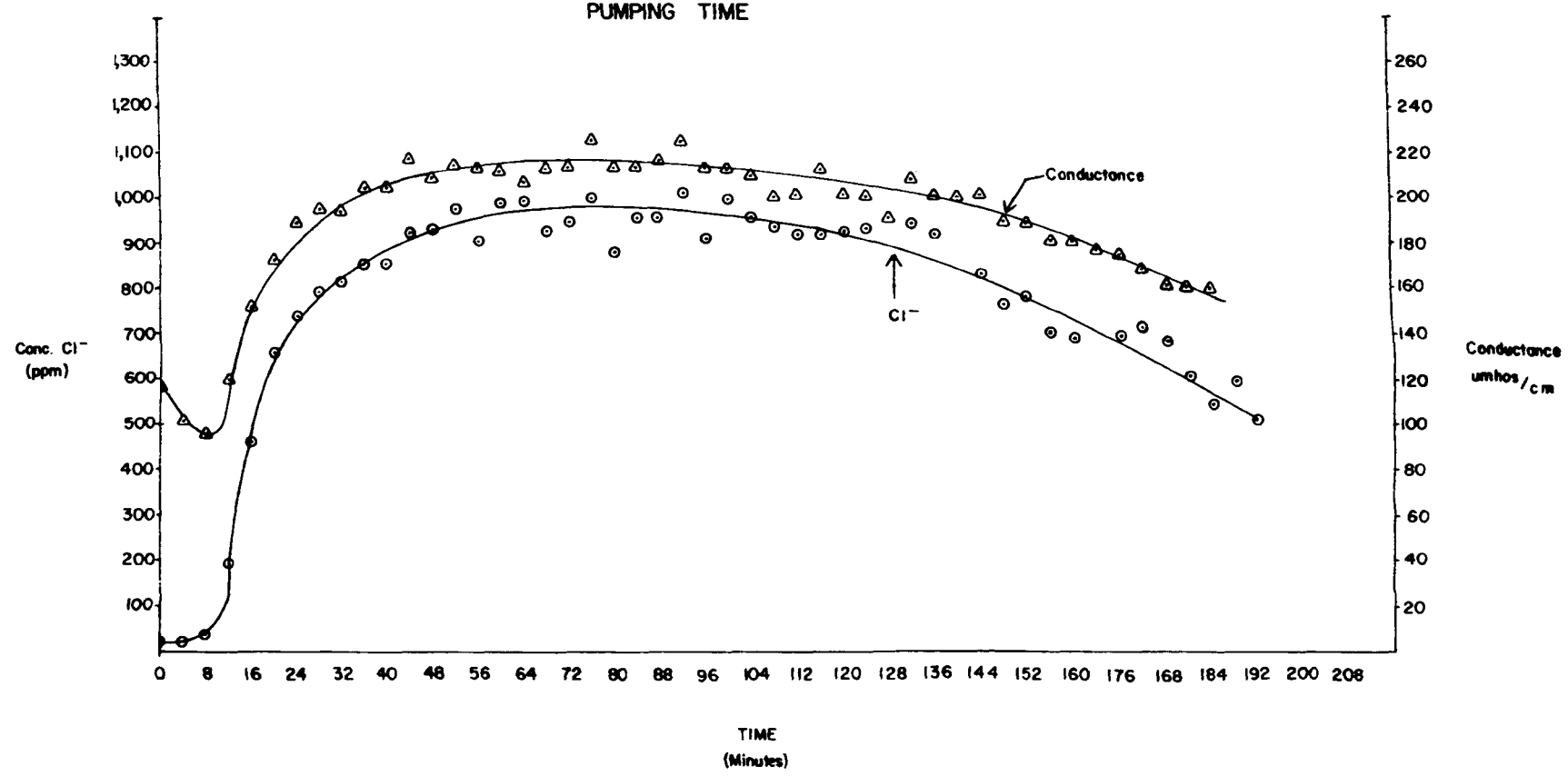
exploratory borings. The low permeabilities measured in the clay-silt substratum (less than 10^{-8} cm/sec) would, however, tend to minimize leachate movement if a generalization can be made from the calculations made with plant J's data.

As previously mentioned in the geological description (section 3), the primary material underlying the ash disposal area at plant L, is a mixture of alluvial and terrace deposits. In certain areas, such as location L4, these deposits consist of unconsolidated materials containing as much as 40 percent gravel. This type of material could not be collected in a Shelby tube for the determination of permeability. In order to determine the groundwater flow in this material, two wells were installed 1.5 meters apart with perforations transecting the pervious gravel material vertically. The difference in hydraulic head between the two wells was 3.1 meters. Nineteen liters of a saturated sodium chloride solution were then injected into the upgradient well. The downgradient well was then pumped and samples collected periodically for the measurement of conductance and chloride. Figure 17 shows a plot of chloride concentration and conductivity versus pumping time for the downgradient well. The figure indicates that the chloride concentration increased substantially within 24 minutes and reached a maximum at approximately 75 minutes. The plot of conductance versus time presents a shape nearly identical to the chloride plot, with a slight decrease in the beginning and a slower return to baseline being the only differences. The slow return to baseline of both parameters is thought to be a result of lateral dispersion of the solute.

Under the conditions of this test, if the time required to reach maximum concentration is assumed to be the flow time between the two wells, then 0.03 cm/sec would be the velocity of the ground water in this material. Using Darcy's law, this velocity converts to a permeability (K) of 0.14 cm/sec, substantially higher than values measured in the laboratory on other subsurface materials. At plant L, there are two locations (L4 and L5) where this highly permeable alluvial material was found. The water quality at both these locations, however, was not significantly different from the background wells 10CW and 11CW. This seemed to indicate that attenuation processes in the overlying clay-silt stratum were precluding ash leachate from infiltrating the porous alluvial material. However, if the ash leachate should ever enter the highly permeable alluvium, minimal attenuation, characteristic of this type of material, would allow the rapid lateral spread of ash leachate.

Figure 17

TRACER TEST OF CONDUCTANCE AND CHLORIDE
vs
PUMPING TIME



SECTION 8

LABORATORY ATTENUATION STUDIES

This section presents the results of the soil column attenuation studies performed on natural soils from plants L and J, and kaolinite clay.

ATTENUATION BY NATURAL SOIL COLLECTED AT PLANT L

A sample of the ash pond dike material from plant L was one of three soil materials used in the attenuation experiment described in section 4. As previously mentioned in that section, samples of the soil column effluent were analyzed for the constituents listed in Table 8. These data are tabulated, along with an analysis of the ash leachate used in the attenuation studies, and are presented in appendix C. The soil sample from plant L, was also analyzed by X-ray diffraction for quartz, and the clay minerals montmorillonite, kaolinite, and illite. The analysis found the clay minerals present in the following relative abundance: kaolinite > montmorillonite > illite, and quarts was the most predominate crystalline phase present.

Figures 18, 19, 20, and 21 are plots of plant L's soil column effluent concentrations for magnesium, sodium, potassium, aluminum, barium, copper, zinc, nickel, and sulfate, versus the cumulative effluent volumes. Also shown on these plots are the "initial" influent leachate concentrations for the above parameters. In Figure 18, magnesium, sodium, and potassium are plotted. The illustration shows that the concentrations of magnesium and sodium in the column effluent exceeded the initial influent concentration for the duration of the experiment, indicating solubilization of these elements occurred in the soil. Potassium, however, initially had a concentration less than the influent, which increased above the influent in subsequent samples and eventually equilibrated (concentration in equaled concentration out) with the initial leachate concentration. This seems to indicate that potassium was initially attenuated by the soil, and later merely passed through the column unaffected. This is further illustrated in Table 22, where mass balances have been calculated on twelve parameters including those illustrated in Figures 18 through 21.

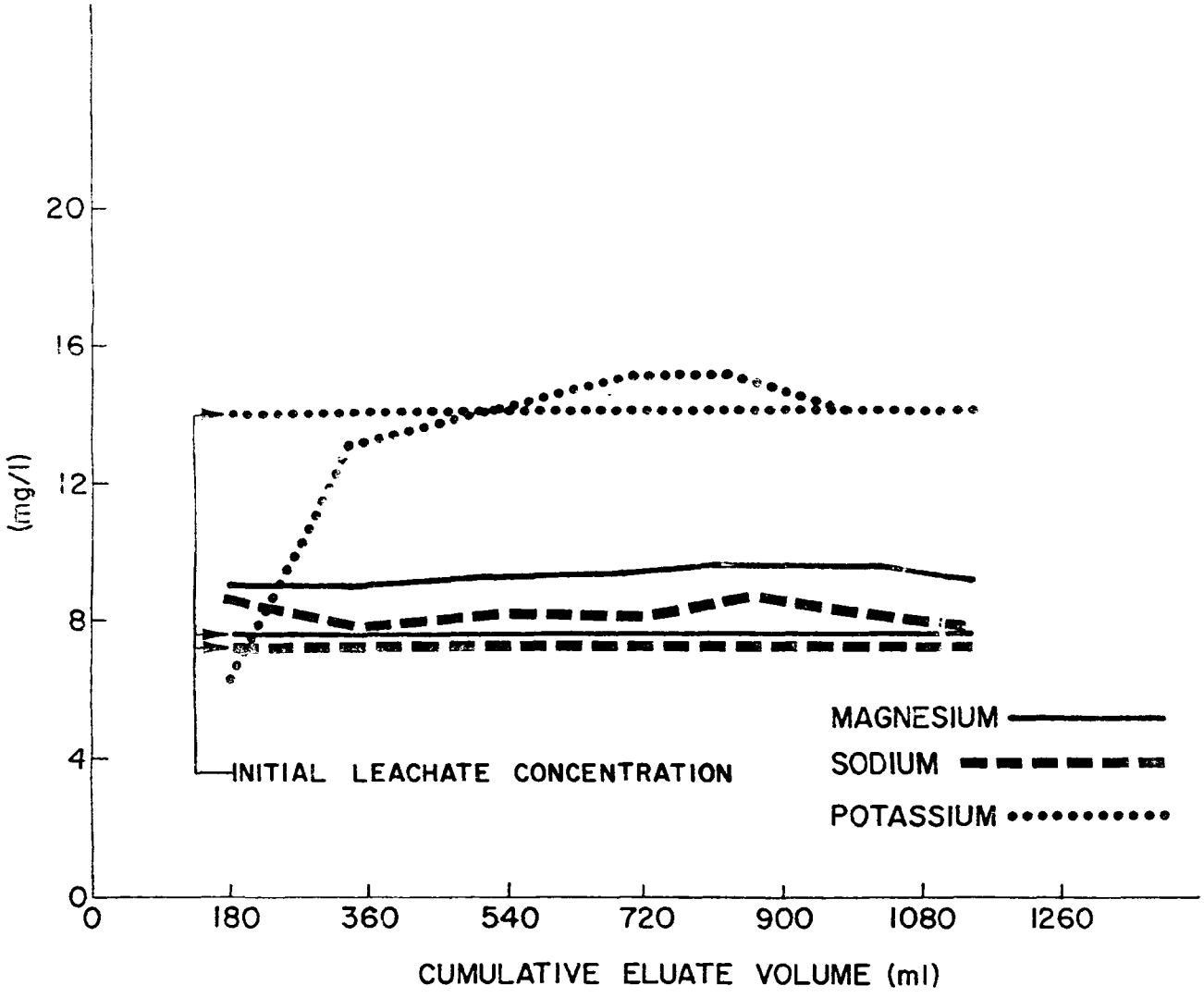


Figure 18. Concentrations of magnesium, sodium, and potassium in the effluent from plant L's soil column.

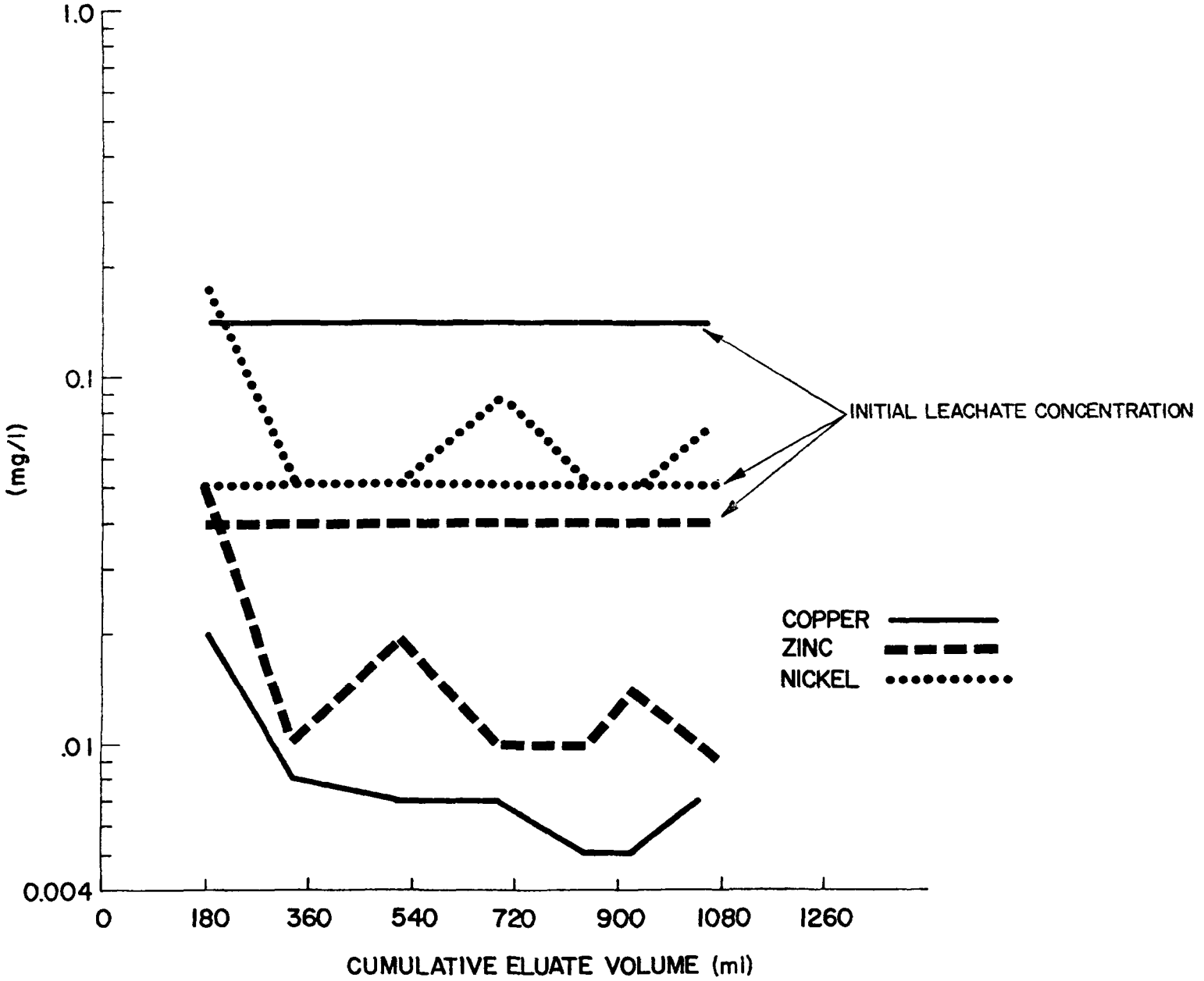


Figure 19. Concentrations of copper, zinc, and nickel in the effluent from plant L's soil column.

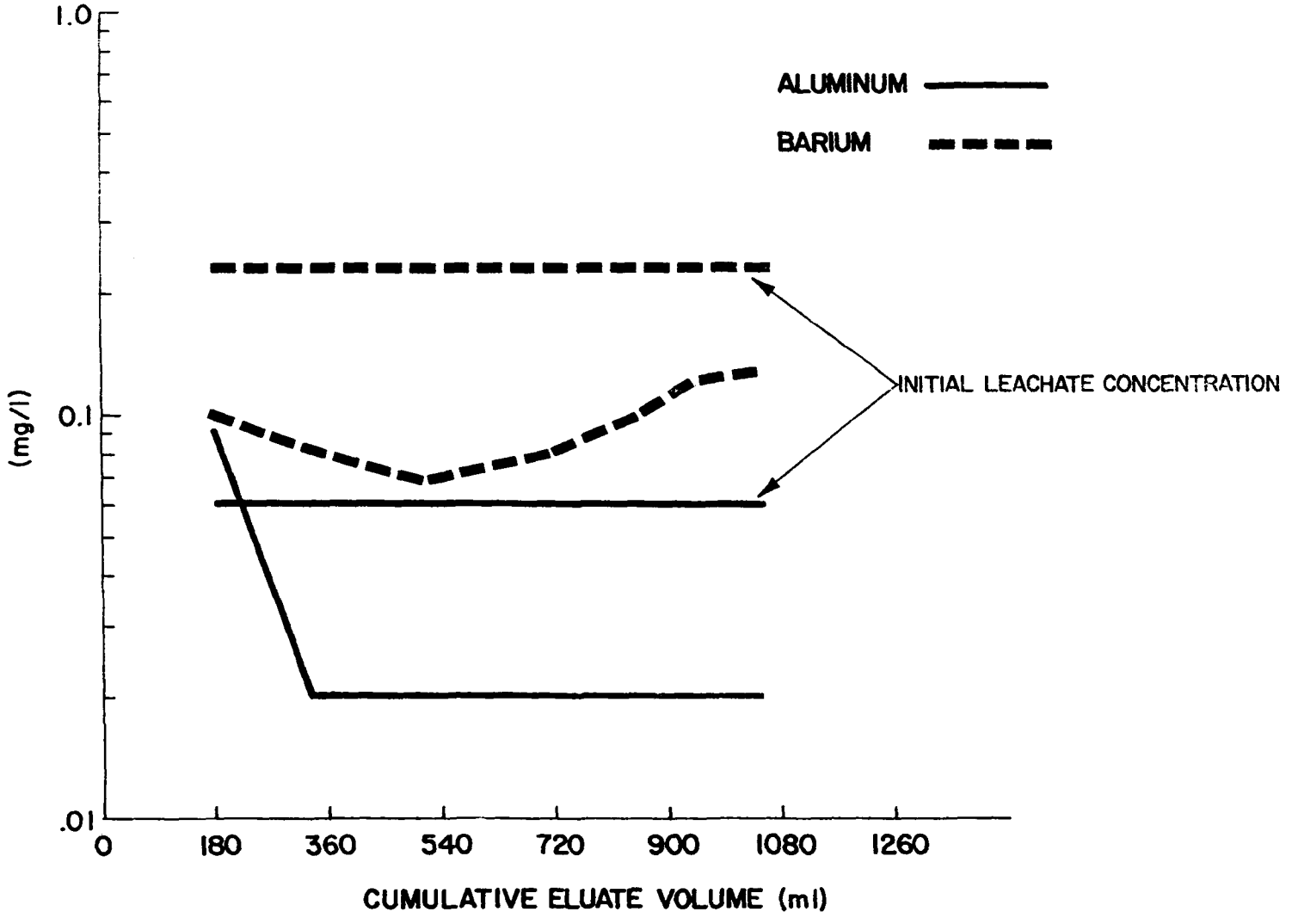


Figure 20. Concentrations of aluminum and barium in the effluent from plant L's soil column.

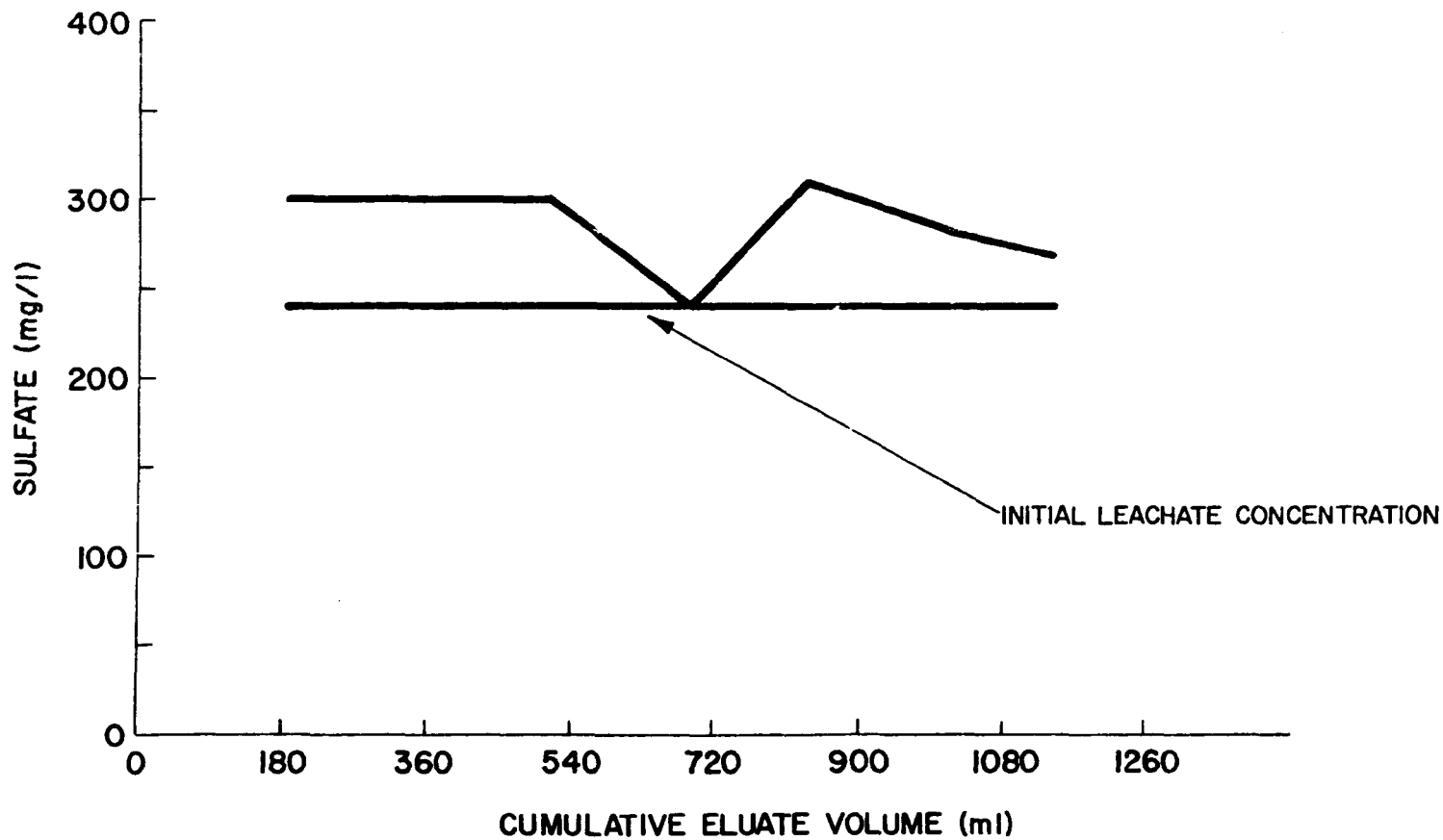


Figure 21. Concentration of sulfate in the effluent from plant L's soil column.

The mass input to the soil columns was determined by multiplying the total volume of eluate that passed through the column by the initial influent concentration. To determine the mass output of the column, the volume of each composite eluate sample was multiplied by the concentration of the constituent measured therein, and these values summed. The difference between the mass in and mass out is the amount retained, or contributed by the soil column. These data indicate that magnesium and sodium had, respectively, 16 and 5 percent increases in mass between the influent and effluent of the soil column, while 3 percent of the potassium was removed in the soil.

In Figure 19, copper, nickel, and zinc concentrations in the soil column effluent are plotted. Copper concentrations were less than the initial leachate concentration in all samples analyzed, and gradually decreased with the volume eluted. Zinc showed a trend similar to copper. With the exception of the first sample, all samples analyzed for zinc were less than the initial leachate concentration. The concentration of nickel in the leachate was less than the analytical detection limit, which accounts for effluent values not plotted below the initial leachate concentration line. However, samples of the soil column effluent did contain some measureable quantities of nickel indicating solubilization from the soil. In Table 22, the data indicate that copper and zinc had, respectively, 97 and 40 percent removal during the test. Calculations were not performed for nickel because it was not detected in the leachate.

The concentrations of aluminum and barium in the effluent from plant L's soil column are illustrated in Figure 20, and the plot for sulfate in Figure 21. All of the effluent samples analyzed for barium and aluminum had concentrations less than the initial leachate value, with the first eluate volume for aluminum being the only exception. The data in Table 22, show that 70 percent of the aluminum and 57 percent of the barium were removed in the soil column. The sulfate plot in Figure 21, indicates solubilization occurring within the soil column. This indication is supported by the mass balance data in Table 22, which shows a 15 percent increase in sulfate mass between the soil column influent and effluent.

Calcium, manganese, iron, and mercury data are not plotted, but from the mass balance data in Table 22, it is indicated that 11 percent of the calcium, 85 percent of the manganese, essentially 100 percent of the iron, and 87 percent of the mercury were removed in the soil column. Cadmium, chromium, lead, beryllium, and selenium were all less than the minimum detectable limits in all samples, including the initial leachate sample, and for that reason were not addressed in this analysis.

Also presented in Table 22, are the number of chemical equivalents removed from the leachate and the number added to the soil column effluent, with the sum of both listed at the bottom of the table. These

TABLE 22. MASS BALANCE OF PLANT L'S SOIL COLUMN INFLUENT AND EFFLUENT

Constituent	Mass IN (mg)	Mass OUT (mg)	Percent removal	Equivalents removed	Percent increased	Equivalents added
Magnesium	8.66	10.03	0	0	16	0.11
Sodium	8.44	8.87	0	0	5	0.02
Potassium	15.96	15.45	3	0.01	0	0
Copper	0.16	0.01	97	0.004	0	0
Zinc	0.05	0.03	40	0.0004	0	0
Aluminum	0.07	0.02	70	0.01	0	0
Barium	0.26	0.11	57	0.002	0	0
Sulfate	273.6	315.3	0	0	15	0.87
Calcium	210.9	187.8	11	1.16	0	0
Manganese	4.79	0.74	85	0.15	0	0
Iron	17.1	<0.01	>99	0.92	0	0
Mercury	0.0023	0.0003	87	1.9×10^{-5}	0	0
Total				2.26		1.00

data indicate that 2.26 meq (milliequivalents) were removed in the soil column, while 1.0 meq was added to the column effluent. This amounted to a net decrease of 1.26 meq through the soil column.

ATTENUATION BY NATURAL SOIL COLLECTED AT PLANT J

A sample of plant J's ash pond dike material was used to determine the attenuation of coal-ash leachate by a natural soil type being used in ash pond construction, as was the soil from plant L, previously discussed. The soil sample from plant J, contained a percentage of clay minerals that when subjected to X-ray diffraction analysis were found to be present in the following relative abundance: illite > kaolinite > montmorillonite. In addition to these clay minerals, the soil contained quartz as the most predominant crystalline phase. The cation exchange capacity of the soil was 17.0 meq per 100 grams, as determined by the method of Bascomb, which is described in appendix A.

In Figures 22 through 24, plant J's soil column effluent concentrations are plotted against the cumulative effluent volumes for magnesium, sodium, potassium, aluminum, barium, copper, zinc, and nickel. The initial leachate concentrations for the above parameters are also shown in these plots. In Figure 22, magnesium, sodium, and potassium are plotted. The illustration shows that the concentrations of magnesium and sodium in the soil column effluent exceeded the influent concentration in all samples analyzed during the experiment. Again, as with plant L's soil column study, the plots indicated solubilization of these elements within the soil column. The plot for potassium is similar to the one generated from plant L's attenuation data. Initially the effluent concentration was less than the influent, and then gradually increased to nearly the same concentration, but never quite equilibrated with the influent. This indicates that potassium was being attenuated, to some degree, for the duration of the experiment. This is also illustrated in Table 23, where mass balances have been calculated on eleven constituents, in a manner previously described. As the data in this table indicate, magnesium and sodium had, respectively, 20 and 10 percent increases in mass between the influent and effluent of the soil column, while 12 percent of the potassium was removed in the soil.

Figure 23 illustrates the plotted concentrations of copper, zinc, and nickel in plant J's soil column effluent. Copper concentrations fluctuated, but were always less than the influent value. The zinc concentration in the column effluent initially was higher than the influent, but immediately declined to remain less than the influent value for the experiment's duration. The mass balance data from Table 23 show that copper and zinc, respectively, had 94 and 57 percent removal of mass in the soil column. A balance on nickel could not be calculated because it was not detected in most samples.

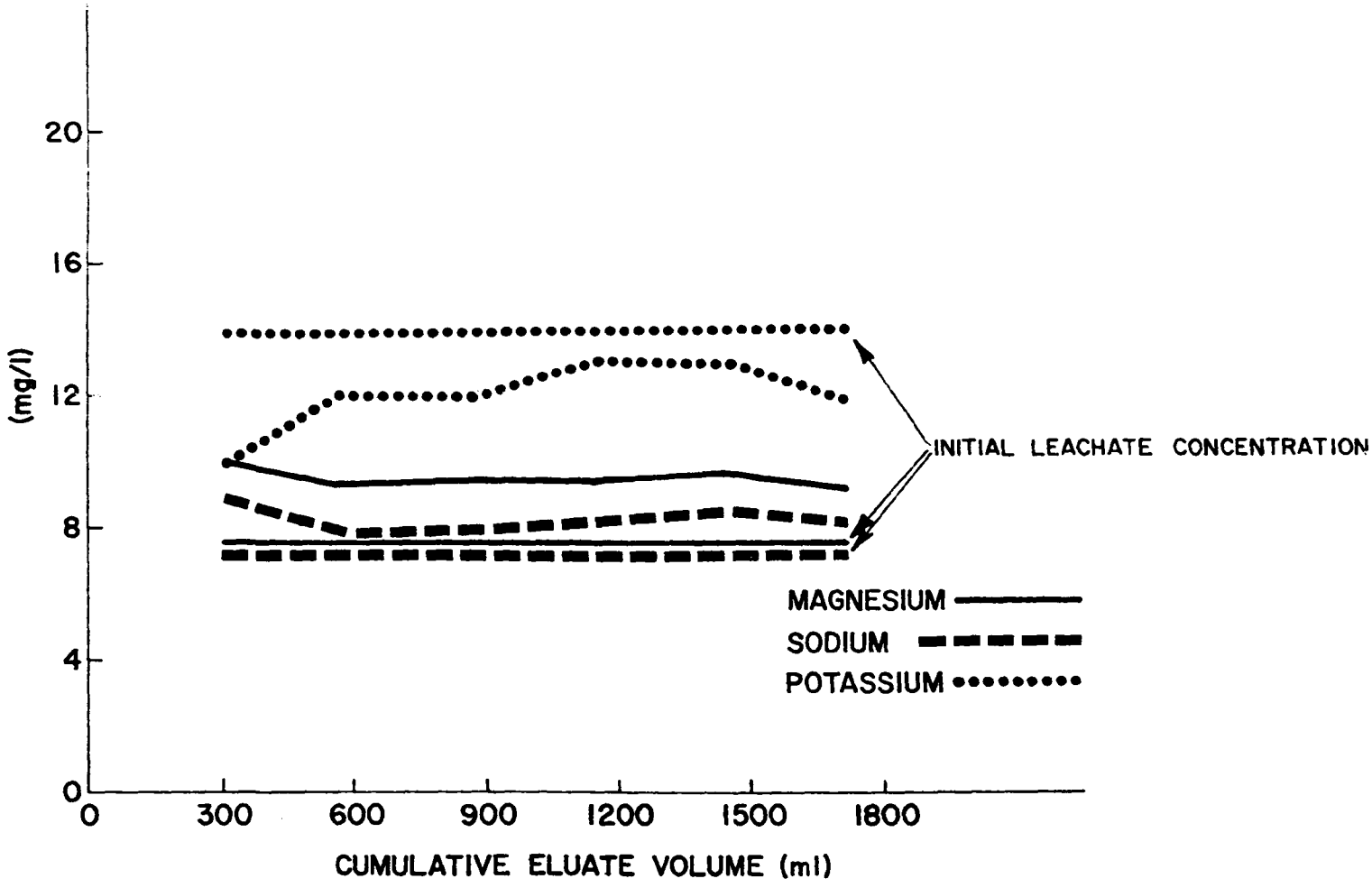


Figure 22. Concentrations of magnesium, sodium, and potassium in the effluent from plant J's soil column.

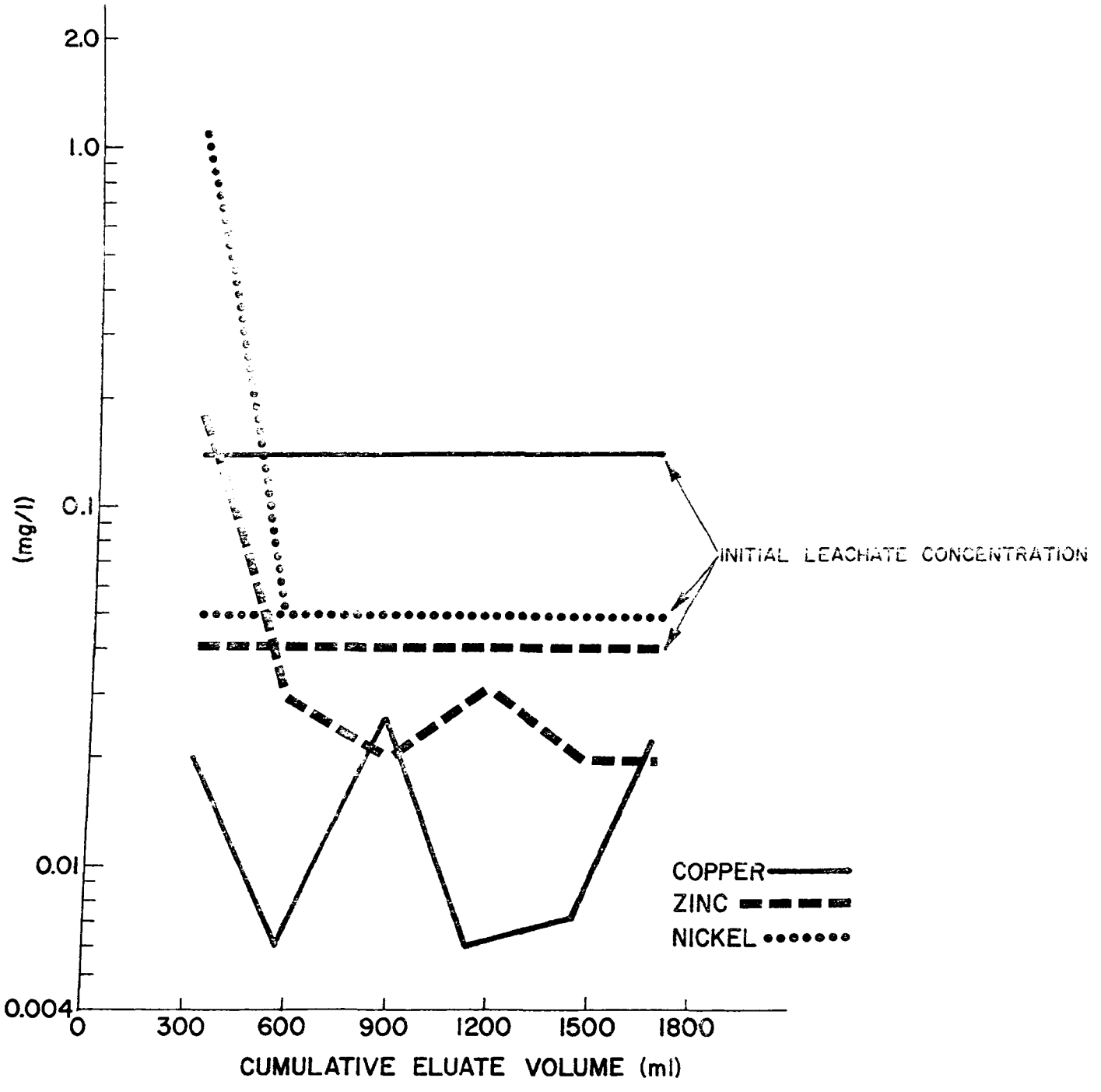


Figure 23. Concentrations of copper, zinc, and nickel in the effluent from plant J's soil column.

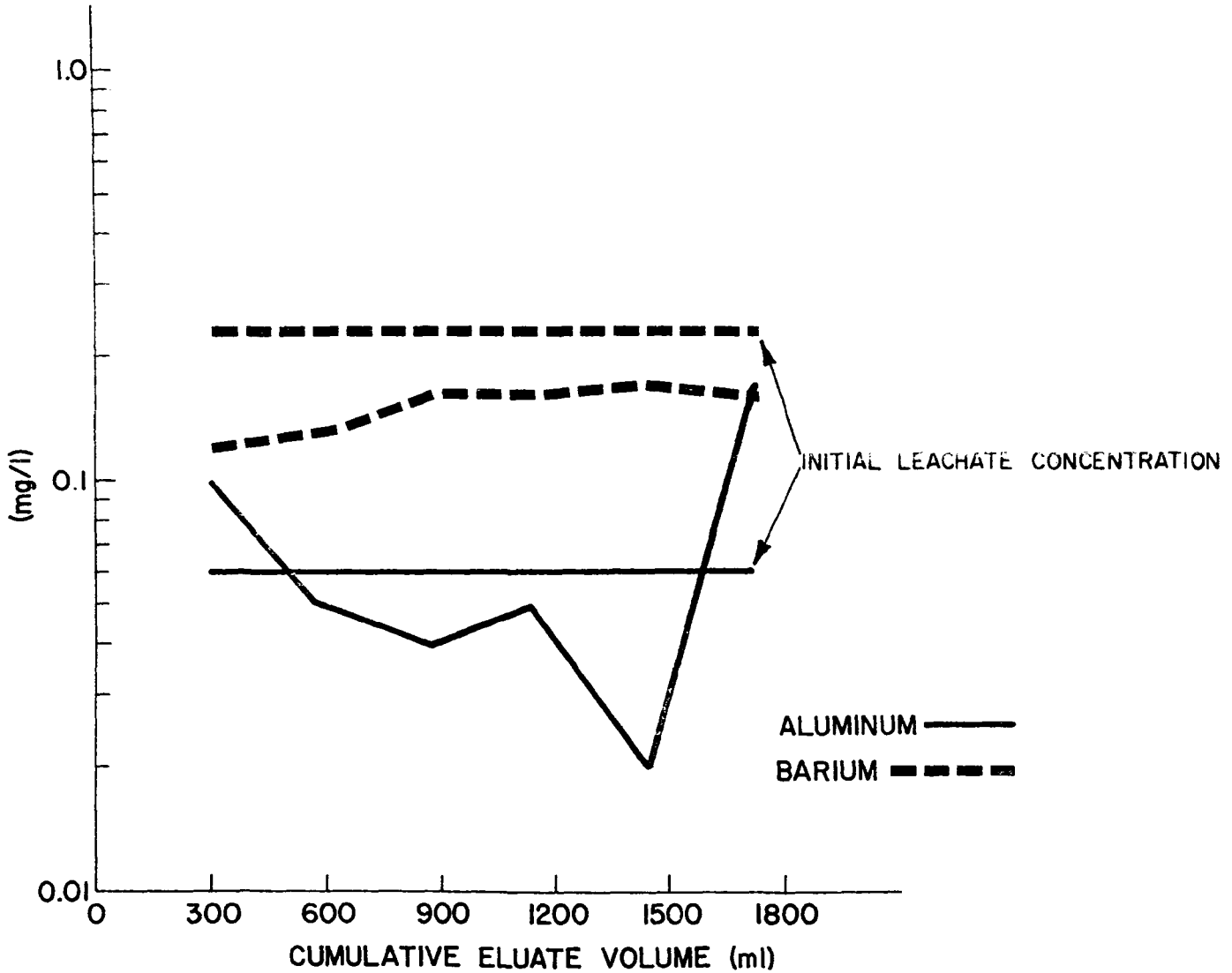


Figure 24. Concentrations of aluminum and barium in the effluent from plant J's soil column.

TABLE 23. MASS BALANCE OF PLANT J'S SOIL COLUMN INFLUENT AND EFFLUENT

Constituent	Mass IN (mg)	Mass OUT (mg)	Percent removal	Equivalents removed	Percent increased	Equivalents added
Magnesium	13.00	15.65	0	0	20	0.22
Sodium	12.31	13.59	0	0	10	0.06
Potassium	23.94	21.18	12	0.07	0	0
Copper	0.24	0.01	94	0.01	0	0
Zinc	0.07	0.04	57	0.0009	0	0
Aluminum	0.10	0.11	0	0	10	0.001
Barium	0.39	0.27	32	0.001	0	0
Calcium	316.35	261.30	17	2.75	0	0
Manganese	7.18	1.77	75	0.20	0	0
Iron	26.65	0.08	≈100	1.38	0	0
Total				4.41		0.28

Aluminum, however, began with an effluent concentration greater than the influent, then decreased to below the influent value where it remained for all samples except the last which was again greater in concentration than the influent. Barium had 32 percent removal within the soil column, according to the data in Table 23. Aluminum had a 10 percent increase in mass between influent and effluent.

Although the data for calcium, manganese, and iron were not plotted, the mass balance data in Table 23 indicate that 17 percent of the calcium, 75 percent of the manganese, and nearly 100 percent of the iron was removed in the soil column. Cadmium, chromium, lead, beryllium, mercury, and selenium were all less than their analytical detection limits in nearly all samples. Not enough sample was collected for sulfate analysis. Table 23 also shows that 4.41 chemical meq were removed in the soil column from plant J, while 0.28 meq were added to the column effluent. Thus, a net decrease of 4.13 meq occurred between the soil column influent and effluent.

ATTENUATION BY KAOLINITE

In natural soils there are three major clay minerals that may be present in relative amounts depending on the geographical location; they are kaolinite, montmorillonite, and illite. Each of these clays has the ability to attenuate pollutants from aqueous solutions, although selectively and at different rates.[25] Attempts were made to study the attenuation of coal-ash leachate by each of these clays. However, expansion of the clay minerals montmorillonite and illite upon wetting inhibited percolation to such a degree that experiments with these two clays were abandoned. It was possible, however, to study the attenuation capabilities of kaolinite. The results of that investigation are presented in Figures 25 through 27, and Table 24.

In Figure 25, column effluent concentrations of magnesium, sodium, and potassium are plotted against the cumulative eluate volume from the kaolinite clay column. The illustration shows that concentrations of magnesium and sodium in all effluent samples analyzed, except the last, exceeded the influent leachate concentration. This indicates that solubilization of these two elements occurred within the clay column. Potassium, on the other hand, had concentrations in the column effluent which exceeded the influent concentrations in all samples except the first and last. This would seem to indicate that potassium is also being solubilized to some degree within the clay column. In Table 24, mass balance data agree with the plotted data, in that magnesium, sodium, and potassium respectively, had 23, 17, and 9 percent increases in mass between the clay column influent and effluent.

Figure 26 illustrates the plotted concentrations of copper, zinc, and nickel in the kaolinite column effluent. Copper concentrations were less in the column effluent than in the influent for all samples except

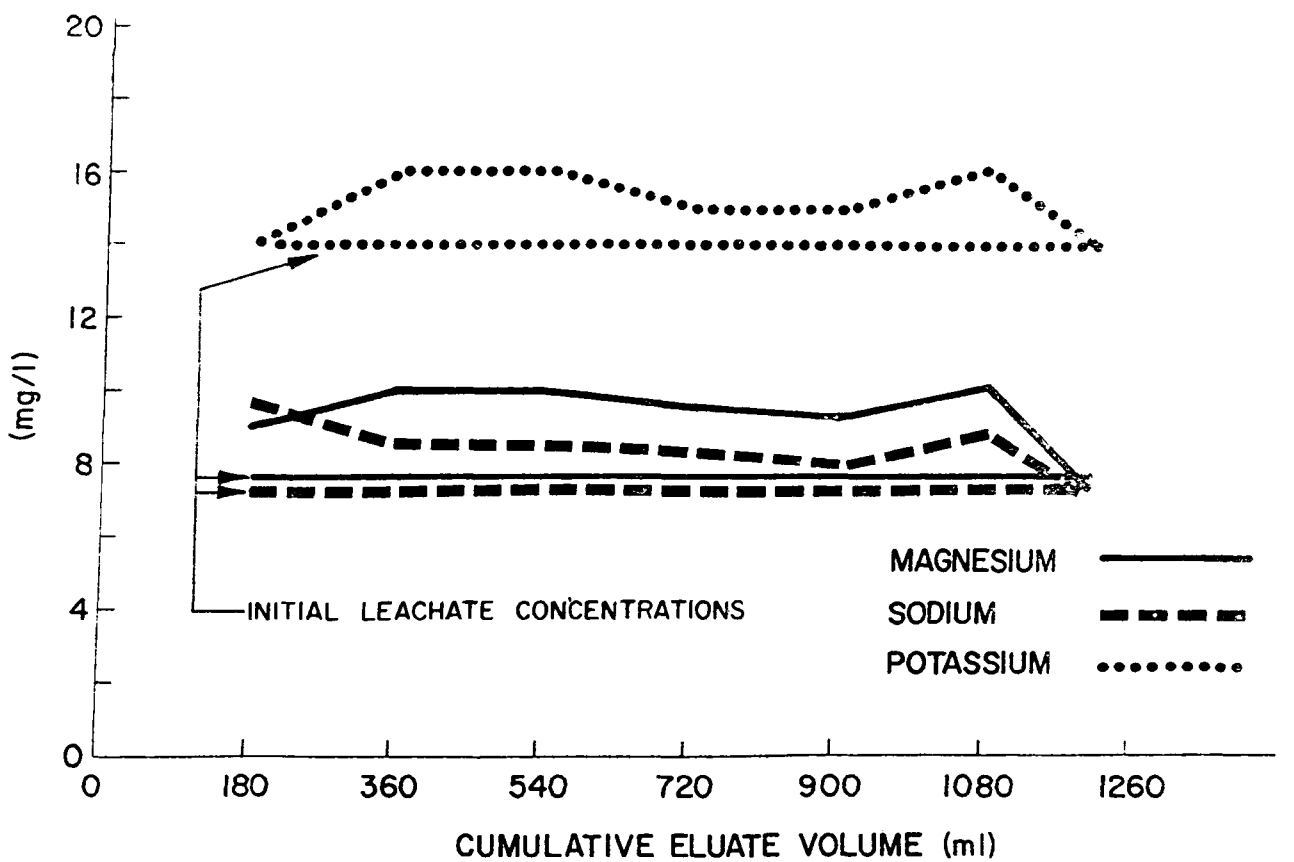


Figure 25. Concentrations of magnesium, sodium, and pottasium in the kaolinite clay column effluent.

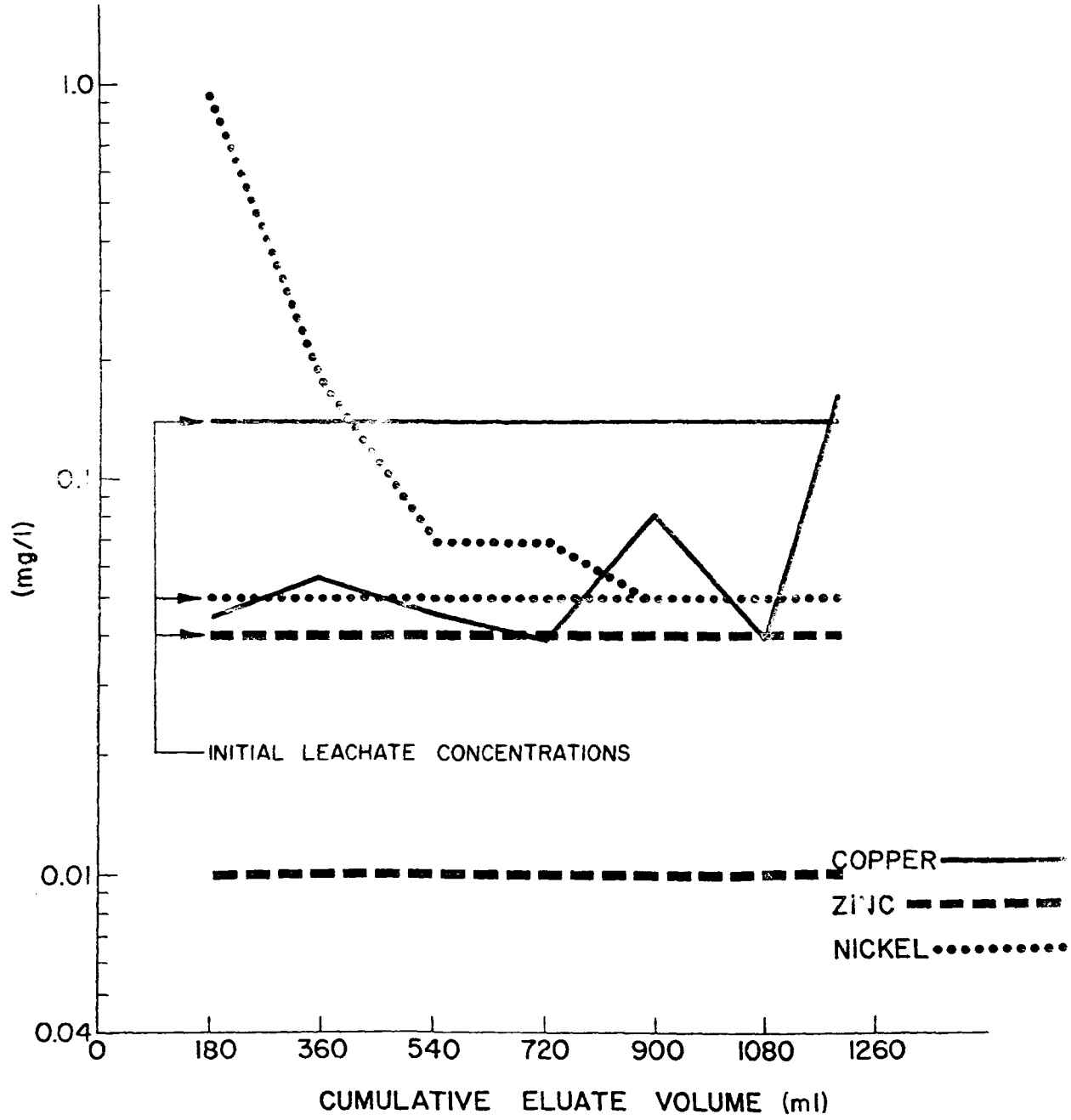


Figure 26. Concentrations of copper, zinc, and nickel in the kaolinite clay column effluent.

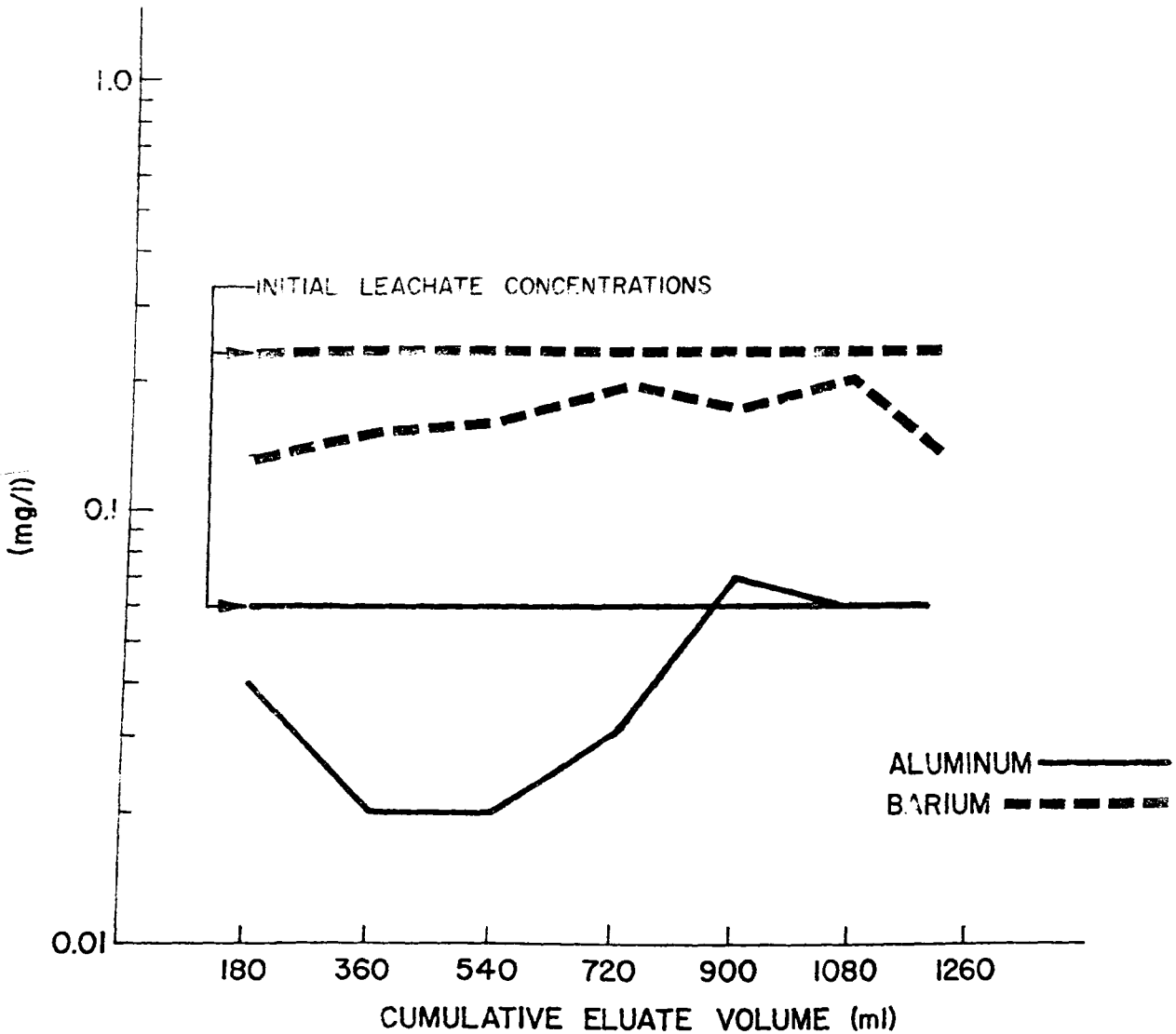


Figure 27. Concentrations of aluminum and barium in the kaolinite clay column effluent.

TABLE 24. MASS BALANCE OF KAOLINITE PACKED COLUMN INFLUENT AND EFFLUENT

Constituents	Mass IN (mg)	Mass OUT (mg)	Percent removal	Equivalents removed	Percent increased	Equivalents added
Magnesium	9.12	11.21	0	0	23	0.17
Sodium	8.64	10.11	0	0	17	0.06
Potassium	16.80	18.24	0	0	9	0.03
Copper	0.17	0.07	56	0.003	0	0
Zinc	0.05	0.03	50	0.001	0	0
Aluminum	0.07	0.05	30	0.002	0	0
Barium	0.28	0.20	29	0.001	0	0
Calcium	222.00	180.00	19	2.09	0	0
Manganese	5.04	0.99	80	0.14	0	0
Iron	18.00	0.05	99.7	0.96	0	0
Mercury	0.0024	0.0003	88	0.000021	0	0
Sulfate	345.60	429.60	0	0	24	1.75
Total				3.20		2.01

the last. All effluent zinc samples analyzed were less than the influent leachate concentration. The concentration of nickel in the column effluent initially exceeded the column influent, then decreased to equilibrate with the influent concentration, which was nickel's minimum detectable limit. Copper and zinc removal within the clay column, based on mass balance data in Table 24, was respectively 56 and 50 percent. A balance on nickel was not calculated because it was not detected in the influent and most of the effluent samples.

Plots of aluminum and barium concentration in the kaolinite column effluent are illustrated in Figure 27. All samples analyzed for barium had concentrations less than the initial leachate concentration. Aluminum concentrations were less than the influent in the early eluate volumes, then gradually increased to become equal with the influent concentration. The data from Table 24 indicates that aluminum and barium were reduced in the kaolinite column by 30 and 29 percent, respectively.

For calcium, manganese, iron, and mercury, the mass balance data in Table 24 indicate that 19 percent of the calcium, 80 percent of the manganese, nearly 100 percent of the iron, and 80 percent of the mercury was removed in the kaolinite clay column. Sulfate had a 24 percent increase in mass from influent to effluent.

In Table 24, the data also indicates that 3.20 chemical meq were removed in the kaolinite column, while 2.01 meq were added to the column effluent. As a result, a net of 1.19 chemical meq were attenuated from the initial leachate influent by the kaolinite clay column.

DISCUSSION OF LEACHATE ATTENUATION STUDY

The attenuation processes that occur in soils are a potential major influence precluding groundwater contamination by leachate from coal ash disposal areas. In an attempt to determine the extent of ash leachate attenuation by various soils, the laboratory investigations reported on above were conducted. Other investigators have used this technique to determine the attenuation of various aqueous wastes by different soils, clays, and other porous material.[26,27,28]

For example, in a study by Griffin, et al,[26] the attenuation of pollutants in municipal landfill leachate by the clay minerals montmorillonite, kaolinite, and illite was investigated. Their study determined the following clay mineral hierarchy for attenuation capabilities, montmorillonite > illite > kaolinite, and that the principal attenuation mechanism for lead, cadmium, mercury, and zinc was precipitation in the soil columns surface layers. In a study by Fetter[27] to determine attenuation of secondarily treated wastewater by a calcareous glacial outwash soil, the findings suggested that heavy metals removal was through ion exchange. Still other investigators, such as Leeper,[28] consider the adsorption reactions with hydrous oxides of iron, aluminum,

and manganese to be the major mechanism for the attenuation of metals in soil. As one can see from this small, but representative sampling, the literature is inconclusive as to which mechanism is the major factor influencing attenuation by soils. Indeed, no one mechanism is universally responsible for the attenuation processes that occur in soils receiving liquid wastes or leachate. In fact, the mechanisms may vary for each situation depending on the characteristics of the soil, the characteristics of the liquid waste or leachate, and the hydrological conditions.

The major mechanism influencing attenuation of ash leachate in this study is not readily discernable from the previously discussed data. It may be concluded with a certain degree of confidence, however, that ion exchange is not solely responsible for the removal of constituents from the ash leachate, for the following reason.

The two natural soils from plants L and J, and the kaolinite clay used in the column tests had cation exchange capacities, respectively, of 20.0, 17.0, and 16.0 meq per 100 g (the cation exchange capacity of the silica was negligible at 1.2 meq/100 g). Five grams each of the soils and clay material was used in each column, which yielded a total exchange capacity for the columns of 1.0 meq plant L material, 0.85 meq plant J material, and 0.80 meq for the kaolinite column. The number of meq's attenuated by these same respective columns was 1.26, 4.13, and 1.19 meq. Each column has thus exceeded its available exchange capacity; consequently, ion exchange is not the only mechanism accounting for attenuation in this study. Actually, ion exchange may be only a minor influence, and precipitation and/or adsorption may be the major influencing mechanisms affecting attenuation, but the data do not differentiate between these two mechanisms.

A comparison of the mass balance data in Tables 22, 23, and 24 shows that magnesium and sodium had a net increase in mass between the column influent and effluent for all three attenuation experiments. This indicates that these two elements were solubilized by the ash leachate as it passed through the soil columns. Of the three materials used in this study, the kaolinite clay released the most magnesium and sodium. Potassium was also released from the kaolinite, while the two natural soils, from plants J and L, attenuated potassium.

Copper and zinc were both retained in all three attenuation columns, copper more so than zinc. Copper was attenuated the least by the kaolinite clay. The two natural soils attenuated greater than 90 percent of the copper. Barium was attenuated in all three columns, but the kaolinite clay retained the least. Aluminum was attenuated in the kaolinite column and by the soil from plant L. Aluminum solubilized in plant J's column. Calcium, manganese, and iron were all attenuated in the three columns. Iron had the largest attenuation of the constituents analyzed with essentially 100 percent removal in each column; manganese followed with 75 percent plus attenuation.

In general, soils that are composed of high percentages of clay minerals will, by one mechanism or another, tend to attenuate solutes more so than will materials containing high percentages of sand.

SECTION 9

THEORETICAL CONSIDERATIONS

Using information reported in the literature to date regarding coal-ash leachate and the attenuation of leachates in general, the results of this study, and some fundamental knowledge of the hydrogeochemical environment, a schematic diagram of ash pond leachate generation and attenuation was prepared (see Figure 28). This diagram illustrates some of the basic concepts associated with solid waste disposal in general and presents some details relating to coal-ash disposal in particular. The diagram does not necessarily indicate conditions and mechanisms associated with all ash disposal sites, but is designed to relate some of the physical and chemical processes that may be pertinent to an environmental evaluation of groundwater degradation at coal-ash disposal areas.

In this illustration, fly ash, bottom ash, and pyrites are sluiced to the ash pond, along with other miscellaneous plant discharges, such as acidic coal-pile drainage. Once in the disposal pond, the ash and other heavy particles settle out, with the supernatant overflowing into an adjacent surface water. Supernatant that does not leave the pond via the surface overflow infiltrates into the settled ash, carrying with it any solutes picked up during sluicing of the ash from the plant and mixing with other wastes discharged to the pond. After infiltration, the pond supernatant percolates down through the saturated aerobic zone where readily soluble ions of calcium, magnesium, sodium, and sulfate are added to solution. Some slight dissolution of certain metals may occur, and sulfite, if not already in solution, solubilizes.

Further downward percolation leads to the anoxic zone, which is created by the depletion of dissolved oxygen by sulfite or other oxidation processes. It is in the anoxic zone, which occurs either below the water table or deep enough to prevent surface aeration, where the percolating water acquires the culmination characteristics of coal-ash leachate. The anoxic zone is a reducing acidic environment in which dissolution of metals can occur, sulfides are formed, and high concentrations of ferrous iron may occur. It is also in this zone where the hydraulic gradient of the groundwater begins to exert its energy potential on the leachate, altering the direction component of its velocity from strictly downward to lateral.

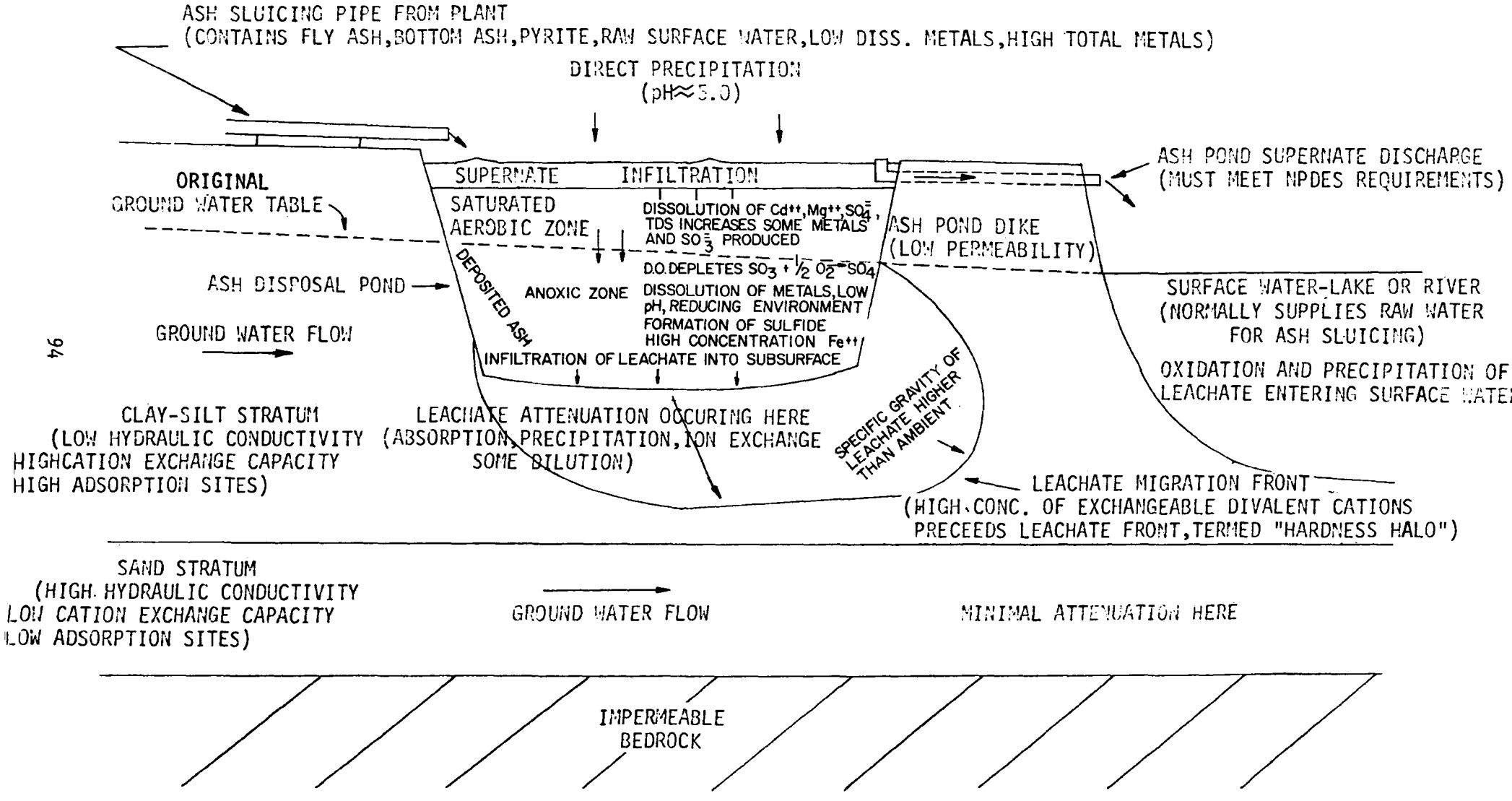


FIGURE 28. SCHEMATIC OF COAL-ASH
LEACHATE GENERATION AND ATTENUATION

Eventually the leachate begins to infiltrate the bottom of the ash disposal area. This may occur at a relatively high rate if the pond bottom is of a highly permeable material, such as sand, or at a lower rate if the material is a low permeable clay-silt, such as illustrated in Figure 28. In the clay-silt stratum attenuation of solutes in the leachate will begin to occur. Attenuation mechanisms, such as ion exchange, chemical precipitation, and physical adsorption, will act to lessen the leachate migration. As the leachate plume advances through the subsurface environment, metal ions with an affinity for adsorption and exchange sites will replace weakly-bound divalent cations, such as calcium and magnesium. These displaced divalent cations will move along preceding the leachate plume and create what has been termed a "hardness halo." Conservative constituents, such as chloride and sulfate, may even precede this hardness halo. The rate of leachate migration will depend on the hydraulic conductivity and the rate of attenuation.

If the leachate plume should reach a highly permeable stratum such as the sand stratum depicted in Figure 28, then the potential for increased groundwater degradation can occur. A sand stratum or aquifer offers little in the way of attenuation capacity and much as an avenue for leachate migration. Hydraulic conductivities of sandy material are normally greater than those of clay, and the number of adsorption and exchange sites are fewer, which will tend to decrease the rate of attenuation.

Leachate studies thus far suggest that coal-ash disposal sites, and perhaps solid waste disposal sites in general, might be constructed in such a manner as to allow leachate to percolate downward through an attenuation blanket. The attenuation blanket would need to be of design and material that would allow optimum flow and attenuation, thus acting as a treatment system.

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APPENDIX A

ANALYTICAL METHODS

APPENDIX A

ANALYTICAL METHODS

The elements, aluminum, barium, beryllium, calcium, cadmium, chromium, copper, iron, magnesium, manganese, nickel, and lead in the interstitial water, soil column effluents and groundwater well samples, were measured by direct atomic absorption spectrophotometry using techniques described in Standard Methods[29] and by EPA.[30] Mercury was determined by the cold vapor technique recommended by EPA. Arsenic and selenium were measured using the gaseous hydride method, also recommended by EPA.

Sulfate was measured using the turbidimetric method, and pH values were obtained in the field using the glass electrode. Conductivity and alkalinity were also measured in the field using established procedures.[29,30]

Soil core samples were analyzed for aluminum, barium, beryllium, calcium, cadmium, chromium, copper, iron, magnesium, manganese, nickel, and lead by first undergoing a wet acid digestion followed by direct measurement with atomic adsorption spectrophotometry.[30] Mercury was measured in the soil core samples using EPA's recommended methods.[30] Arsenic and selenium were set digested and then determined by the gaseous hydride method previously mentioned.

Standard powder X-ray diffraction techniques were used to determine the relative amounts of quartz, kaolinite, montmorillinite, and illite present in the soils.

Oxidation-reduction potentials were determined with a silver-silver chloride electrode.

Vertical and horizontal permeabilities of soil samples were determined by encasing soil specimens 3.5 cm in diameter and approximately 7.6 cm long in a rubber membrane and placing in a triaxial chamber. Back pressure to 70,310 kgs/m^2 (100 psi) was applied to assure specimen saturation. The average coefficient of permeability was then determined under a constant head test method by measuring the quantity of water flowing through the specimen in a given time.

The moisture content of soil samples was determined as per ASTM procedure D-2216. Bulk densities were determined by weighing a soil specimen 15 cm long and 8.9 cm in diameter, then coating the specimen with paraffin and submerging in water to determine its volume. The moisture content of the specimen was then determined and the bulk density calculated using the specimen's weight, volume, and moisture content.

Grain size classifications were determined by sieve separation of large particles followed by the hydrometer technique for the silt and clay fraction.

Dissolved oxygen concentrations in groundwater samples were determined *in situ* by lowering a membrane electrode into the monitoring wells. The membrane electrode was also used on groundwater samples brought to the surface for dissolved oxygen determinations.

DETERMINATION OF CATION EXCHANGE CAPACITY*

Reagents

Triethanolamine solution: Triethanolamine (commercial) 90 ml diluted to 1:1, and pH adjusted to 8.1 by adding 2N-hydrochloric acid (140-150 ml). This solution is diluted to 2:1. Protect from carbon dioxide during storage.

Barium chloride solution: $BaCl_2$, $2H_2O$ 244 g per 1 (approximately 2N).

Buffered barium chloride reagent: Mix equal volumes of the above solutions.

Magnesium sulphate solution: $MgSO_4$, $7H_2O$ 6.2 g per 1 (approximately 0.05N).

EDTA solution: Sequestric acid disodium salt 3.723 g per 1 (0.02N).

Catechol Violet indicator: 0.1 g dissolved in 100 ml of water.

Method

Transfer 5 g of soil (<2 mm air-dry, of known moisture content) to a tightly stoppered polythene centrifuge bottle. Note the weight of bottle plus soil (W_1). Treat calcareous soils with approximately 100 ml of the buffered barium chloride reagent, preferably with gentle shaking for 1 hr. Centrifuge at 1500 rpm (RCF) 415) for 15 min. and discard the supernatant liquid. For noncalcarous soils this first washing can be omitted. Treat with a further 200 ml of reagent overnight, centrifuge and again discard the supernatant liquid. Add approximately 200 ml of distilled water and shake for a few minutes to break up the soil cake. Centrifuge and discard the supernatant liquid. Weigh the bottle with contents (W_1). Pipette into the bottle 100 ml of magnesium sulphate solution and shake the stoppered bottle occasionally over a period of 2 hr. Centrifuge and transfer the clear liquid immediately to a stoppered flask.

To a 5-ml aliquot of the solution add 6 drops of 2N-aq. ammonia and titrate with standard EDTA solution using 2 drops of Catechol Violet indicator. The end-point is indicated by a color change from clear blue to reddish purple (Titre A_1 ml). This titre must be corrected for the effect of the volume (not chloride content) of liquid retained by the centrifuged soil after the wash water:

Corrected titre $(A_2) = A_1(100 + W_2\ W_1)/100$ ml

Aliquots of 5 ml of the original magnesium sulphate solution are also titrated under similar conditions (Titre B).

CEC of the soil = $8(B - A_2)$ meq/100 g

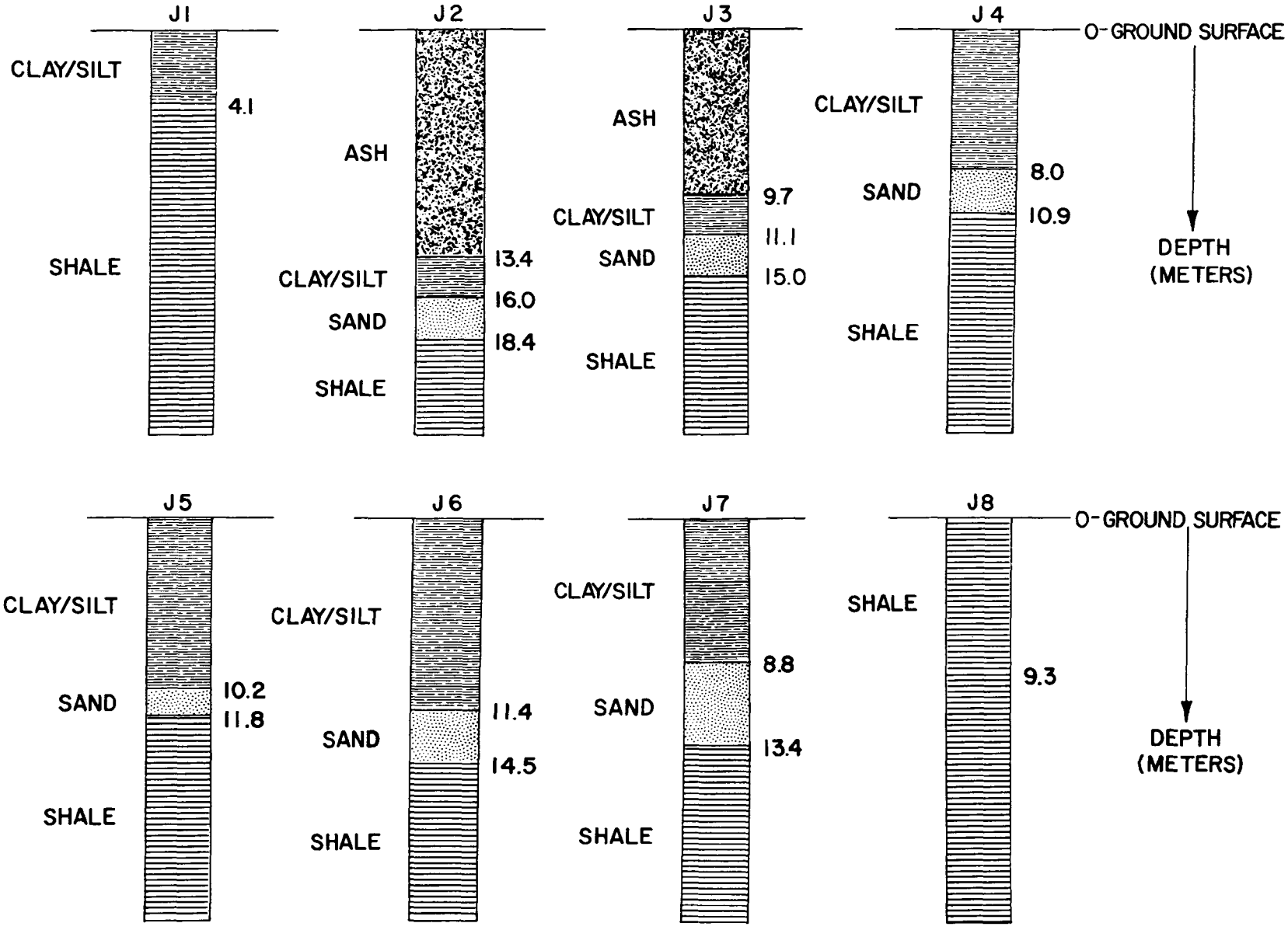
---

*Bascomb, C. L. "Rapid Method for the Determination of Cation-Exchange Capacity of Calcareous and Noncalcareous soils." J. of Sci. Food and Agric., 15, 1964. pp. 821-823.

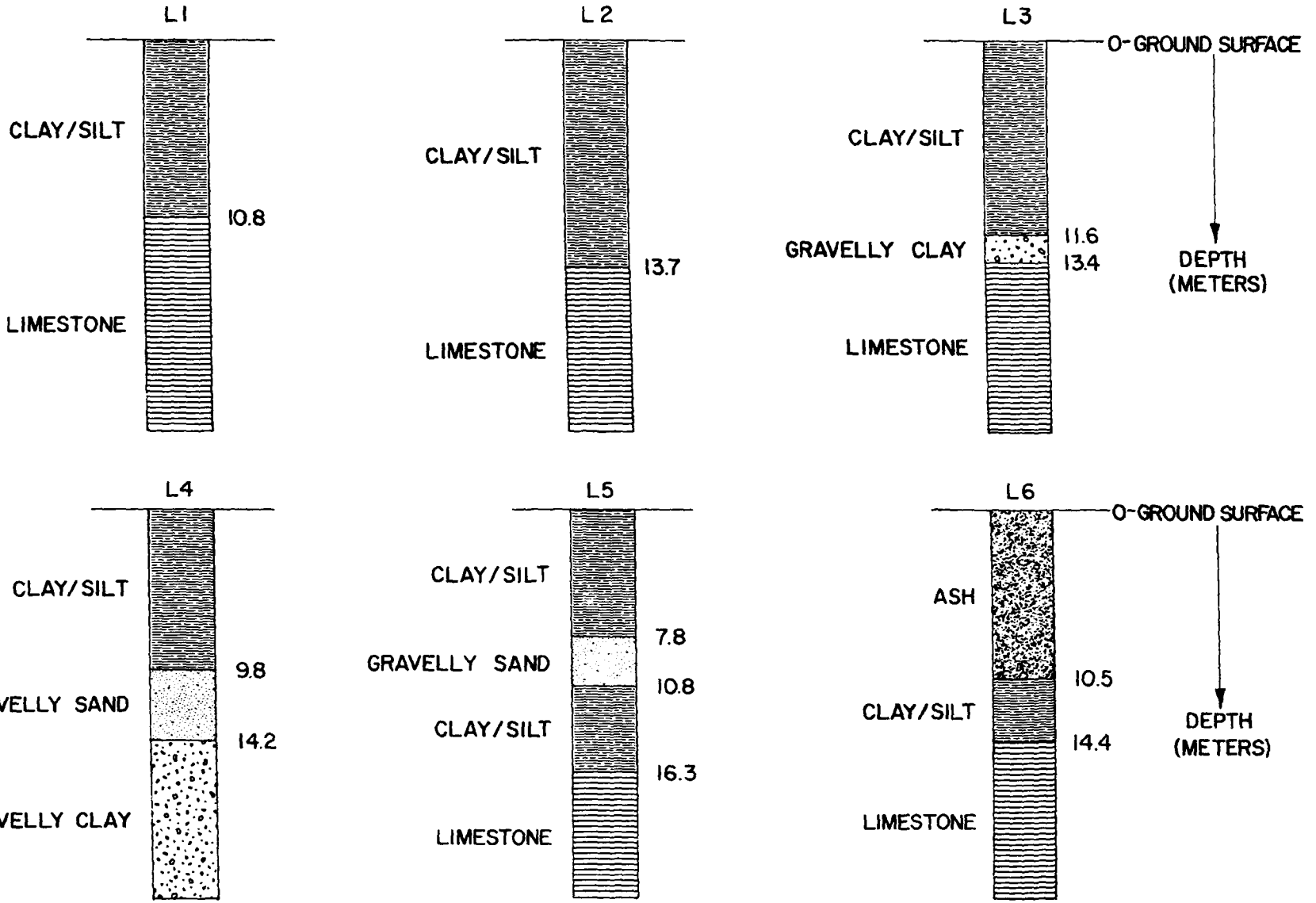
APPENDIX B

VERTICAL PROFILES OF SUBSTRATUM AT PLANTS J AND L

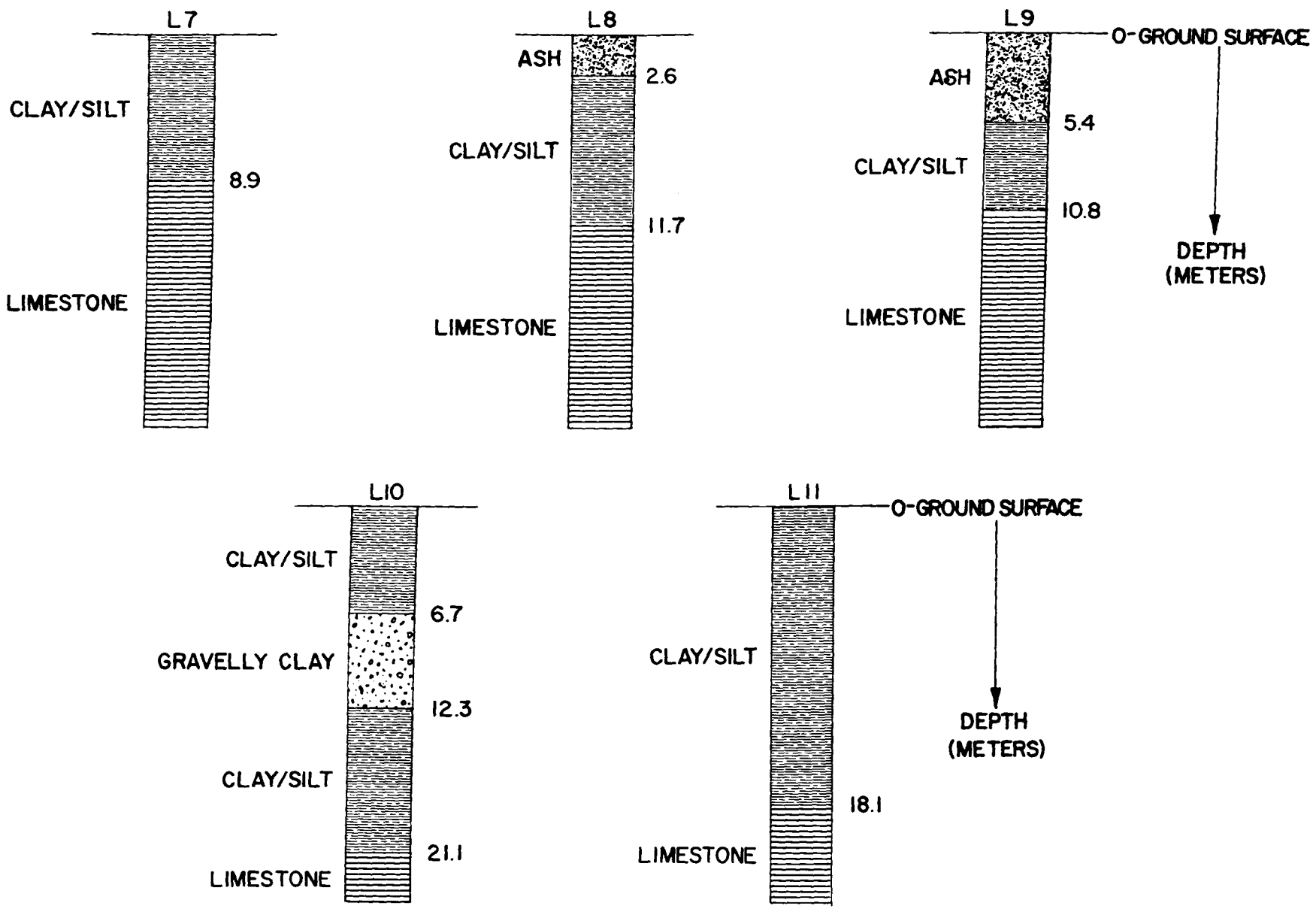
VERTICAL PROFILE OF THE SUBSTRATUM AT PLANT J's MONITORING WELL LOCATIONS



VERTICAL PROFILE OF THE SUBSTRATUM AT PLANT L's MONITORING WELL LOCATIONS



VERTICAL PROFILE OF THE SUBSTRATUM AT PLANT L's MONITORING WELL LOCATIONS



APPENDIX C

ANALYTICAL RESULTS OF COLUMN ATTENUTATION STUDIES

TABLE C-1. ANALYSIS OF COAL ASH LEACHATE USED IN SOIL ATTENUATION STUDY

Constituent	Value	Constituent	Value
pH, std. units	7.8	Lead, mg/l	<0.010
Eh, millivolts	-280	Beryllium, mg/l	<0.002
Temperature, °C	17	Barium, mg/l	0.23
Conductivity, μmhos/cm^2	1800	Manganese, mg/l	4.2
Alkalinity, mg/l as $CaCO_3$	340	Sodium, mg/l	7.2
Calcium, mg/l	185	Potassium, mg/l	14
Magnesium, mg/l	7.6	Selenium, mg/l	<0.002
Iron, mg/l	15	Total dissolved solids, mg/l	720
Copper, mg/l	0.14	Sulfide, mg/l	0.07
Zinc, mg/l	0.04	Sulfate, mg/l	240
Nickel, mg/l	<0.05	Nitrite and Nitrate as nitrogen, mg/l	0.02
Aluminum, mg/l	0.06	Phosphate as Phosphorus, mg/l	0.08
Cadmium, mg/l	<0.01		
Mercury, mg/l	0.002		
Chromium, mg/l	<0.05		

TABLE C-2. ANALYTICAL RESULTS OF COLUMN ATTENUATION STUDIES

	Analysis of effluent from soil column--Plant L						
Composite volume, ml	180	150	180	150	150	180	120
Total volume eluted, ml	180	330	510	660	810	990	1110
Calcium, mg/L	120	180	190	180	180	180	170
Magnesium, mg/L	9.0	9.0	9.3	9.4	9.6	9.6	9.2
Sodium, mg/L	8.6	7.9	8.2	8.1	8.6	8.2	7.9
Potassium, mg/L	6.3	13	14	15	15	14	14
Iron, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Manganese, mg/L	0.48	0.06	0.26	0.44	0.650	0.83	0.86
Copper, mg/L	0.02	0.008	0.007	0.007	<0.005	<0.005	0.007
Zinc, mg/L	<0.05	<0.01	0.19	<0.01	<0.01	0.14	<0.01
Nickel, mg/L	0.18	0.05	0.05	0.09	<0.05	<0.05	0.07
Sulfate, mg/L	300	300	300	240	310	280	270
Cadmium, mg/L	0.009	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lead, mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chromium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Aluminum, mg/L	0.09	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Barium, mg/L	0.1	0.08	0.07	0.08	0.1	0.12	0.13
Beryllium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Mercury, mg/L	0.03	0.0005	0.0003	0.0002	0.0003	0.0003	0.0002
Selenium, mg/L	<0.004	<0.002	<0.002	<0.004	<0.002	<0.002	<0.01

TABLE C-2 (continued)

	Analysis of effluent from soil column--Plant J					
Composite volume, ml	300	270	300	270	300	270
Total volume eluted, ml	300	570	870	1140	1440	1710
Calcium, mg/L	160	160	160	160	160	150
Magnesium, mg/L	10	9.4	9.5	9.5	9.7	9.2
Sodium, mg/L	8.9	8.0	8.0	8.2	8.4	8.2
Potassium, mg/L	10	12	12	13	13	12
Iron, mg/L	0.12	0.068	0.063	0.053	0.039	0.03
Manganese, mg/L	0.5	0.49	0.77	1.1	1.1	0.94
Copper, mg/L	0.02	0.006	0.02	0.006	0.007	0.022
Zinc, mg/L	0.16	0.03	0.02	0.03	0.02	0.02
Nickel, mg/L	1.1	<0.05	<0.05	<0.05	<0.05	<0.05
Sulfate, mg/L	*	*	*	*	*	*
Cadmium, mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead, mg/L	0.032	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Aluminum, mg/L	0.1	0.05	0.04	0.05	<0.02	0.17
Barium, mg/L	0.12	0.13	0.1	0.16	0.17	0.16
Beryllium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Mercury	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Selenium, mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

TABLE C-2 (continued)

Analysis of effluent from kaolinite clay column

Composite volume, ml	180	180	180	180	180	180	120
Total volume eluted, ml	180	360	540	720	900	1080	1200
Calcium, mg/L	130	150	150	160	160	170	120
Magnesium, mg/L	9.0	9.9	9.9	9.5	9.2	10	7.2
Sodium, mg/L	9.6	8.5	8.5	8.3	7.8	8.8	7.0
Potassium, mg/L	14	16	16	15	15	16	14
Iron, mg/L	0.046	0.013	0.013	0.022	0.099	0.063	0.014
Manganese, mg/L	0.75	0.22	0.25	0.96	1.1	1.3	0.92
Copper, mg/L	0.045	0.056	0.046	0.039	0.081	0.04	0.16
Zinc, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12
Nickel, mg/L	0.96	0.18	0.07	0.07	0.05	0.05	<0.05
Sulfate, mg/L	*	*	*	*	*	*	*
Cadmium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lead, mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chromium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Aluminum, mg/L	0.04	<0.02	<0.02	0.03	0.07	0.06	0.06
Barium, mg/L	0.13	0.15	0.16	0.19	0.17	0.2	0.14
Beryllium, mg/L	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mercury, mg/L	<0.0002	<0.0002	<0.0002	<0.0002	0.0003	0.0003	0.0003
Selenium, mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.01

*Not enough sample for analysis.

APPENDIX D

USED IN COLUMN ATTENUATION STUDIES

TABLE D-1. CHEMICAL CHARACTERISTICS OF CLAY MINERALS USED IN COLUMN ATTENUATION STUDIES

Illite

Constituent	Value	Constituent	Value
Chlorine, mg/l	460.0	Zinc, µg/g	17
Sulfate, mg/l	480.0	Nickel, µg/g	26
Bromine	1.2	Cadmium, µg/g	<1.0
Calcium, µg/g	4000	Lead, µg/g	12.0
Magnesium, µg/g	2500	Chromium, µg/g	<5.0
Sodium, µg/g	300	Aluminum, µg/g	7700
Potassium, µg/g	5300	Barium, µg/g	830
Iron, µg/g	6100	Beryllium, µg/g	5.0
Total Manganese, µg/g	65	Mercury, µg/g	0.27
Copper, µg/g	52	Arsenic, µg/g	1.2
		Selenium, µg/g	<1.0

Kaolinite

Constituent	Value	Constituent	Value
Chlorine, mg/l	30.0	Zinc, µg/g	52
Sulfate, mg/l	120.0	Nickel, µg/g	21
Bromine	<0.2	Cadmium, µg/g	<1.0
Calcium, µg/g	120	Lead, µg/g	10.0
Magnesium, µg/g	110	Chromium, µg/g	<5.0
Sodium, µg/g	60	Aluminum, µg/g	840
Potassium, µg/g	70	Barium, µg/g	61
Iron, µg/g	1400	Beryllium, µg/g	3.0
Total Manganese, µg/g	830	Mercury, µg/g	0.60
Copper, µg/g	15	Arsenic, µg/g	10.0
		Selenium, µg/g	<1.0

Montmorillonite

Constituent	Value	Constituent	Value
Chlorine, mg/l	26.0	Zinc, µg/g	70
Sulfate, mg/l	1800.0	Nickel, µg/g	<5.0
Bromine	<0.2	Cadmium, µg/g	<1.0
Calcium, µg/g	770	Lead, µg/g	48.0
Magnesium, µg/g	3400	Chromium, µg/g	<5.0
Sodium, µg/g	1100	Aluminum, µg/g	2900
Potassium, µg/g	200	Barium, µg/g	13
Iron, µg/g	1700	Beryllium, µg/g	2.0
Total Manganese, µg/g	22	Mercury, µg/g	0.17
Copper, µg/g	3	Arsenic, µg/g	2.3
		Selenium, µg/g	<1.0

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16. ABSTRACT The report gives results of research to: (1) develop methodology for the field-collection of coal-ash leachate; (2) chemically characterize ash leachates from power plants using different coal sources; (3) determine the characteristics of the hydrogeochemical environment in which the leachate occurs; and (4) determine the attenuation of coal-ash leachate by various soil types. Groundwater monitoring wells were installed around ash ponds at two TVA plants. Continuous soil-core samples were collected and analyzed periodically. Ash leachate was percolated through different clays and soils to study attenuation rates. Results include indications that: (1) coal-ash leachate is highly variable, but characteristically high in dissolved solids, B, Fe, Ca, Al, and SO4; ash leachate is acidic, with measured pH as low as 2; (2) the coal sources associated with the study produced ash leachate with similar characteristics; (3) an inert-gas lift pump was effective in collecting anoxic groundwater samples while minimizing oxidation; (4) differences were found in the characteristics of leachate samples obtained by extracting the interstitial soil water and samples collected from the monitoring wells; interstitial water samples contained higher concentrations of metals and were more acidic than well samples; and (5) the flux of metals in the ash pond leachate was negligible compared to ash pond surface overflow.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Leaching	Stationary Sources	07D,07A
Water Quality	Coal Ash	
Ground Water		08H
Coal		21D
Ashes		21B

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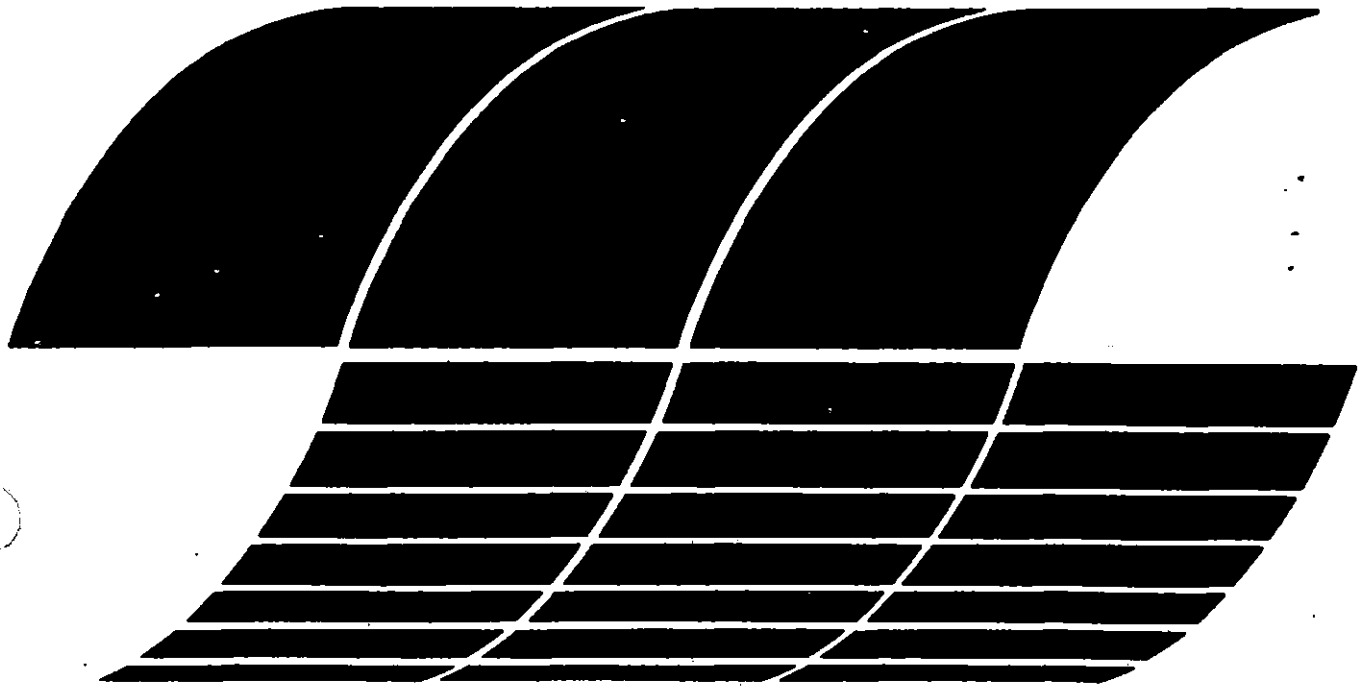
EPA-600/7-80-067
March 1980

Behavior of Coal Ash Particles in Water: Trace Metal Leaching and Ash Settling

Interagency Energy/Environment R&D Program Report



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EPA-600/7-80-067

March 1980

Behavior of Coal Ash Particles in Water: Trace Metal Leaching and Ash Settling

by

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ABSTRACT

At a TVA 1000-MW coal-fired power plant, approximately 700 tons (635,040 kg) of ash residues (fly and bottom ashes) produced by burning coal must be disposed of daily. The chief determinants of amount of ash produced are the type of coal burned, ash content of the coal, and method of firing (type of boiler). Dry or wet handling and disposal are employed, depending on the availability of water, proximity of the disposal site, environmental regulations, and cost. The existing prevalent method for ash disposal is by wet sluicing to ash ponds near the power plants. The average size of TVA ash ponds is about 180 acres--17 percent of the total area of the plant sites. This report addresses six major areas of concern in wet ash disposal, namely the (1) characteristics of ashes and ash pond effluents, (2) effects of ash and raw water characteristics on the pH of ash pond water, (3) methods for pH adjustment of ash pond effluents, (4) settling characteristics of both fly ash and bottom ash, (5) leaching of minerals from ashes, and (6) relationship of trace metals to pH and concentration of suspended solids in ash pond effluents.

The chemical characteristics of ash pond effluents are affected by the ash material and the quantity and quality of water for slucing. TVA ash pond effluents vary from a pH of 3 to 12. The acidity and alkalinity depend on the content of sulfur oxides and alkaline metal oxides in the ash and on the buffering capacity of water used for sluicing. Methods for adjusting the pH of ash pond effluents may include (1) controlling the ash-to-water ratio for ash sluicing, (2) combining effluents with other wastewaters within power plants, or (3) adding chemicals. Because of high ash concentration during sluicing, 90 percent of fly ash particles follow hindered-zone settling behavior and settle faster than those remaining ash particles, which follow discrete settling behavior. Mathematical equations were developed to delineate the ash settling behavior and to estimate the residual suspended solids concentration in the effluent of a sedimentation basin or settling pond.

Mathematical analyses indicated the leaching of trace metals from ash depends on the concentration of each trace metal in the ash matrix, its chemical bonding in the ash, and particle size of ash. Laboratory results showed that pH also influenced the leaching concentrations of trace metals. A delineation of potential trace metal pollution resulting from ash disposal under various ash-to-water contacting ratios was provided by laboratory studies. Trace metals in 14 ash pond effluents were monitored quarterly. Several trace metals were found to occur in potentially toxic quantities and some trace metals were present in both dissolved and suspended forms. Adjustment of effluent pH between 6 and 9 and reduction of suspended solids concentrations to 30 mg/l reduced the total concentrations of many trace metals such as chromium, copper, lead, and zinc. However, these measures did not appreciably reduce the total concentrations of arsenic, boron, cadmium, iron, manganese, and selenium. Iron was found mostly in suspended form.

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SECTION 1

INTRODUCTION

Coal ashes resulting from burning coal in steam electric utility boilers consist of fly ash, bottom ash, and slag. Fly ash is a powdery residue that is normally collected from the stack gas by mechanical collectors and/or electrostatic precipitators. Bottom ash, which is darker than fly ash, is collected in the bottom of the furnace section. Slag is molten bottom ash, which turns black when quenched with water in the wet-bottom boiler combustion process.

The major factors affecting the amount of ash materials collected are the type of fossil-fuel used, ash content of the fuel, and methods of firing.[1-3] In general, 700 tons (635,040 kg) of ashes can be produced daily at a Tennessee Valley Authority (TVA) 1000-megawatt (MW) power plant burning coal from the Appalachian and midwestern regions. These ashes must be disposed of daily. In 1975, about 60 million tons (5.4×10^{10} kg) of ashes were generated by U.S. electric utilities; only about 16.3 percent of the total amounts of ash produced were used.[4] The current national emphasis on using coal to produce energy, coupled with the expanded use of lignite and western coal, has caused the continuing rise in ash production. Therefore, the problems associated with the disposal of coal ashes will continue.

In October 1974, the U.S. Environmental Protection Agency (EPA) established effluent guidelines to limit the discharge of pollutants from existing and new point sources within the steam-electric power generating category (Table 1). The limits set for oil and grease, polychlorinated biphenyls, pH, and suspended solids for wet and dry ash disposal are shown in Table 1. In June 1976, EPA launched a massive program aimed at controlling 129 priority pollutants discharged by 21 major industrial categories, including the steam-electric power generating industry. The proposed regulations will be published in 1980. In addition to the Federal effluent guidelines, each state may also have its own water quality and effluent standards for discharges into public waters. The various states may establish discharge limitations more stringent than those established by the EPA under the National Pollution Discharge Elimination System (NPDES) permit issuing program.

Ash disposal siting and operation are major items of consideration during licensing procedures for new coal-fired power plants. At existing plants, many utilities are being directed either to adopt corrective procedures to relieve adverse public opinion, or to simply meet the stricter regulations adopted or proposed by Federal and State agencies. Nevertheless, economic consideration, in addition to the environmental

TABLE 1. CHEMICAL EFFLUENT GUIDELINES AND STANDARDS, STEAM-ELECTRIC POWER GENERATING PLANTS[a]

	BPCTCA July 1, 1977		BATEA July 1, 1983		New Source Standards	
All discharges						
pH (except once-through cooling)	6.0-9.0		6.0-9.0		6.0-9.0	
Polychlorinated biphenyls	0		0		0	
	Average daily	Daily maximum	Average daily	Daily maximum	Average daily	Daily maximum
Bottom ash transport water						
Total suspended solids	30	100	30 ÷ 12.5	100 ÷ 12.5	30 ÷ 20	100 ÷ 20
Oil and grease	15	20	15 ÷ 12.5	20 ÷ 12.5	15 ÷ 20	20 ÷ 20
Fly ash transport water						
Total suspended solids	30	100	30	100	0[c]	0[c]
Oil and grease	15	20	15	20	0[c]	0[c]
Low-volume sources						
Total suspended solids	30	100	30	100	30	100
Oil and grease	15	20	15	20	15	20
Metal cleaning wastes and boiler blowdown						
Total suspended solids	30	100	30	100	30	100
Oil and grease	15	20	15	20	15	20
Total iron	1.0	1.0	1.0	1.0	1.0	1.0
Total copper	1.0	1.0	1.0	1.0	1.0	1.0
Cooling tower blowdown						
Zinc	-	-	1.0	1.0	None detectable	None detectable
Chromium	-	-	0.2	0.2	None detectable	None detectable
Phosphorus	-	-	5.0	5.0	None detectable	None detectable
Other corrosion inhibitors	-	-	Case-by-case	Case-by-case	None detectable	None detectable
Free available chlorine[b]	0.2	0.5	0.2	0.5	0.2	0.5
Once-through cooling						
Free available chlorine[b]	0.2	0.5	0.2	0.5	0.2	0.5
Material storage and construction runoff						
Total suspended solids[c]	50		50		50	

[a]All units are in milligrams per liter. Allowable discharge is the quantity obtained by multiplying flow by standard in milligrams per liter.

[b]Neither free available chlorine nor total residual chlorine may be discharged from any unit for more than 2 h in any one day, and not more than one unit in any plant may discharge free available chlorine or total residual chlorine at any one time unless the utility can demonstrate that the units in a particular location cannot operate at or below this level of chlorination.

[c]Limitations were remanded by the Fourth Circuit Court of Appeals in July 1976.

Source: U.S. Environmental Protection Agency. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam-Electric Power Generating Point Source Category. EPA-440/1-74-029-a, October 1974. 840 p.

considerations, is still an important factor for ash disposal. Thus, the selection of ash ponds or landfill for ash disposal is site-specific, depending on the comparison and evaluation of the environmental and engineering-economic factors. Environmental factors include air quality, aesthetics, aquatic ecology and water quality, land use, noise, public health and safety, socioeconomic, and terrestrial ecology. Engineering and economic factors include hydrology, site development, transportation and access, geology, treatment equipment, land availability, and cost. For instance, dry disposal of fly ash could be more desirable than wet disposal for some new coal-fired power plants, particularly in arid regions; whereas wet ash could be more economical than dry ash disposal for plants located in regions with an abundant supply of water.

The prevalent method for ash disposal at existing plants is wet sluicing of ash to settling ponds near the power plants. The ash pond is usually designed for ultimate disposal of total ash produced during a specified time period. Typical water requirements for sluicing coal ashes generally range from 1200 to 40,000 gal of water per ton of fly ash (5 to 167 liters per kg) and from 2400 to 40,000 gal of water per ton of bottom ash (10 to 167 liters per kg).[5] For TVA's 12 coal-fired power plants, ash sluicing water requirements average about 11.5×10^6 gpd (43.5×10^6 liters per day) per 1000 MW capacity.[7] In the United States, about 40 percent of the water requirements for ash sluicing at coal-fired power plants are greater than 10×10^6 gpd (37.9 liters per day) per 1000 MW capacity.

The most significant potential problems associated with ash disposal in ponds are (1) acidic or alkaline character of ash pond water and quantities of suspended solids and trace metals in surface water effluents and (2) quantities of trace metals in groundwater leachates. To meet the "best available control technology economically achievable" (BATEA) effluent guidelines, existing coal-fired power plants using ash ponds generally have to either (1) separate the fly ash and bottom ash disposal ponds and recycle or provide a higher degree of treatment for removing suspended solids from bottom ash pond effluents or (2) achieve for combined ash pond effluents a suspended solids concentration equal to a weighted average of the limits for fly ash and bottom ash transport water. New coal-fired power plants using ash ponds would have to (1) recycle or provide a higher degree of treatment for removing suspended solids from bottom ash pond effluents and (2) completely recycle fly ash pond effluent. In all cases, the pH must be maintained between 6 and 9 for any surface water discharges.

It is important to determine how adjustments in pH and reduction of suspended solids concentrations affect trace metal concentrations in ash pond discharges.

The scope of this study involved field survey of ash ponds at 12 TVA coal-fired power plants and bench-scale tests on TVA ash pond discharges. This report addresses six major areas of concern in wet ash

disposal, namely, the (1) characteristics of ashes and ash pond effluents, (2) effects of ash and raw water characteristics on the pH of ash pond water, (3) methods for pH adjustment of ash pond effluents, (4) settling characteristics of both fly ash and bottom ash, (5) leaching of minerals from ashes, and (6) relationship of trace metals to pH and concentration of suspended solids in ash pond effluents.

This report is complementary to two other studies: "Design of a Monitoring Program for Ash Pond Effluents" and "The Effects of Coal-Ash Leachates on Ground Water Quality," which are part of a project entitled "Characterization of Effluents from Coal-Fired Utility Boilers" supported under EPA interagency energy-environment research and development program.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Eight specific conclusions can be drawn from this study:

1. At a TVA 1000 MW coal-fired power plant, approximately 700 tons (635,040 kg) of ash residues (fly ashes and bottom ashes) produced by the burning of coal must be disposed of daily. Nationally, the increased use of coal for power generation will result in increased ash production, land requirements for ash disposal, and potential for contamination of water supplies.

2. The options for ash disposal that are generally available are ponding and landfill. The selection of ash disposal methods is site-specific, depending on the evaluation and comparison of the environmental, engineering, and economic factors. The environmental factors include air quality, aesthetics, aquatic ecology and water quality, land use, noise, public health and safety, socioeconomics, and terrestrial ecology. The engineering and economic factors include hydrology, site development, transportation and access, geology, treatment equipment, land availability, and cost. The existing prevalent method for ash disposal is by wet sluicing to ash ponds near the power plants The average size of TVA ash ponds is about 180 acres (728,460 square miles), which is about 17 percent of the total area of the plant sites.

3. The principal environmental problems in ash disposal are acidic or alkaline character of the ash pile runoff and ash pond effluent, quantities of suspended solids in the runoff and effluent, and quantities of trace metals in leachate, runoff, and effluent from the disposal sites.

4. The pH of the ash transport water depends on either the buffering capacity of makeup water and the ratio of alkaline metal oxides to sulfur oxides in the ashes or the ratio of total dissolved alkaline metal ions to sulfate ion in the transport water. The equilibrium pH value of water, after being in contact with fly ash, was acidic if the mole ratio of CaO plus MgO to sulfur oxides as SO_3 in ash was less than 5; if the ratio is above 5, the ash transport water ranged from neutral to alkaline. The pH of the ash pond effluent increased with the increase of concentration ratio of dissolved calcium to sulfate in the effluent. The ash pond effluent was neutral (pH 7) if the concentration ratio of dissolved calcium to sulfate (in milligrams per liter) was close to 0.4. Also, it is interesting to relate the factors that affect the pH

of ash transport water to coal sources, and types of boilers. For the TVA power plants with circular, horizontal, opposed, tangential, and vertical boilers that use pulverized coal from western Kentucky, northern Alabama, and southern Illinois, the ash pond effluents are alkaline. For those plants with tangential boilers that use pulverized coal from eastern Tennessee, eastern Kentucky, and Virginia, the ash pond effluents are neutral or acidic. The pH of the effluents from plants with cyclone furnace boilers is neutral or acidic, even though the coal sources are western Kentucky and southern Illinois.

5. Methods for adjusting the pH of ash pond effluents may include (1) controlling the ash-to-water ratio for ash sluicing, (2) combining ash pond effluents with other wastewaters within power plants, or (3) adding chemicals. The quantities of chemicals such as lime, limestone, soda ash, and caustic soda required for acid effluent neutralization were relatively small. The amounts of chemicals such as strong acid and CO_2 for neutralizing alkaline effluents were relatively large, especially in consideration of the large flow of ash pond discharge. At some plants, neutralization of alkaline ash pond effluent by routing it into condenser cooling water intake or condenser discharge has many practical advantages as well as the obvious economic value of eliminating the need for costly chemical treatemnt of ash pond effluents.

6. About 90 percent of the fly ash particles, following hindered-zone or flocculent settling behavior, settled faster than those residual fine ash particles which follow discrete settling behavior. The flocculent settling behavior was caused by the high ash concentration during sluicing and settling. Mathematical equations were developed to delineate the ash settling behavior and to estimate the residual suspended solids concentration in the effluent of a sedimentation basin or settling pond. The design of ash settling basins or ponds should be based on laboratory settling analysis. Discharge of cenospheres into settling pond effluents must be prevented at some plants to meet the effluent limitation guidelines for suspended solids.

7. Theoretical analyses of mass transfer rates of minerals from ash into water indicated that the principal factors affecting the mineral leaching rate of fly ash were the concentration and form of chemical species in ash, molecular diffusivity, particle size, and intensity of turbulence. Experimental

results indicated that the dissolved minerals that leached from ash into sluice water (river water) at the ambient temperature reached their equilibrium concentrations within 4 h, and that the equilibrium concentration levels depended on the ash concentration. However, ash deposited in the bottom of the ash pond may continue to leach while the ash is in contact with ground water if the surrounding environment is changed to anaerobic and low-pH conditions. The determination of concentration levels of chemical constituents leaching from ashes were analyzed mathematically. The amounts of minerals leaching from ash depend on the concentration and form of chemical species in ash, particle size of the ash, and diffusivity of each individual species. Laboratory results indicated that pH also influenced the leaching concentrations of many chemical species. A delineation of potential trace metal pollution resulting from ash disposal under various ash-to-water contacting ratios was provided by both laboratory testing and field monitoring at TVA's 12 coal-fired power plants.

8. Several trace metals in the ash pond discharges were found to occur in potentially toxic quantities, and some trace metals were present in both dissolved and suspended forms. The distribution of specific trace metals between the dissolved and suspended forms is site-specific, but it is important to analyze the trace metals in both the dissolved and suspended forms for monitoring trace metals in ash pond discharges. Adjustment of acidic ash pond discharges up to pH 6 or of alkaline ash pond discharges down to pH 9, and reduction of suspended solids concentrations to 30 mg/l reduced total concentrations of many trace metals, such as chromium, copper, lead, and zinc. However, adjustment of pH between 6 and 9 did not appreciably reduce total concentrations of arsenic, boron, cadmium, iron, manganese, and selenium. The solubilities of arsenic, boron, and selenium are independent of pH. Dissolved cadmium and manganese may be greatly removed at pH above 9 and 12, respectively. Because of the high iron content in the suspended ash particles, total iron concentrations could not be reduced to the 1 mg/l level at neutral pH, even though total suspended solids concentrations in some ash pond effluents were reduced to 30 mg/l.

Six special areas needed for further research are recommended as below:

1. The determination of the chemical formula of metallic oxides and other important constituents such as sulfur oxides in fly and bottom ashes.

2. The distribution of trace metals in the surface and bulk of ash particles.

3. The formulation of dynamic models on trace metal leaching from ash into water including the considerations of rates of chemical reaction, pH, temperature, and buffer intensity of water.

4. The chemical speciation of trace metals in ash pond effluents to determine the oxidation states of trace metals, especially for arsenic, chromium, and selenium.

5. A demonstration of reduction of trace metals in ash pond effluents by practical treatment methods such as pH adjustment, chemical precipitation, and coagulation; for example, a reduction of arsenic in ash pond effluents to 0.05 mg/l through the above conventional treatment methods.

6. The identification and analysis of toxic organic compounds in ashes and ash pond effluents.

SECTION 3

LITERATURE REVIEW

Coal is formed by the partial decomposition of vegetative matter under anaerobic conditions and varying degrees of temperature and high pressure. Organic matter composed of carbon, hydrogen, oxygen, nitrogen, and sulfur is the principal constituent of coal. Inorganic matter occurs partly in coal and primarily in ash. The major minerals present in U.S. bituminous coals are listed in Table 2. Many trace elements are also found in coal (Table 3). The average concentrations of some trace elements in coal throughout the coal regions of the United States are presented in Table 4.

Coal ash, the combustion byproduct from coal-fired power plants, is derived primarily from the inorganic mineral constituents in coal. The nature of the inorganic residual results from the geologic and geographic factors associated with the coal deposits. The ash content in U.S. coals, as summarized in Figure 1, varies from one coal bed to another. In general, these raw coals contained an average of 14 percent ash.[11] However, as coal consumption in the United States continues to increase, the quality of coal being used is deteriorating and the ash content is increasing.[12-16] Some of the subbituminous and lignite coals now being used contain 15 to 18 percent noncombustible mineral constituents.[17]

During combustion of coal in the furnace, the distribution of fly ash and bottom ash depends on method of firing and type of combustion chamber.[5] When pulverized coal is burned in a dry-bottom furnace, 70 to 95 percent of the ash material is released as fly ash, and the other 5 to 30 percent is released as bottom ash. On the other hand, when pulverized coal is burned in a wet-bottom furnace, about 50 percent of the ash is released as fly ash, and the other 50 percent falls to the bottom of the furnace as bottom ash or slag. With the cyclone furnace, 70 to 80 percent of the total ash is removed from the bottom of the furnace as bottom ash or slag, and 20 to 30 percent is released as fly ash in the flue gas.

Fly ash generally occurs as very fine spherical particles, ranging in diameter from 0.5 to 100 μm or greater and having a specific gravity of 2.0 to 2.9.[17] Bottom ash and slag occur as angular- and porous-surface texture particles, ranging in diameter from 0.05 to 50 mm and having a specific gravity of 2.2 to 2.8.[18] Some low-weight, hollow-sphere particles called cenospheres are found in fly ash. The true specific gravity of the cenospheres ranges from 0.4 to 0.6.[17] The cenospheres can be as much as 4 to 5 percent by weight, or 15 to 20 percent by volume, of the fly ash generated at coal-fired power plants.[19]

TABLE 2. CLASSIFICATION OF COMMON MINERALS FOUND IN COAL

SHALE GROUP (Group M)
- Muscovite ($KAl_2(AlSiO_3O_{10})(OH)_2$)
- Hydromuscovite
- Illite ($K(MgAl,Si)(Al,Si_3)O_{10}(OH)_8$
- Bravaisite
- Montmorillonite ($(MgAl)_5(Si_4O_{10})_3(OH)_{10}\cdot 12H_2O$

KAOLIN GROUP (Group K)
- Kaolinite ($Al_2Si_2O_5(OH)_4$)
- Levisite
- Metahalloysite

SULFIDE GROUP (Group S)
- Pyrite (FeS_2)
- Marcasite (FeS_2)

CARBONATE GROUP (Group C)
- Ankerite $CaCO_3\cdot(Mg,Fe,Mn)CO_3$
- Calcite ($CaCO_3$)
- Siderite ($FeCO_3$)

CHLORIDE GROUP (Group O)
- Sylvite (KCl)
- Halite (NaCl)

OXIDE GROUP (Group O)
- Quartz (SiO_2)
- Hematite (Fe_3O_4)
- Magnetite (Fe_2O_3)

ACCESSORY MINERALS GROUP
- Sphalerite (ZnS)
- Feldspar $(K, Na)_2O\cdot Al_2O_3\cdot 6SiO_2$
- Garnet $(3CaO\cdot Al_2O_3\cdot 3SiO_2)$
- Hornblende $(CaO\cdot 3FeO\cdot 4SiO_2)$
- Gypsum $(CaSO_4\cdot 2H_2O)$
- Apatite $(9CaO\cdot 3P_2O_5\cdot CaF_2)$
- Zircon ($ZrSiO_4$)
- Epidote $(4CaO\cdot 3Al_2O_3\cdot 6SiO_2\cdot H_2O)$
- Biotite $(K_2O\cdot MgO\cdot Al_2O_3\cdot 3SiO_2\cdot H_2O)$
- Augite $(CaO\cdot MgO\cdot 2SiO_2)$
- Prochlorite $(2FeO\cdot 2MgO\cdot Al_2O_3\cdot 2SiO_2\cdot 2H_2O)$
- Chlorite $(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$
- Diaspore $(Al_2O_3\cdot H_2O)$
- Lepidocrocite $(Fe_2O_3\cdot H_2O)$
- Barite ($BaSO_4$)
- Kyanite $(Al_2O_3\cdot SiO_2)$
- Staurolite $(2FeO\cdot 5Al_2O_3\cdot 4SiO_2\cdot H_2O)$
- Topaz $(AlF)_2SiO_4$
- Tourmaline $H_9Al_3(BOH)_2Si_4O_{19}$
- Pyrophyllite $(Al_2Si_4O_{10}(OH)_2)$
- Penninite $(5MgO\cdot Al_2O_3\cdot 3SiO_2\cdot 2H_2O)$

Source: Lucas, J. R., et al. Plant Waste Contaminants In: Coal Preparation, J. W. Leonard and D. R. Mitchell, eds., The American Institute of Mining, New York, 1968. pp. 17.1-17.54.

TABLE 3. TRACE INORGANIC ELEMENTS IN COAL

Constituent	Mean Value	Unit	Standard Deviation	Minimum Value	Maximum Value
As	14.02	PPM	17.70	0.50	93.00
B	102.21	PPM	54.65	5.00	224.00
Be	1.61	PPM	0.82	0.20	4.00
Br	15.42	PPM	5.92	4.00	52.00
Cd	2.52	PPM	7.60	0.10	65.00
Co	9.57	PPM	7.26	1.00	43.00
Cr	13.75	PPM	7.26	4.00	54.00
Cu	15.16	PPM	8.12	5.00	61.00
F	60.94	PPM	20.99	25.00	143.00
Ga	3.12	PPM	1.06	1.10	7.50
Ge	6.59	PPM	6.71	1.00	43.00
Hg	0.20	PPM	0.20	0.02	1.60
Mn	49.40	PPM	40.15	6.00	181.00
Mo	7.54	PPM	5.96	1.00	30.00
Ni	21.07	PPM	12.35	3.00	80.00
P	71.10	PPM	72.81	5.00	400.00
Pb	34.78	PPM	43.69	4.00	218.00
Sb	1.26	PPM	1.32	0.20	8.90
Se	2.08	PPM	1.10	0.45	7.70
Sn	4.79	PPM	6.15	1.00	51.00
V	32.71	PPM	12.03	11.00	78.00
Zn	272.29	PPM	694.23	6.00	5350.00
Zr	72.46	PPM	57.76	8.00	133.00
Al	1.29	Percent	0.45	0.43	3.04
Ca	0.77	Percent	0.55	0.05	2.67
Cl	0.14	Percent	0.14	0.01	0.54
Fe	1.92	Percent	0.79	0.34	4.32
K	0.16	Percent	0.06	0.02	0.43
Mg	0.05	Percent	0.04	0.01	0.25
Na	0.05	Percent	0.04	0.00	0.20
Si	2.49	Percent	0.80	0.58	6.09
Ti	0.07	Percent	0.02	0.02	0.15

Source: Ruch, R. R., et al. Occurrence and Distribution of Potentially Volatile Trace Elements in Coal. EPA 12-74-054, U. S. Environmental Protection Agency, July 1974. 96 P.

TABLE 4. AVERAGE CONTENT (%) OF TRACE METALS IN COALS

	Trace metal content (%) in coal					
Metal	Appalachian	Interior Eastern	Interior Western	Great Northern Plains	Southwestern	Western
Antimony	0.001[a]	NA[b]	NA	NA	NA	NA
Arsenic	0.0031[c]	0.0011[d]	NA	0.08[c]	0.0073[e]	0.0004[a]
Beryllium	0.0025[e]	0.0025[e]	0.0015[c]	0.0015[e]	0.00006[a]	0.0015[e]
Cadmium	NA	NA	NA	NA	0.000003[c]	NA
Chromium	0.0013[d]	0.002[e]	0.0014[c]	0.0007[e]	0.006[a]	0.00069[d]
Copper	0.0015[d]	0.0011[e]	0.0012[c]	0.0015[e]	0.0008[c]	0.00046[d]
Lead	0.0009[c]	0.0011[c]	0.0004[e]	0.0007[e]	0.0006[d]	0.0008[c]
Mercury	0.000015[e]	0.000013[e]	0.000019[e]	0.000007[e]	0.000013[c]	0.000007[e]
Nickel	0.0014[e]	0.0015[e]	0.0017[a]	0.00072[e]	0.0006[d]	0.00053[d]
Thallium	0.00018[d]	0.00007[d]	NA	NA	NA	0.00005[d]
Silver	0.00008[d]	NA	NA	NA	NA	NA
Zinc	0.00082[c]	0.0044[e]	0.0193[d]	0.0059[a]	0.0009[d]	0.0025[d]

[a]Product of average of the range of element percentages in ash and average ash content of coal.

[b]Not available.

[c]Based on average of the ranges of percentage of the element in coal.

[d]Product of average value of element in coal and average ash content of coal.

[e]Based on average percentage of element in coal as reported.

Sources: Magee, E. M., et al. Potential Pollutants in Fossil Fuels. EPA-R2-73-249. U.S. Environmental Protection Agency, June 1973. 151 p.

Wachter, R. A., and T. R. Blackwood. Source Assessment: Water Pollutants from Coal Storage Areas. EPA-600/2-78-004m, May 1978. 106 p.

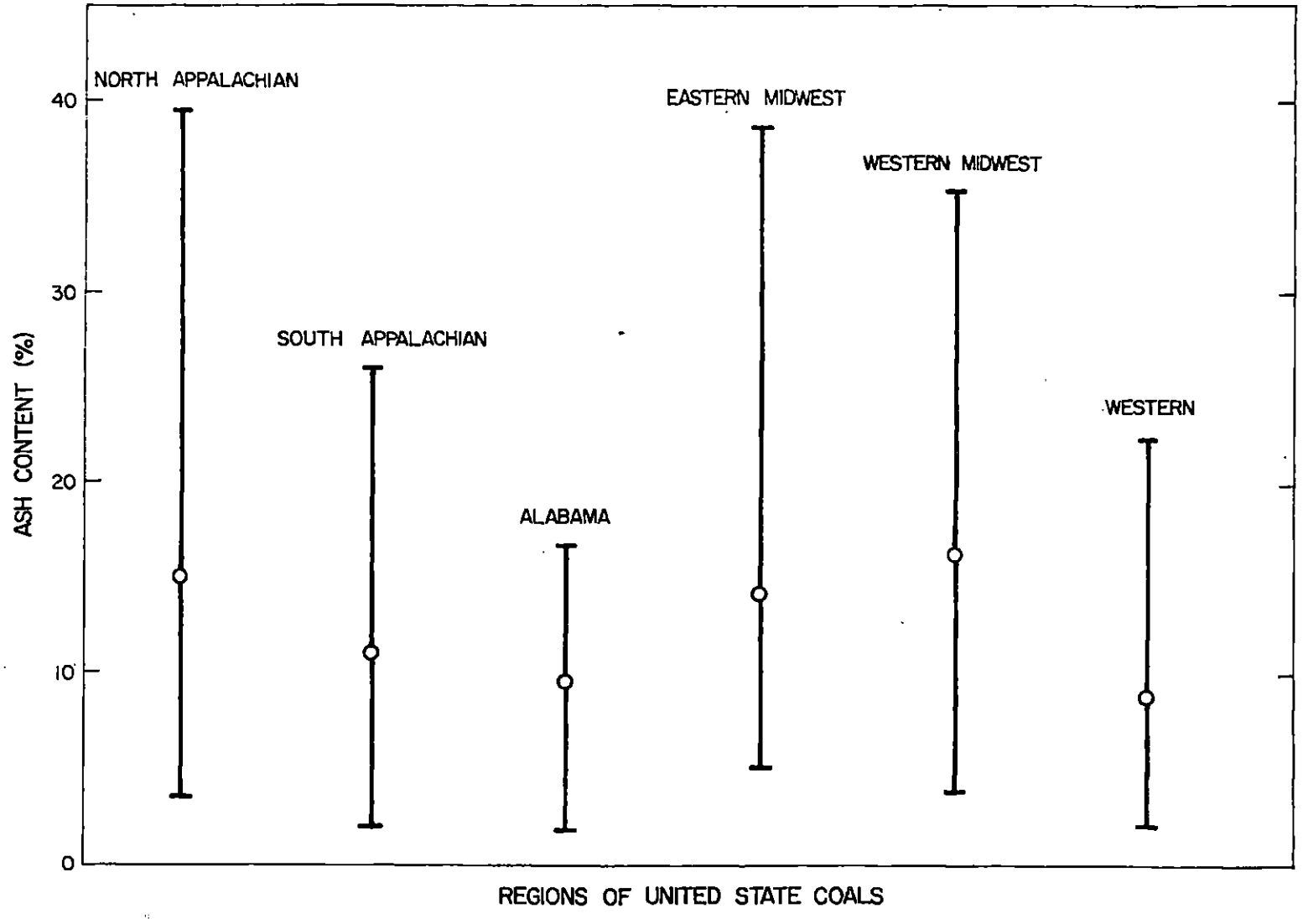

Figure 1. Range and average of ash content in U.S. coals.

Source: Cavallaro, J. A., et al. Sulfur Reduction Potential of the Coals of the United States. Report No. 8118, Bureau of Mines, U.S. Department of the Interior, 1976. 323 p.

The composition of fly ash and bottom ash varies greatly and depends on the geographical area from which the coal is derived, combustion conditions, and other factors such as the removal efficiency of air pollution control devices. The primary constituents in fly ash and bottom ash may be metal oxides such as alumina, calcium oxide, ferric oxide, magnesium oxide, potassium oxide, silica, sodium oxide, and titanium oxide, and other constituents such as sulfur oxides and carbon residuals. Almost 40 percent of the ash component is silica, and another 40 percent of the ash consists of alumina and ferric oxide.[20] Fifteen years ago, two studies reported that a wide range of trace contaminants, including 17 trace metals, were identified in fly ash from coal-fired power plants.[21-22] Recent studies of coal ashes[23-34] have indicated that virtually every mineral constituent accumulated along the deposit of coal on the earth's surface can be found in coal ashes. The elements contained in coal ashes can be divided into five groups: alkali and alkali earth metals, refractories, transition metals, halogens, and volatiles. Some recent studies[27-35] have established that many trace elements, particularly the more volatile ones, are richer in fly ash than in raw coal, and the specific concentrations of many trace elements in fly ash increase significantly with decreasing particle size of fly ash. Also, the natural radionuclides have been reported in fly ash and bottom ash from coal-fired power plants.[36-40]

Virtually all ash disposal and utilization techniques expose ash to water at one time or another. The exposure ranges from complete immersion of ash into water such as sluicing and ponding, or intermittent percolation of water through ash landfill areas. Therefore, the water quality problems of effluent and leachate from ash disposal depend on the methods of ash disposal; e.g., the quantities of suspended solids and trace metals depend on whether the ash is disposed of in ash ponds, ash storage piles, or landfill sites. The water quality problems associated with particular ash ponds have been reported extensively.[41-53]

SECTION 4

pH OF ASH SLUICE WATER

The pH of water contacted with ash material may vary from acid to alkaline, depending on ash characteristics and quality and quantity of water used for sluicing. Primarily, the pH of ash sluice water is affected by the amounts and concentrations of chemical species that dissolve from ash into water.

EFFECT OF ASH CHARACTERISTICS

The pH of ash pond effluent relates to those factors affecting the ash characteristics. The operating conditions for TVA's 12 coal-fired power plants are summarized in Table 5. For the plants that use pulverized coal, the pH of the ash pond effluents is mainly affected by the source of coal. Ash pond effluents from plants that receive coal from western Kentucky and southern Illinois are alkaline, whereas those from plants that receive coal from eastern Tennessee, eastern Kentucky, and Virginia are neutral or acidic. However, the pH of the effluents from the two plants with cyclone furnaces is neutral or acidic, even though the coal source for both plants is western Kentucky and southern Illinois.

The fly and bottom ashes are basically glass-like particles, and fly ash is also coated with various oxides during the condensation process after combustion.[1] The composition of this coating varies greatly from ash to ash, depending on the type of coal burned and method of firing (type of boiler). Most of the sulfur oxides and alkaline metal oxides in ash are readily dissolved in water. The alkaline metal oxides of calcium, magnesium, potassium, and sodium can produce a basic reaction in water as

$$M_xO_y + yH_2O \rightarrow x\,M^{(\frac{2y}{x})+} + 2yOH^-. \qquad (1)$$

The sulfur compounds dissolve in water and ultimately yield an acidic reaction. One possibility for sulfur trioxide is:

$$SO_3 + H_2O \rightarrow SO_4^{-2} + 2H^+. \qquad (2)$$

Therefore, the pH of the ash sluice water depends on either the ratio of alkaline metal oxides to sulfur oxides in ash or the ratio of total dissolved alkaline metal ions to sulfate ion in sluice water. CaO and MgO are the two principal alkaline metal oxides in ash. Figure 2 shows

TABLE 5. RELATIONSHIPS BETWEEN PLANT OPERATION CONDITIONS AND pH VALUES OF ASH POND EFFLUENTS AT TVA COAL-FIRED POWER PLANTS

Parameter	Plant D	Plant H	Plant J	Plant E	Plant F	Plant G	Plant I	Plant K	Plant L	Plant B	Plant C	Plant A
Coal sources	E. Kentucky	Virginia E. Kentucky E. Tennessee	E. Kentucky E. Tennessee	W. Kentucky	W. Kentucky S. Illinois	W. Kentucky	W. Kentucky	S. Illinois W. Kentucky	W. Kentucky N. Alabama	W. Kentucky	W. Kentucky S. Illinois	W. Kentucky
Method of firing	Tangential	Tangential	Tangential	Circular tangential	Opposed	Tangential	Tangential horizontal	Circular	Horizontal tangential	Vertical	Cyclone	Cyclone
Ash content in the coal[a], %	15.5	15	19.1	15.3	16.3	15.7	14	15.6	16	14.8	11	18.8
Fly ash of total ash[a], %	75	67	75	67	80	80	70	75	75	50	30	30
Bottom ash of total ash[a], %	25	33	25	33	20	20	30	25	25	50	70	70
Sluice water-to ash ratio[a], gal/ton	10,770	11,425	9,520	9,585	19,490	12,345	42,430	17,265	15,370	-	23,065	12,380[b] 9,810[c]
pH value of raw water[a]	7.5	7.0	7.6	7.0	7.4	7.3	7.4	7.6	7.5	7.5	7.4	7.7
pH value of ash pond effluent[a]	8.6[c]	8.9[c]	6.3[c]	11.1[c]	11.2[c]	9.6[c]	11.2[c]	10.8[c]	10.1[c]	9.8[b] 8.0[d]	7.1[c]	4.4[b] 7.2[d]

[a]Based on average values during 1974.

[b]Fly ash pond only.

[c]Combined bottom and fly ash pond.

[d]Bottom ash pond only.

1 gal/ton = 4.2×10^{-3} l/kg

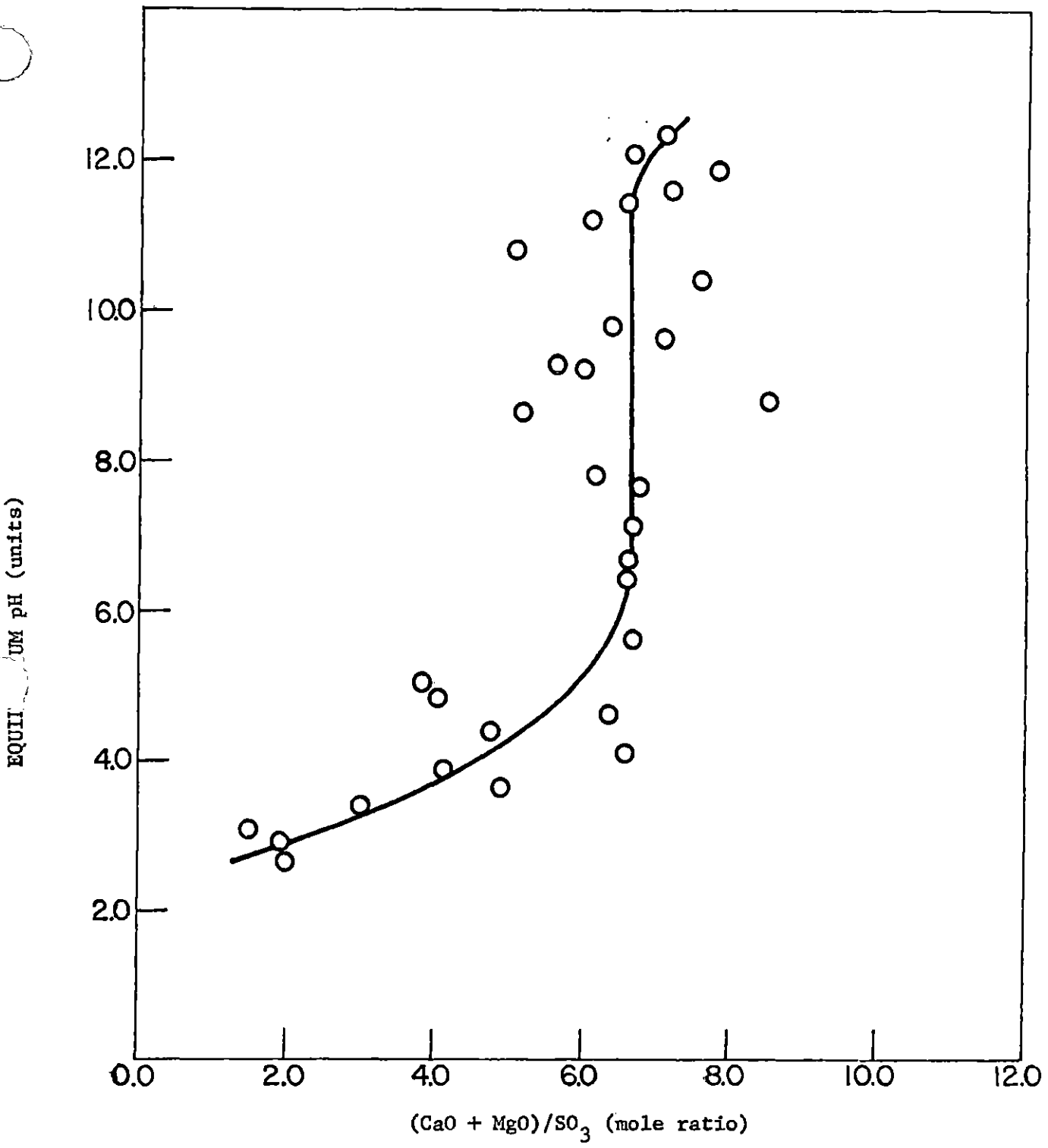

Figure 2. Relationship between the equilibrium pH of ash/water mixture and the mole ratio of CaO plus MgO to SO_3 contained in dry fly ashes.

the relationship of pH to the mole ratio of CaO plus MgO to sulfur oxides as SO_3 contained in fly ashes collected from seven TVA steam plants. The equilibrium pH values of water, after contact with these fly ashes, are acidic if the mole ratios of CaO plus MgO to sulfur oxides as SO_3 are less than about 5. For a mole ratio greater than 5, the ash sluice water can be neutral or alkaline depending on the dissolution of alkaline metal oxides and sulfur oxides from ash into water. The pH values of ash pond effluents at 12 TVA steam plants vary from 3 to 12. Figure 3 illustrates the relationship between pH and the concentration ratio of calcium to sulfate in ash pond effluents. In general, the pH increase is proportional to the increase of concentration ratio of calcium to sulfate in ash pond effluents.

EFFECT OF BUFFERING CAPACITY OF SLUICING MAKEUP WATER

The importance of the buffering capacity of makeup water used for sluicing is apparent at Plant J, where the pH of the ash pond effluent varies seasonally from acidic in the winter and spring to slightly alkaline in the summer and fall (Figure 4). The cause of this variation is that the water used for sluicing consists of two separate river waters--one, containing low alkalinity, is used for makeup water in winter and spring; and another, containing relative high alkalinity, is used for makeup water in summer and fall.

EFFECT OF ASH-TO-WATER RATIO DURING SLUICING

The equilibrium pH of ash sluice water is also affected by the concentration of ash during sluicing as shown in Figure 5. Recently the effect of ash-to-water ratio on the pH of ash transport water has been dramatically demonstrated at two TVA alkaline ash ponds. At plant G, the raw water flow for ash sluicing has increased from 10.6×10^6 to 16.4×10^6 gpd (40.1×10^6 to 62.1×10^6 liter per day) (the average ash concentration of ash slurry during sluicing decreased from 19.4 to 12.6 g per liter) and the pH of ash pond water has dropped from 9.6 to 9. At plant I, the raw water flow for ash sluicing has increased from 14×10^6 to 21.6×10^6 gpd (53×10^6 to 81.8×10^6 liter per day) (the average ash concentrations of ash slurry during sluicing decreased from 5.6 to 3.7 g per liter) and the pH of the ash pond water has dropped from 11.2 to 9.3.

The effect of ash-to-water ratio on pH can be important for those ashes that have pH values close to either 6 or 9; therefore, a slight change in ash-to-water ratio during sluicing can shift the pH values within the limitation range.

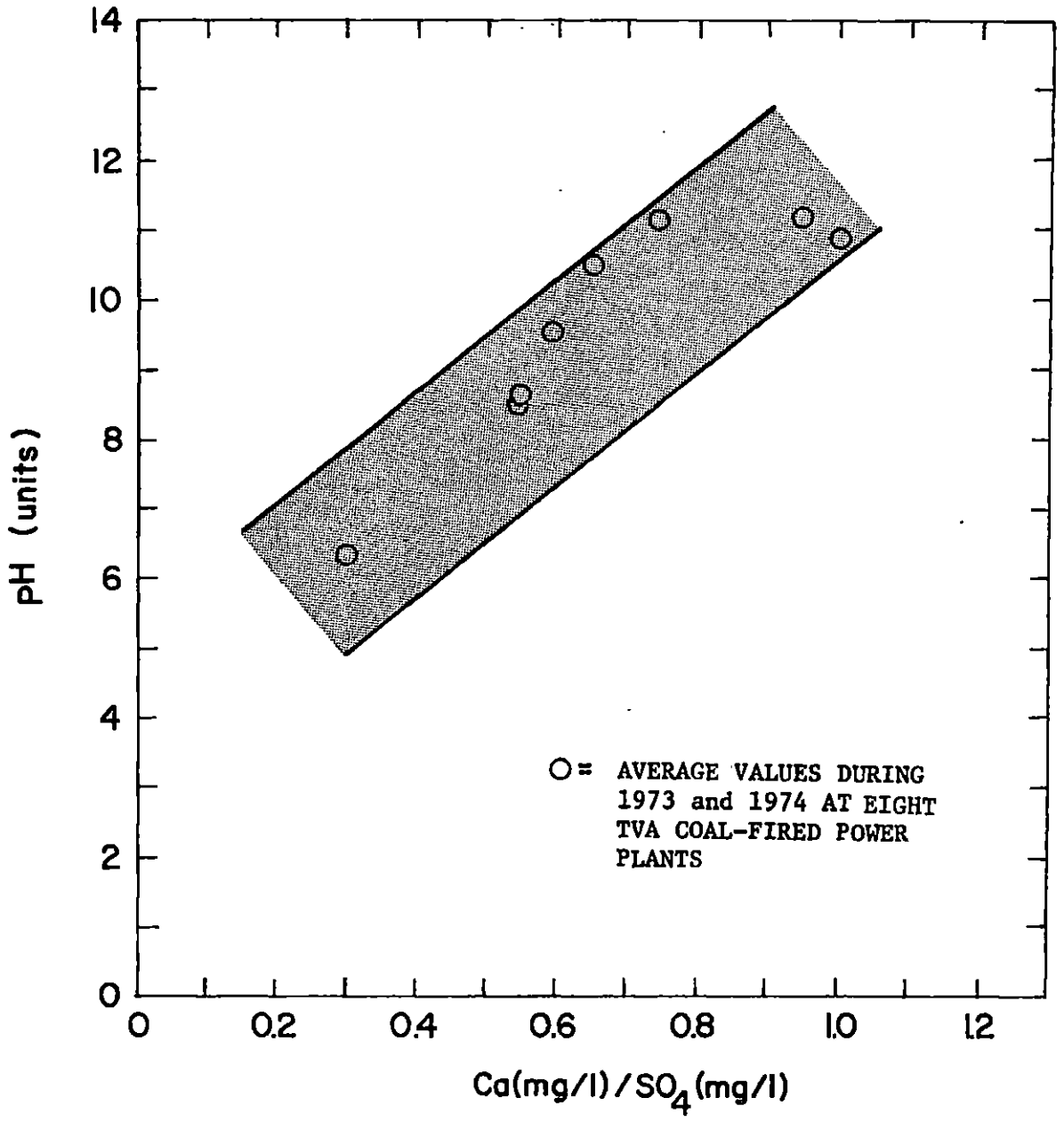

Figure 3. Relationship between pH and concentration ratios of calcium to sulfate in effluents from combined ash ponds.

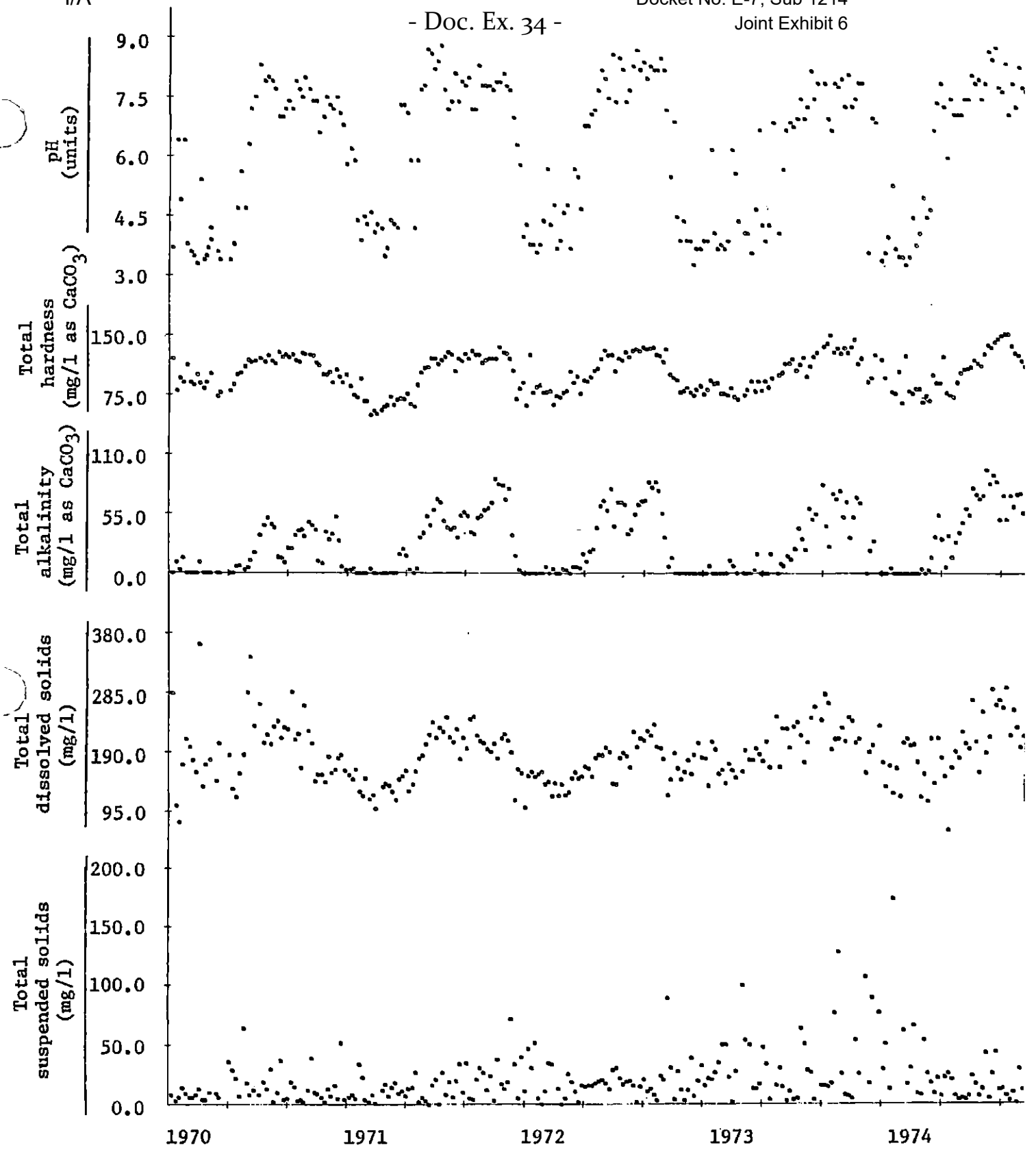

Figure 4. Seasonal variation of water quality parameters in an ash pond effluent

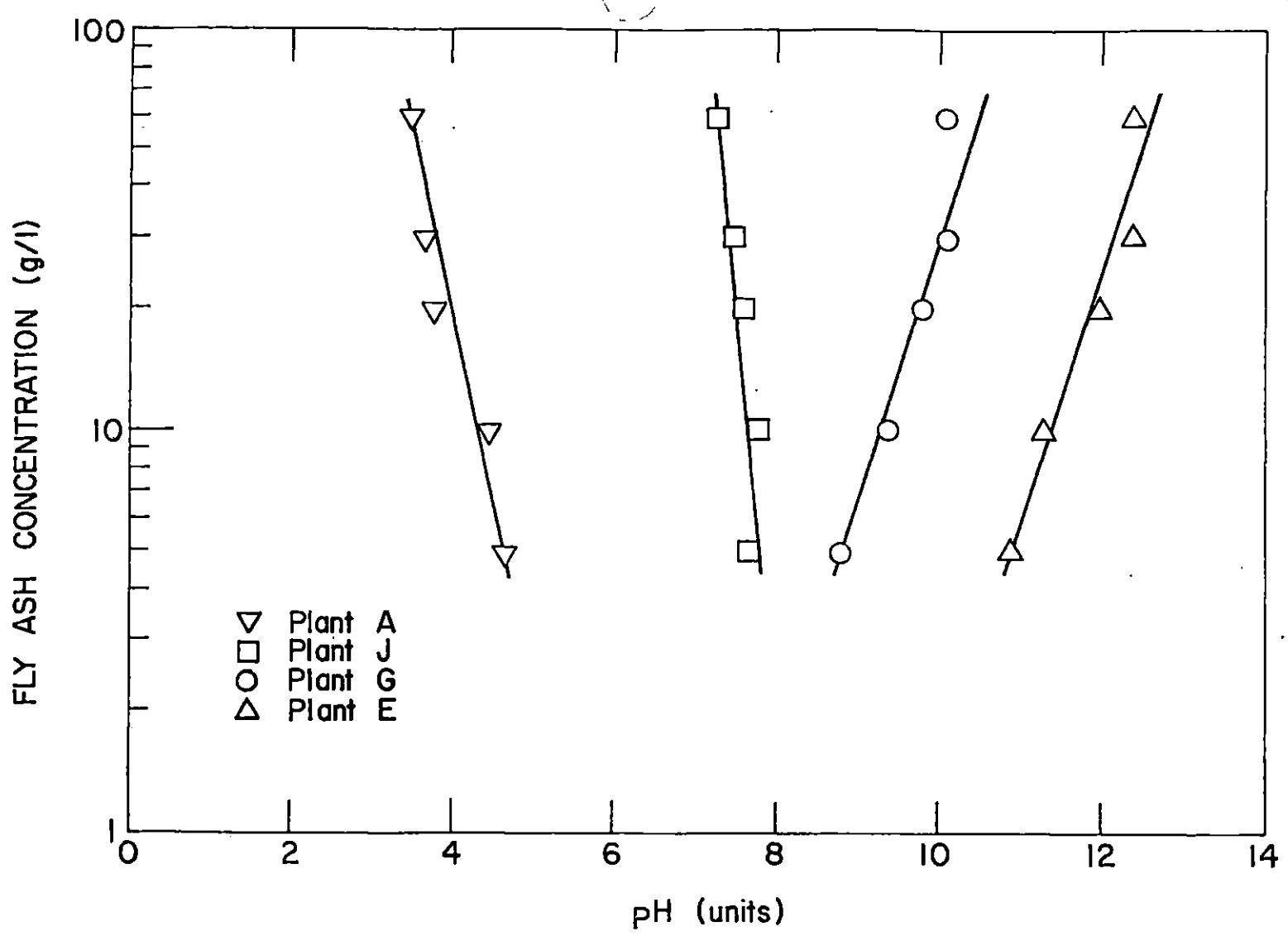

Figure 5. Relationship between equilibrium pH and the concentration of ash in the sluice water.

SECTION 5

pH ADJUSTMENT OF ASH SLUICE WATER

The pH of ash pond effluents may be adjusted by (1) controlling the ash-to-water ratio for ash sluicing, (2) combining ash pond effluents with other waste streams within power plants, or (3) adding chemicals.

Various titration curves of acid and alkaline ash pond effluents from TVA steam plants are shown in Figures 6 and 7. The quantity of chemicals required for neutralization of acidic effluents is relatively small, and the increase in the concentration of total dissolved solids is insignificant (usually less than 60 mg/l). However, the amount of chemicals required for neutralizing alkaline effluents is relatively large, especially when considering the large volume of ash pond discharges, and the increase in total dissolved solids concentration may be as much as 300 mg/l.

NEUTRALIZATION OF ACIDIC ASH POND EFFLUENTS

The degree of acidity of ash sluice water is affected by the ash concentration during sluicing. Therefore, the alkaline reagent requirement for neutralization is also affected. Figure 8 shows that the caustic soda requirement for adjusting the pH of acidic ash sluice water is related to the ash-to-water ratio.

The acidic pond effluents can be treated by a technique commonly used for water and wastewater treatment throughout the industry. Lime, limestone, soda ash, or caustic soda can be added to raise the pH of acidic effluent to 6 and above. The choice of the alkaline reagent depends on the volume of the effluent stream, variability of pH, and price of the neutralizing alkali. The basicity and costs of the acid-neutralizing methods and agents are compared in Table 6. Lime is used most often, despite the frequent formation of precipitates or suspended solids, which must be removed by sedimentation at the end of the flow through ash ponds before the effluents are discharged to receiving waters.

NEUTRALIZATION OF ALKALINE ASH POND EFFLUENTS

The acid requirement for neutralizing alkaline ash pond effluents is also related to the ash-to-water ratio, as shown in Figure 9. Strong acids or CO_2 can be used to neutralize the alkaline ash pond effluents.

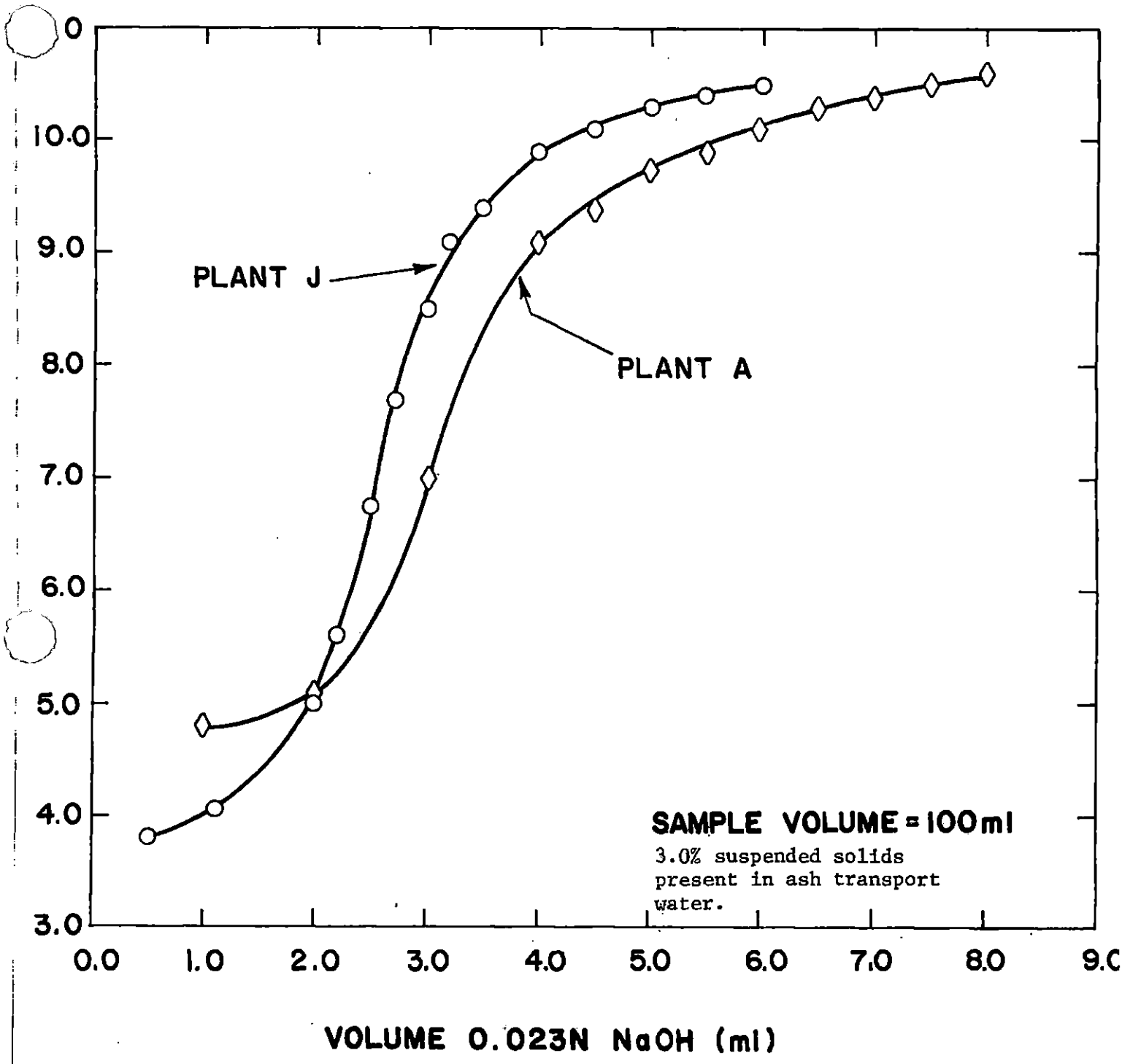

Figure 6. Titration curves of acidic ash pond effluents from TVA steam plants.

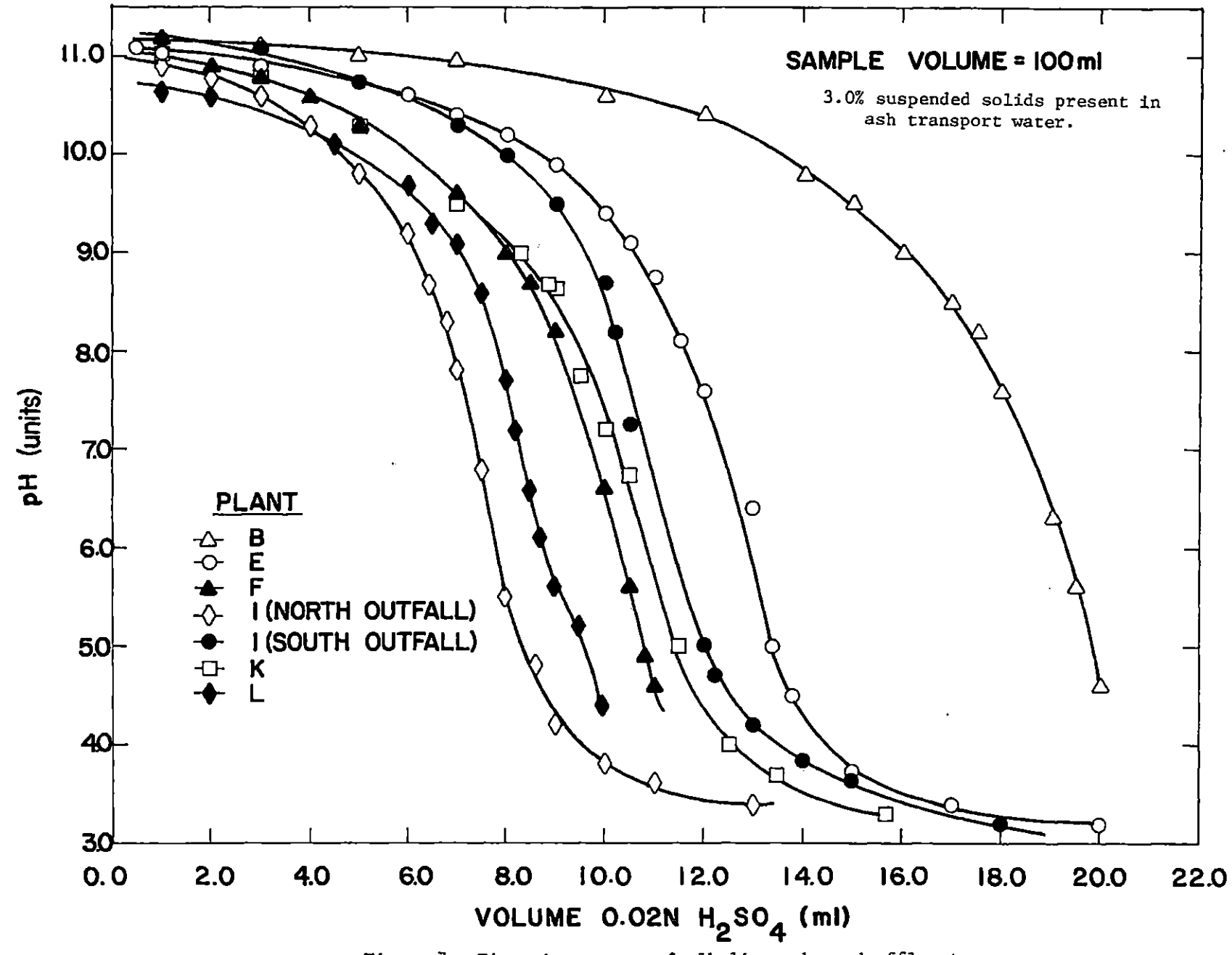

Figure 7. Titration curves of alkaline ash pond effluents from TVA steam plants.

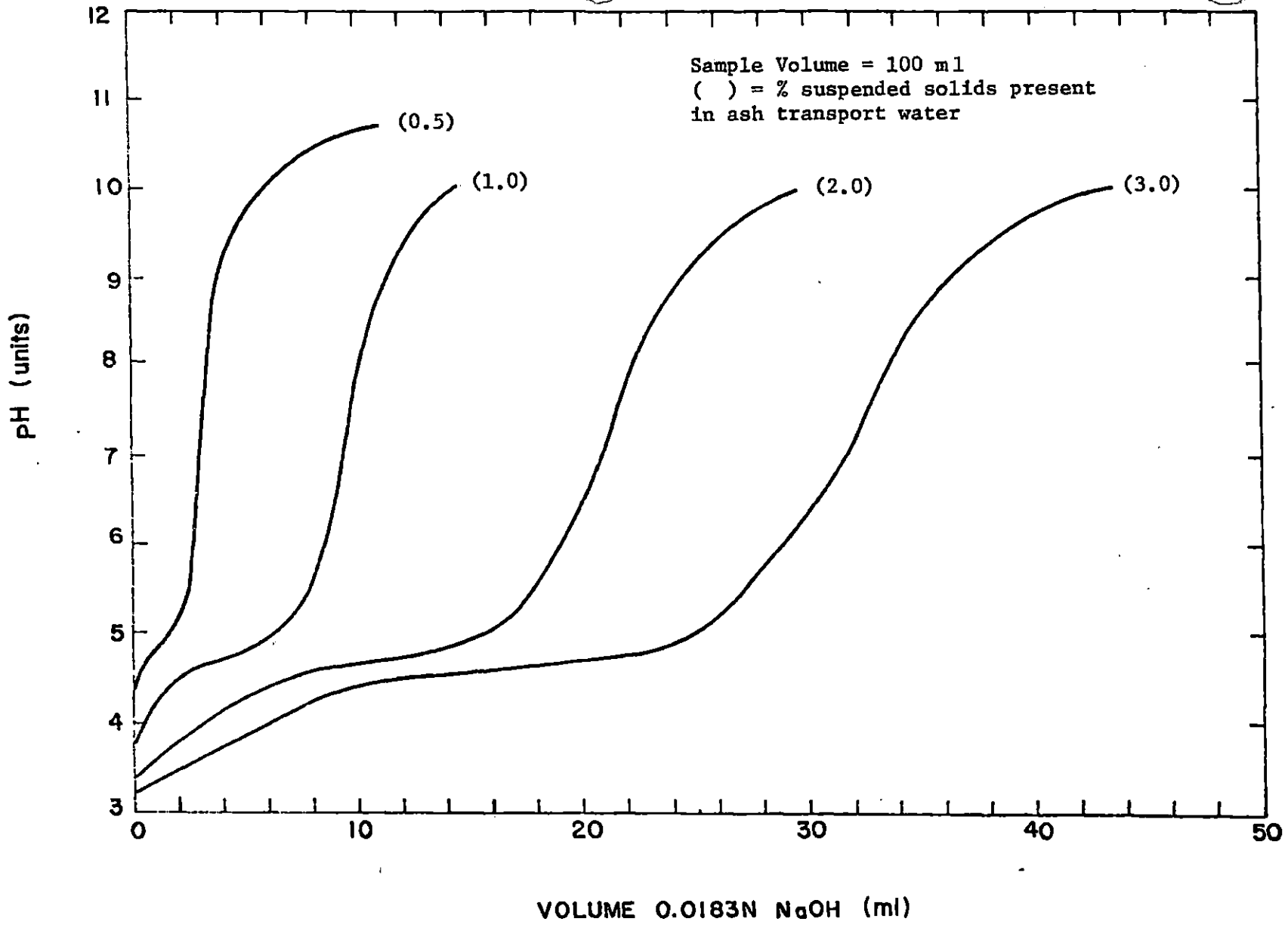

Figure 8. Neutralization of acidic ash sluice water with base (ash-water contacted for 1 h and not separated before neutralization).

TABLE 6. BASICITY AND COST COMPARISONS OF VARIOUS ALKALINE AGENTS[a]

	Cost, $/ton (approx.)[b]	Basicity factor[b]	Cost, $/ton of basicity
NaOH (76% Na_2O)	290	0.687	422
Na_2CO_3 (58% Na_2O)	87	0.507	172
MgO	140	1.306	107
High-calcium hydrated lime	33	0.710	46
Dolomitic hydrated lime	120	0.912	132
High-calcium quicklime	33	0.941	35
Dolomitic quicklime	120	1.110	108
High-calcium limestone	12	0.489	25
Dolomitic limestone	12	0.564	21

[a]Based on 1978 cost quotations.

[b]A measure of the alkali available for neutralization (grams of equivalent CaO per gram).

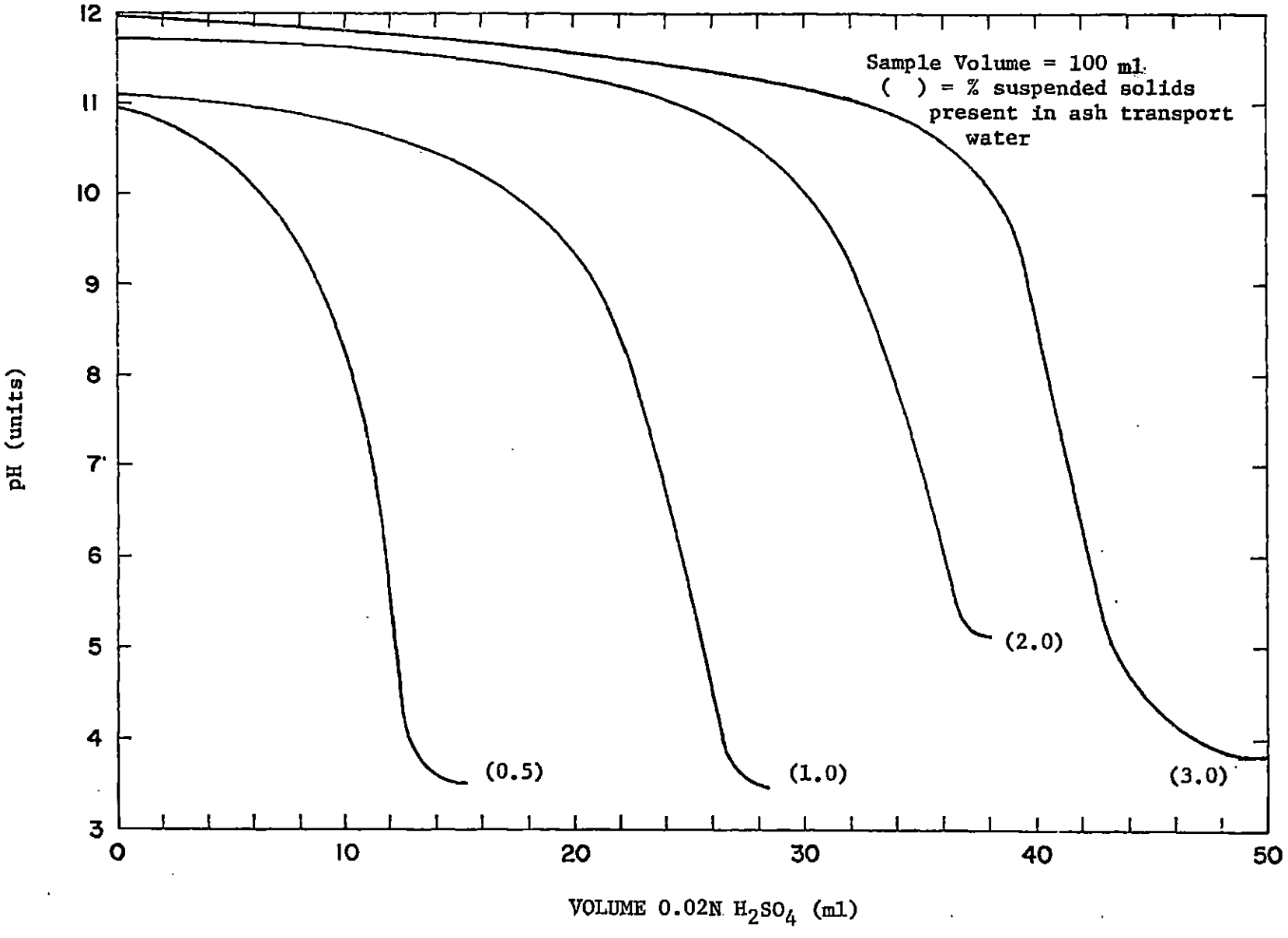

Figure 9. Neutralization of alkaline ash sluice water with acid (ash-water contacted for 1 h and not separated before neutralization).

Strong Acid Treatment

A common method of neutralizing alkaline wastes is to feed sulfuric acid into the waste stream. Techniques and equipment are commercially available to monitor the effluent pH and automatically control the sulfuric acid feed. The sulfuric acid reduces the pH by reacting with the hydroxide and carbonate ions present in highly alkaline water. Neutralization by adding sulfuric acid is ecologically acceptable because the reaction products are primarily sulfate compounds, which are relatively innocuous to biota and are normally present in natural waters. The chief disadvantage of using sulfuric acid is safety-related, (sulfuric acid is a highly corrosive, strong oxidant that is hazardous to handle). In the case of equipment malfunction, the pH of the effluent stream could drop to extremely low values with the potential for adverse environmental impact. The sulfuric acid storage facilities should also be located within a diked area capable of retaining 110 percent of the storage capacity.

Carbonation

An alternative method of neutralizing alkaline wastes is to add carbon dioxide (CO_2) to the waste disposal pond. This process is more acceptable from two standpoints: (1) In the case of equipment malfunction, the pH of the effluent stream will not drop below about 4.5, thus minimizing ecological damage; and (2) the cost of treatment is somewhat less. Carbon dioxide has been used by municipal water treatment plants to recarbonate and neutralize water after the softening process. The softening process involves the addition of excess lime, resulting in conditions similar to the conditions to be expected in the ash disposal ponds.

Two methods available for adding CO_2 to the ash pond are (1) onsite generation of CO_2 by burning a fuel such as oil, natural gas, or coke, and (2) the purchase of commercial CO_2 as a bulk liquid. The yield from the combustion process varies from 12 to 18 percent CO_2, depending on the type of system and fuel used. The combustion process involves more equipment (generally a compressor and scrubber, drier, etc.) than does the use of commercial CO_2. In addition to the cost of equipment for onsite generation of CO_2, other problems remain. The gas provided by combustion is corrosive and relatively impure, increasing the need for equipment maintenance. Also, the nitrogen associated with the CO_2 from the combustion process reduces the solubility rate, thereby requiring greater water contact time in the basin.

Adjustment of CO_2 production in a generator is moderately difficult and time consuming. Considerable care must be exercised to maintain conditions that will assure complete combustion. Natural gas is almost universally used for CO_2 generation. Current prices and availability without interruption during cold weather may require a more expensive second or standby fuel supply. At best, generation of CO_2 for carbonation is a process that is difficult to control; it requires

considerable operator attention and maintenance over the useful life of the equipment. For these reasons, the use of commercially available bulk liquid CO_2 appears to be a viable method for adding CO_2 to effluents. An alternative method, similar to the onsite generation of CO_2, is the use of plant stack gases as a source of CO_2 for neutralizing ash pond effluents.

There are two general methods of carbonating water with bulk carbon dioxide:

1. The most common practice is to admit CO_2 to the bottom of the basin through 3/4- to 2-in.-diameter (1.9- to 5.1-cm-diameter) piping. The gas is diffused by a distribution grid of perforated pipe with 1/16- to 3/32-in. (0.16- to 2.38-cm) holes on 6- to 12-in. (15.2- to 30.5-cm) centers, with the holes pointed downward to obtain a reasonable dispersion of the gas. A line of porous ceramic tubing suitable for CO_2 diffusion is also commercially available. Pipeline regulators are used to reduce the receiver pressure of 240 to 300 psig (17.3 to 21.4 atm) to a flowmeter-calibrated pressure of 50 psig (4.4 atm).

2. A more sophisticated technique of adding CO_2 to water entails the use of a V-notch CO_2 feeder, which carbonates an auxiliary stream of water, which is then piped to the basin. These feeders are available in capacities of up to 1500 lb (680.4 kg) of CO_2 per day. Most models are suitable for modulating CO_2 flow in direct relationship to the water processing rate and eliminate the need for diffusion grids in the basin.

Little information has been published on the efficiency of CO_2 absorption systems, and an estimate of the cost of CO_2 on a per-pound-absorbed basis is difficult. An absorption efficiency of 98 to 99 percent can be achieved in a recarbonation process by using liquid CO_2, and absorption efficiencies in the range of 12 to 18 percent can be achieved for combustion-generated CO_2 because of the low percentage of CO_2 in the gas produced in the combustion process. Figure 10 shows the laboratory result of neutralizing an alkaline ash pond effluent with liquid CO_2.

Combining Streams

A third method of neutralizing the alkaline ash pond discharge at TVA plants involves reaction of the ash pond effluent with the incoming cooling water by feeding the ash pond effluent into the condenser cooling water at the condenser inlet or discharge channel. The alkaline ash pond effluent reacts with the carbon dioxide and bicarbonates naturally present in cooling water, resulting in neutralization of the excess alkalinity present in the ash pond effluent and a slight increase in the pH of the cooling water. Ash pond effluents treated by this method would meet the present water quality limitations.

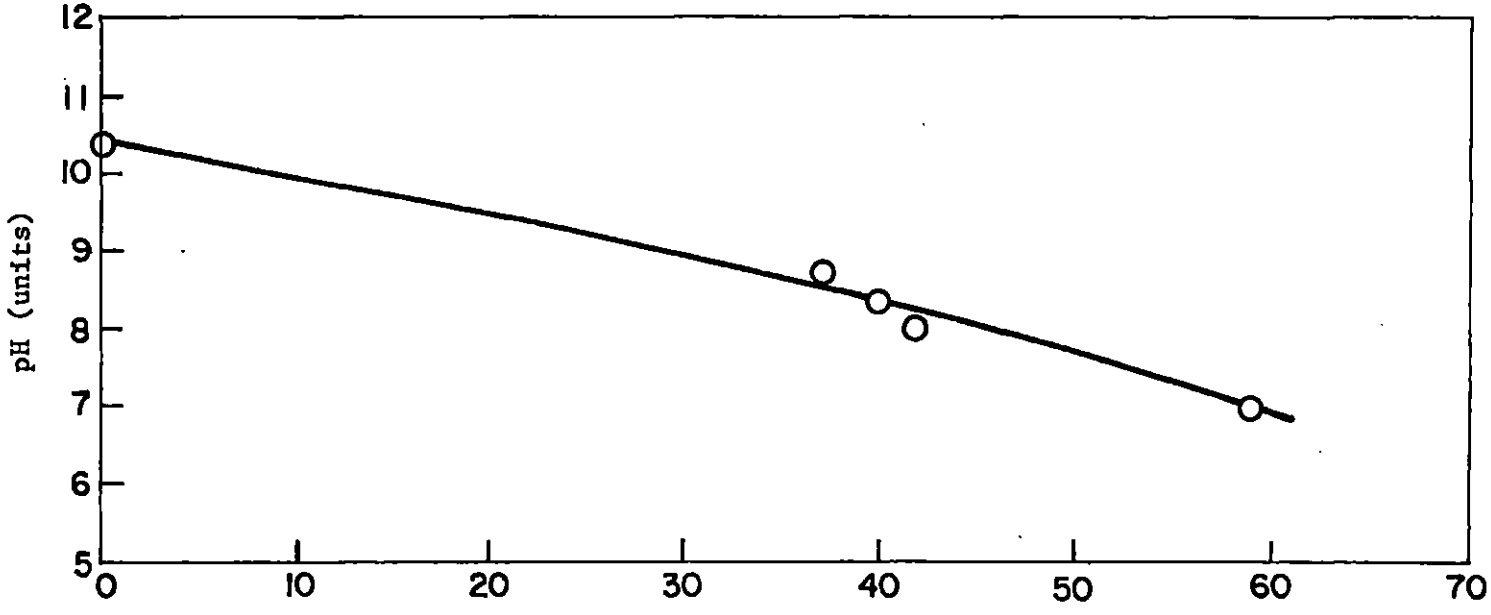

Figure 10. Neutralization of an alkaline ash pond effluent with liquid carbon dioxide.

In the case of combining ash pond effluents with condenser cooling water, the ash pond effluents would meet all the concentration-controlled pollutant limitations (e.g., total suspended solids and oil and grease) before it is introduced into the cooling stream. The only parameter being affected is the pH, which is not controlled on a basis of concentration times flow. Although pH is not considered a pollutant as such, it is controlled within a range that is not detrimental to biota in the discharge area of the receiving waters.

Reuse of ash pond effluent by feeding it into the condenser inlet or discharge has many practical advantages as well as the obvious economic value of eliminating the need for costly chemical treatment of ash pond effluents.

The mixing of alkaline ash pond effluents with cooling water does not generate significant additional dissolved solids, as occurs in chemical treatment, e.g., sulfuric acid and CO_2 treatment methods could add as much as 300 mg/l and 100 mg/l of dissolved solids, respectively, to existing concentrations in effluent streams. The chemical reactions that occur when the streams are combined involve reactants already present in the water and result in a slight increase in reaction products also already present in the cooling water. The primary reactions that take place are shown by two equations:

$$2\ OH^- + CO_2 \rightarrow CO_3^{-2} + H_2O, \qquad (3)$$

and

$$OH^- + HCO_3^- \rightarrow CO_3^{-2} + H_2O. \qquad (4)$$

As shown by the equations, the hydroxide ions in alkaline ash pond water react with carbon dioxide and bicarbonate ions present in cooling water to form carbonates. The neutralization of alkaline ash pond effluents with once-through cooling water has been investigated through bench-scale tests. The water quality of once-through cooling water is the same as that of river water. The maximum necessary ratio of cooling water to alkaline ash pond effluents from TVA steam plants was about 10 to 1 to reduce the pH of alkaline effluents from about 11 to 9 (Figure 11). For a once-through cooling system, the cooling water available is adequate to neutralize ash pond effluent. To reduce the pH of alkaline effluents to 7.5, a reduction that may be needed to meet the quality criteria for cooling system makeup water, the necessary blending ratio for a cooling tower system would have to be greater than 50 to 1. Usually, the amount of effluent from ash ponds is greater than that used for mixing with cooling tower makeup water. Thus, only part of the alkaline effluent could be reused in the cooling tower system.

Changing the pH of cooling water would affect the total CO_2 (carbonic acid, carbonate, and bicarbonate) concentration present in the water. Fish and other aquatic life are sensitive to this balance in

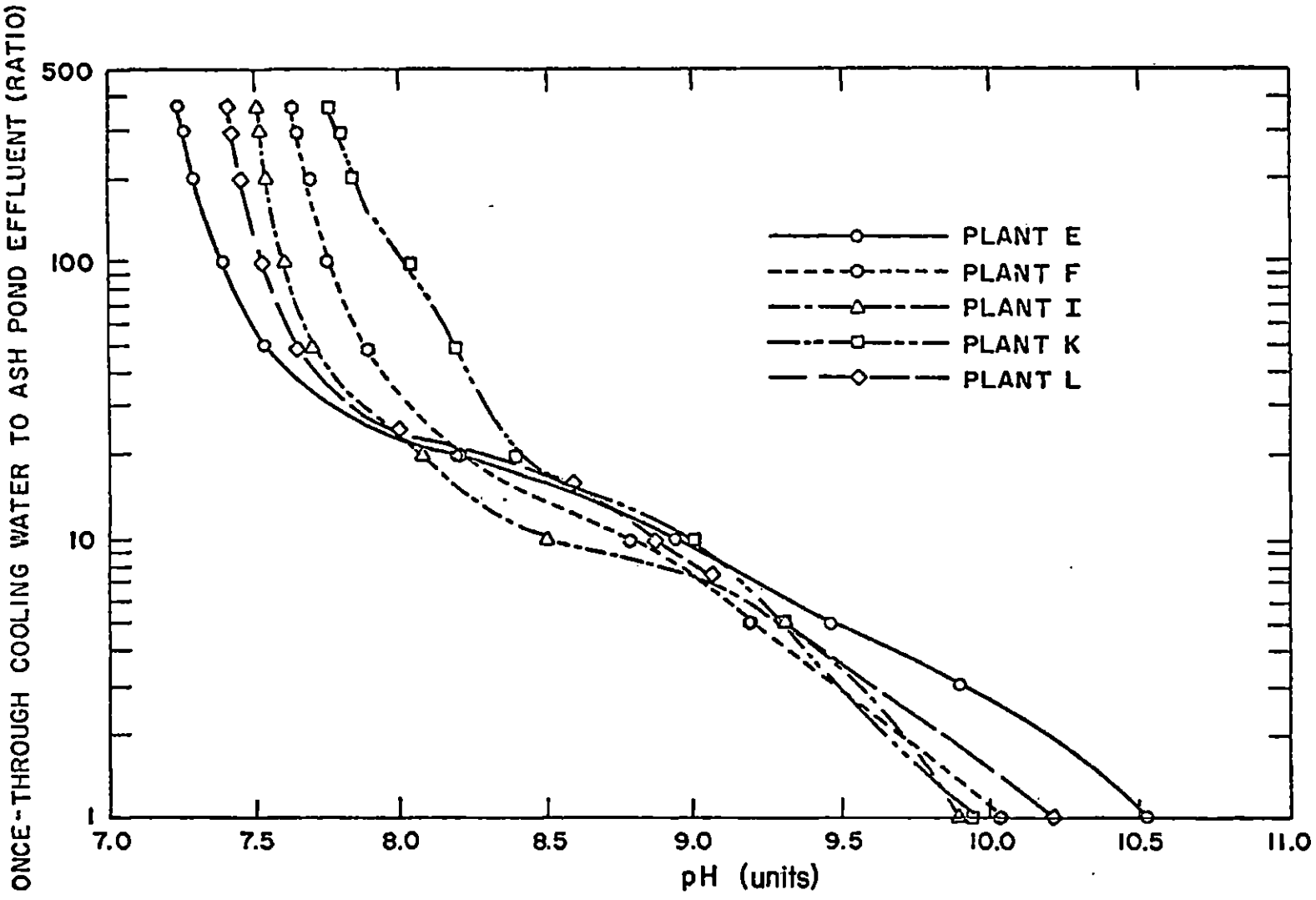

Figure 11. Neutralization of alkaline ash pond effluents with once-through cooling water.

water. However, the actual effect of pH change in cooling water is a small increase in the bicarbonate concentration and a small decrease in the carbonic acid concentration. These small changes would not measurably affect aquatic biota.

A small benefit may be derived from the reuse of ash pond effluent because the change in pH and bicarbonate ion concentration may offset the decrease in pH caused by chlorination of the condenser cooling water, thus reducing the corrosion of condenser tubes and the release of heavy metals such as iron, copper, nickel, and zinc. This effect would be small, but nonetheless may be beneficial when the overall effect of numerous installations is considered.

The major benefits of reusing the ash pond effluent in the feed to the condenser are economic. The benefits of essentially eliminating treatment costs and eliminating the need for adding treatment chemicals to the discharge with no potential adverse ecological effects makes the reuse of ash pond effluents as feed to the condenser cooling water the most practical method available.

SECTION 6

ASH SETTLING

In the course of treating ash sluice water, both "discrete particle settling" and "flocculent settling" take place. Because of the generally high ash concentration in ash sluice water, with interaction and agglomeration of the ash particles, flocculent settling first takes place. Discrete particles settling then occurs for the remaining ash particles and can be analyzed by means of the classic laws of sedimentation formulated by Newton and Stokes.[54] The terminal settling velocity of discrete particles is a function of particle size and density. In the design of a settling pond, the usual procedure is to select a particle with a terminal velocity and to design the basin so that all particles that have a terminal velocity equal to or greater than the specified terminal velocity will be removed. When flocculation occurs, both overflow rate and detention time become significant factors for design. Obviously, the degree of flocculation will be influenced by the initial concentration of suspended solids. The design of ash settling tanks or ponds should include laboratory ash settling analysis of both discrete and flocculent settling behavior. In all cases, one has to account for turbulence, short circuiting, and other interferences that do not occur in the laboratory. Short circuiting in tanks or ponds can be characterized by tracer techniques. The introduction of a plug of dye, salt, or radioactive material into the inlet gives a concentration distribution in the effluent stream that is characteristic of the flow patterns.

PARTICLE SIZE DISTRIBUTION OF ASHES USED FOR SETTLING TESTS

At plants A and E, all the fly ash is collected by electrostatic precipitators. At plant J, the fly ash is removed from stack gas by mechanical collectors followed by electrostatic precipitators. Table 7 shows the size distribution and specific gravity of fly ashes that were collected at these three different steam plants. The specific gravities fall into the range of 2 to 3, except in the size fractions of large particles. The reason for this low specific gravity of large particles may be that the large particles contain some cenospheres. These cenospheres do not settle, but float on the top surface of settling columns. Removal of cenospheres was not considered in this settling study.

The cumulative particle size distribution of fly ashes used for this study is shown in Figure 12. For fly ashes collected by electrostatic precipitators, there were more than 50 percent of the particles less than 10μm; however, for fly ashes collected by mechanical collectors, there were about 50 percent of the particles greater than 40 μm.

TABLE 7. FLY ASH PARTICLE SIZE ANALYSIS

Particle size (μm)	Weight fraction	Specific gravity
Plant J - mechanical collector (cyclone)		
<6.4	0.044	2.28
6.4 - 9.2	0.047	2.43
9.2 - 12.9	0.089	2.34
12.9 - 17.3	0.128	2.40
17.3 - 23.5	0.109	2.31
23.5 - 27.3	0.032	2.35
27.3 - 38.0	0.033	2.55
>38.0	0.518	1.63
Plant J - electrostatic precipitator		
<3.3	0.269	2.23
3.3 - 6.5	0.245	2.17
6.5 - 9.6	0.181	2.21
9.6 - 13.4	0.142	2.14
13.4 - 18.3	0.107	2.14
18.3 - 29.9	0.041	1.59
>29.9	0.015	*
Plant E - electrostatic precipitator		
<3.1	0.237	2.56
3.1 - 5.9	0.134	2.67
5.9 - 8.9	0.103	2.60
8.9 - 11.8	0.096	2.80
11.8 - 16.1	0.073	2.77
16.1 - 21.1	0.062	2.85
21.1 - 23.1	0.022	2.58
23.1 - 44.0	0.056	2.66
>44.0	0.196	1.80
Plant A - electrostatic precipitator		
<3.0	0.195	2.56
3.0 - 5.8	0.171	2.77
5.8 - 9.0	0.140	2.53
9.0 - 11.5	0.132	2.91
11.5 - 16.9	0.103	2.52
16.9 - 22.0	0.108	2.64
22.0 - 30.8	0.039	2.45
30.8 - 44.0	0.044	2.83
>44.0	0.068	2.13

*Not analyzed.

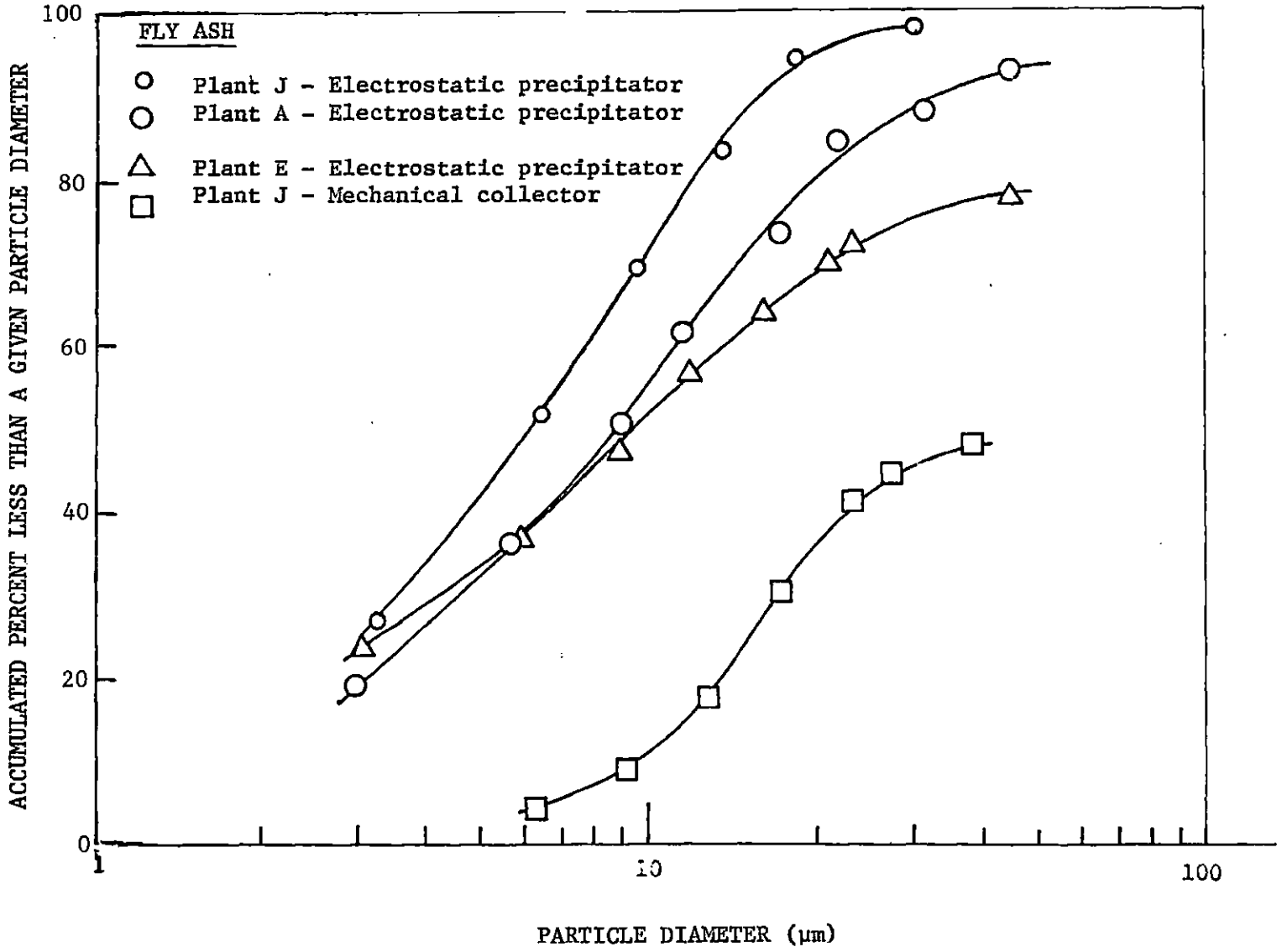

Figure 12. Particle size distribution curves of fly ashes used for settling test.

The fly ash collected by electrostatic precipitators at plant J was the finest, because most of the coarse particles were removed by mechanical collectors ahead of electrostatic precipitators. The particle size distribution curves of fly ashes collected by electrostatic precipitators at plants A and E were lower than that of fly ash collected by mechanical collectors at plant J, because both coarse and fine fly ashes were collected by electrostatic precipitators at Plants A and E.

A sample of bottom ash was obtained from plant J. Grab samples were collected at the end of bottom ash sluice pipe at 5-s intervals during sluicing; all samples were then combined. The particle size distribution and specific gravity of the bottom ash were analyzed, and the results are given in Table 8. The particle size distribution of bottom ash from plant J ranged from about 0.075 to greater than 2 mm, and the specific gravity was about the same as that for fly ash.

The fly and bottom ashes collected from plants A, E, and J were used for the settling study.

ASH SETTLING CHARACTER

Settling studies were carried out by using a column with five sampling ports, as shown in Figure 13. Fly ash collected from the electrostatic precipitators or mechanical collectors was weighted and soaked in tapwater in a bucket; it was then poured into the column, where the tapwater was mixed by a stirrer. The ash-water mixture was then mixed for a few minutes to achieve complete mixing, and samples were taken from ports 1, 3, and 5 to determine the initial suspended solids concentration. As soon as the stirrer was turned off, the settling study started and the samples were taken from the five ports at various time intervals. The time interval after the stirrer was turned off is defined as t, the time of ash settling, and is independent of depth. The time intervals selected for this study generally ranged from 10 minutes to approximately 9000 minutes.

A typical plot of settling curve of suspended solids concentrations at five different depths versus settling time is shown in Figure 14. The sharp drop of suspended solids concentrations at the initial period indicates a hindered-zone settling behavior at this initial high concentration of suspended solids (48,000 mg/l). The zone (defined as an interface between the flocculent particles and the clarified supernatant) settled at a uniform velocity under conditions of hindered settling, and the velocity is a function of the concentration.[54] Unfortunately, the interface between the particle-liquid zone was not visible because of the very fine particles remaining in the clarified zone, which made it impossible to monitor the position of the interface to study the clarification capacity. Instead, a graphical method was used to find the velocity of the interface, as shown in Figure 15, where the suspended solids concentration was plotted as a function of the reciprocal of the settling veolcity t/z (t is again the time of ash settling and z is the vertical distance of ash settling measured from the water surface). This figure clearly shows the settling behavior

TABLE 8. SIZE DISTRIBUTION OF BOTTOM ASH FROM PLANT J

Ash size (μm)	Weight percent	Specific gravity
>2000	45.6	a
2000-420	40.4	2.17
420-147	9.4	2.35
147-75	2.6	2.23
<75	1.8	2.38

[a]Very heterogeneous as to size and porosity--specific gravity not run.

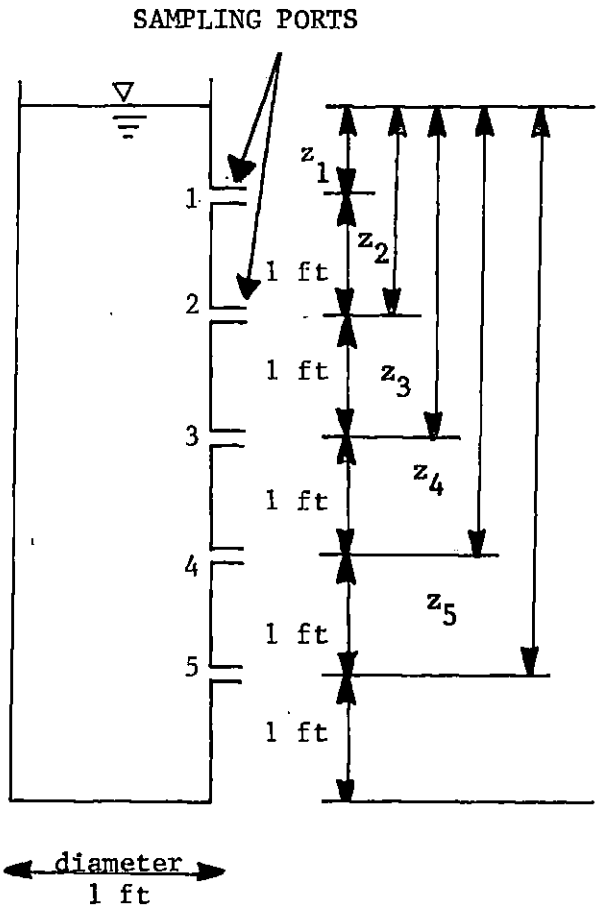

Figure 13. Quiesent settling column with sampling ports (1 ft = 30.48 cm).

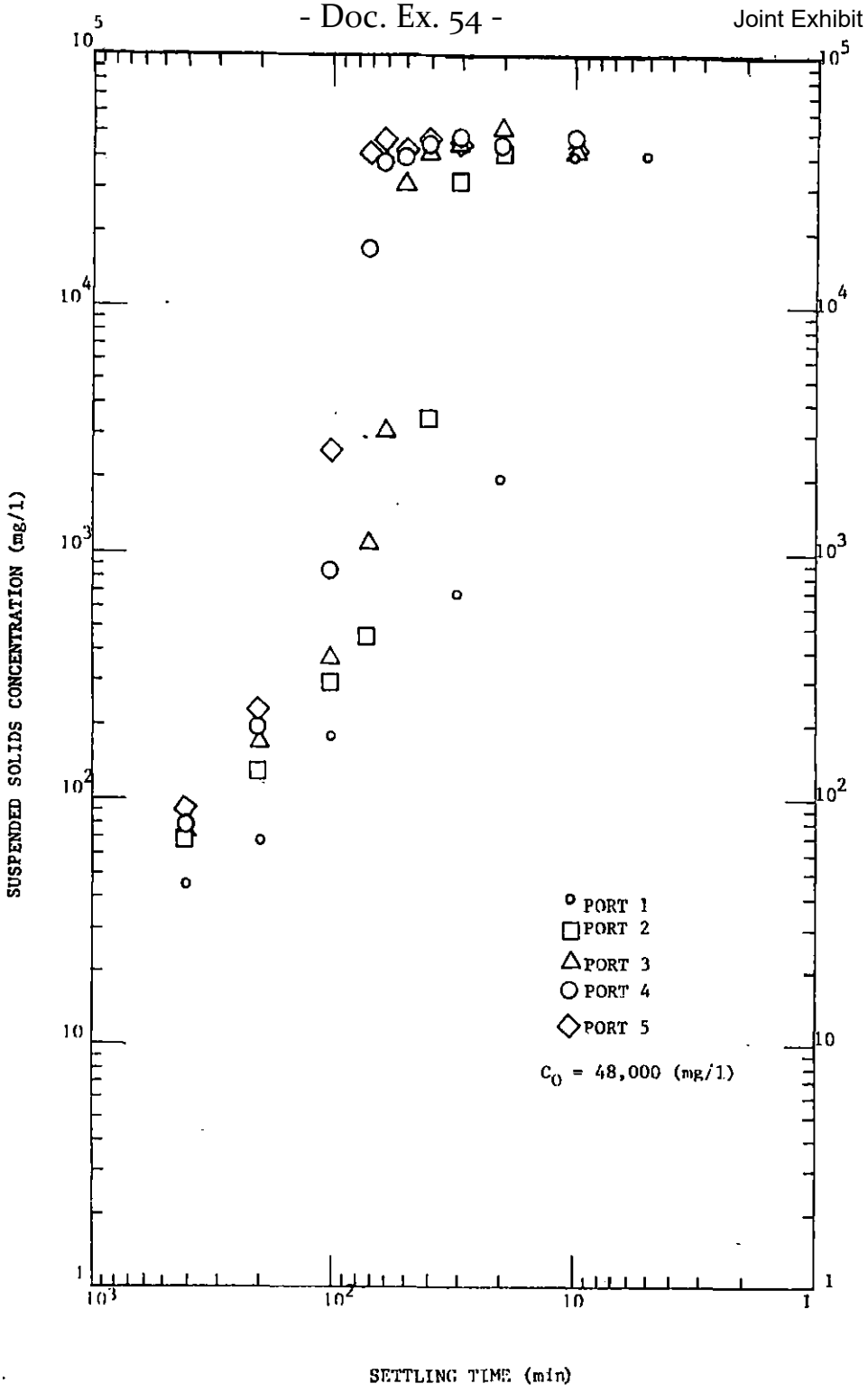

Figure 14. Suspended solids concentration vs. settling time (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_o = 48,000 mg/l).

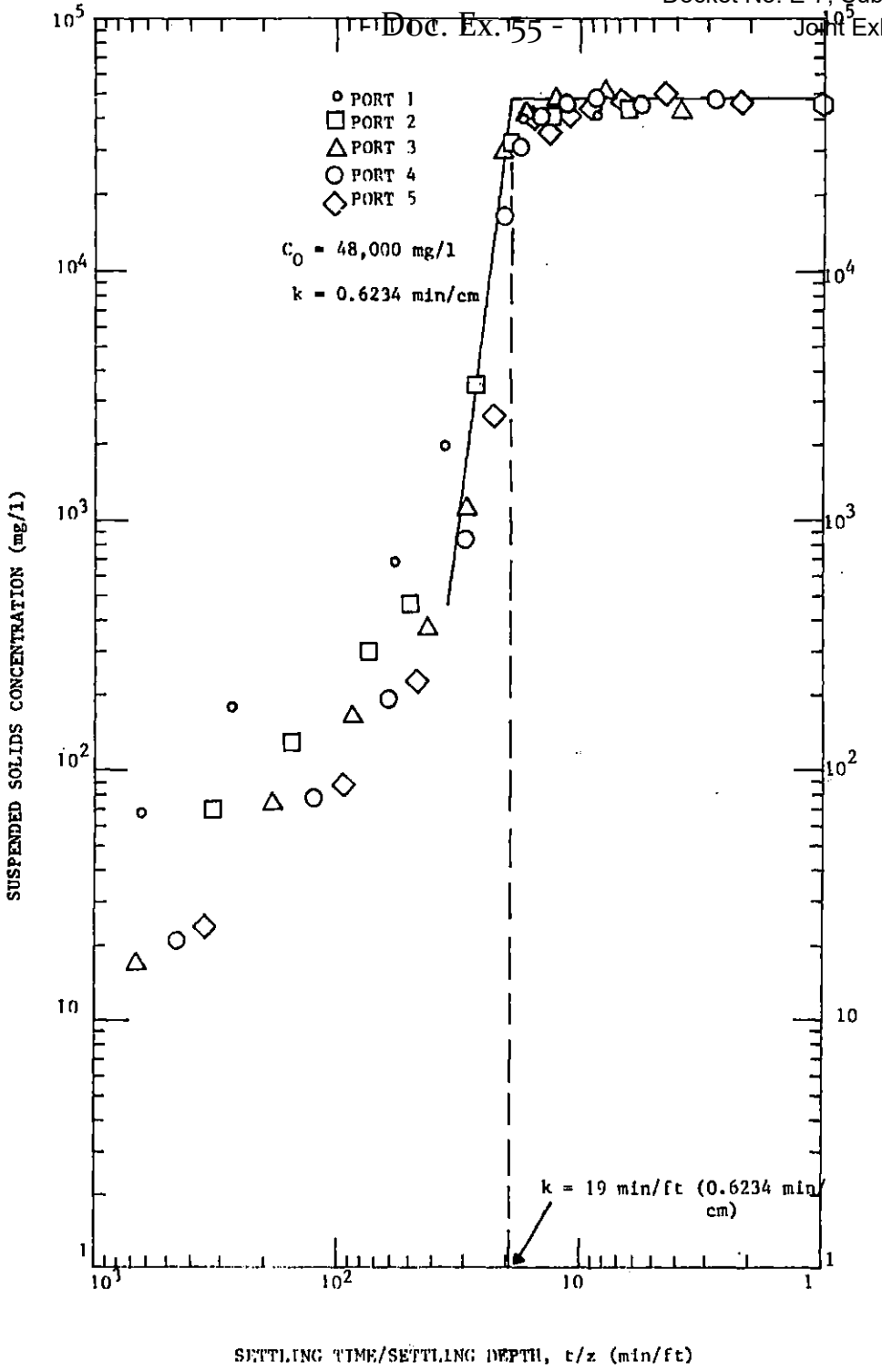

Figure 15. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 48,000 mg/l).

of the zone so that its settling velocity can be determined graphically by finding an intersection point of two lines described in the figure. The value of t/z at this point is denoted as k, which is 19 min/ft (0.6234 min/cm). The settling velocity of the zone is the reciprocal of k at that point of 0.0526 ft/min (1.604 cm/min).

If a suspended solids concentration of less than 30 mg/l is desired in the effluent from the sedimentation basin, this will depend on the degree of fine ash particle settling after the zone settling. An attempt was made to use concepts of discrete particle settling and flocculent suspention, developed by Camp[55] and O'Connor and Eckenfelder,[56] respectively, to estimate the removal efficiency of sedimentation basins. This attempt was not successful because the concentration gradient over depth was too shallow to get either a meaningful settling-velocity analysis curve by Camp's method, especially at the low settling velocity, or meaningful isoconcentration lines by the O'Connor and Eckenfelder method. For low suspended solids concentrations (less than 100 mg/l), the slope of the settling-velocity analysis curve was too flat and the slopes of the isoconcentration lines were too steep to use for estimating the fractional removal.

Therefore, a new approach was developed to interpret the fly ash settling data in this study.

As the interface of settling zone passes a certain point, the suspended solids concentration will change at this point at a drastic rate, but will then rapidly slow down after the interface passes. The profile of the suspended solids concentration versus settling time is assumed to be a straight line. This assumption is accurate enough to analyze the settling data and predict the performance of a sedimentation tank, especially if the low suspended solids concentration range is of prime interest. For low concentration of suspended solids, the rate of ash settling is very slow.

This concept was applied to the data in Figures 14 and 15 to generate Figure 16, where the suspended soldis concentration was plotted as a function of a new variable, t - kz, which indicates the time measured after the interface of hindered settling zone passed the settling depth z. Here k is a value obtained from Figure 15. Figure 16 clearly describes a well-defined relationship for all of the data, which were obtained from five different ports.

The theoretical retention time, t_d, requirement for ash settling can be determined by the following equation:

$$t_d = \frac{DA}{Q} \qquad (5)$$

where

D = depth of sedimentation basin or pond,
A = area of sedimentation basin or pond, and
Q = flow rate of ash transport water into a sedimentation basin or pond.

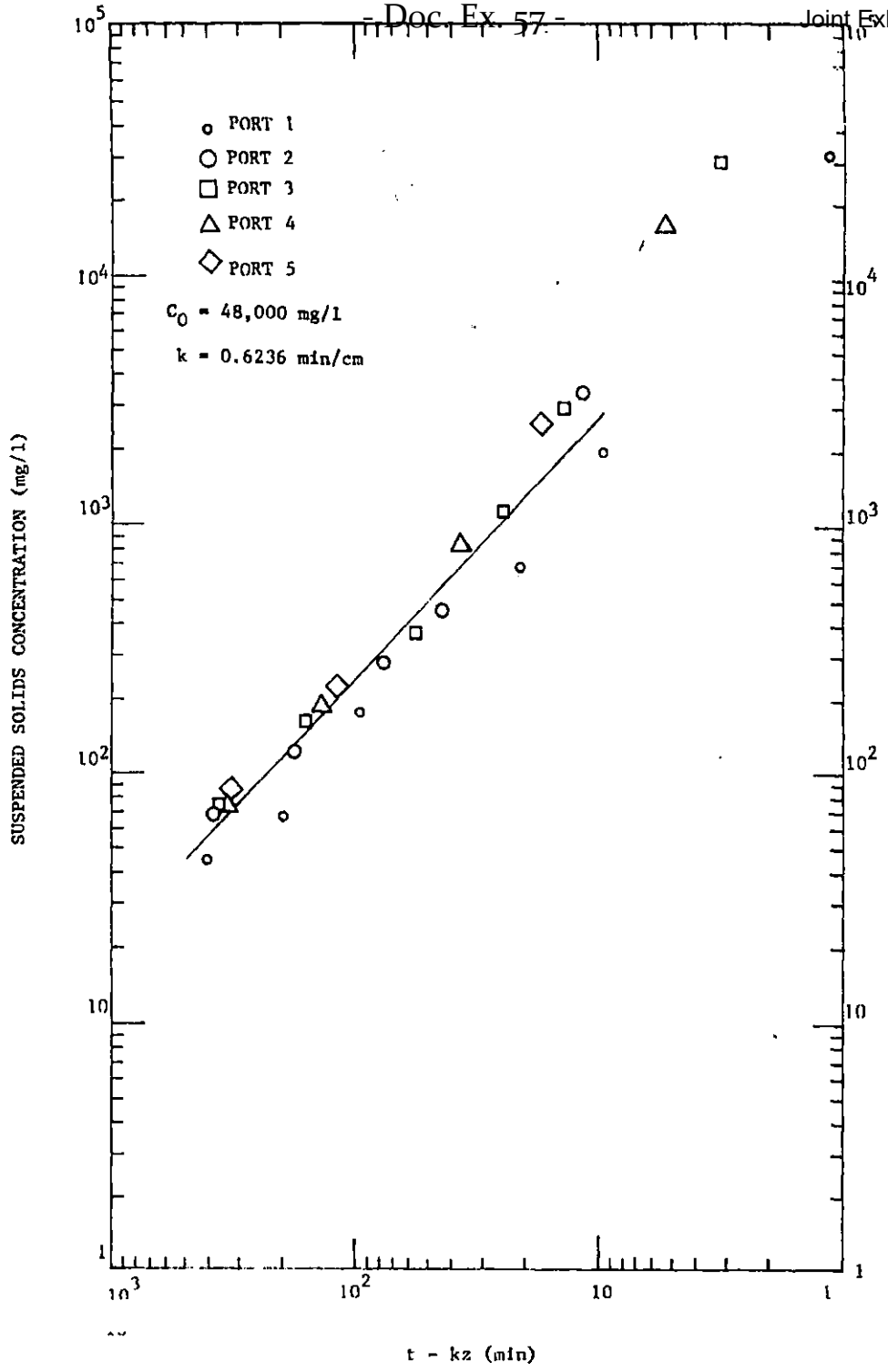

Figure 16. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 48,000 mg/l).

In Figure 16, the data can be described by a straight line. The relationship of instantaneous suspended solids concentration in effluent to any instantaneous settling time t and vertical settling depth z can be expressed as below:

$$\ln C = a \ln (t - kz) + \ln b, \tag{6}$$

where

C = suspended solids concentration, mg/l
a,b = constants.

For these specific data, a and b are found to be -1.0546 and 31,000, respectively. Then the average suspended solids concentration in the effluent, C_{eff}, over the whole depth of the settling basin or pond at a retention time t_d will be

$$C_{eff} = \frac{1}{D} \int_o^D C dz = \frac{b}{kD(a+1)} [t_d^{a+1} - (t_d - kD)^{a+1}], \tag{7}$$

where $t_d \geq kD$ and $a \neq -1$. (8)

This approach is also valid even for the case where the data follow piecewise straight lines for concentrations of suspended solids below 100 mg/l.

For some cases where the data follow a semilog paper, the relationship of an instantaneous suspended solids concentration in effluent to any instantaneous settling time and vertical settling depth can be expressed as

$$C = a \ln (t - kz) + b. \tag{9}$$

Similarly, the average suspended solids concentration in effluent will be

$$C_{eff} = \frac{1}{D} \int_o^D C dz,$$

or

$$C_{eff} = b - \frac{a}{kD} [(t_d - kD) \ln (t_d - kD) - t_d \ln t_d + kD], \tag{10}$$

where

$$t_d \geq kD. \tag{11}$$

If the data do not follow the above mathematical equations, the average suspended solids concentration in effluent still can be estimated by segmenting the depth of sedimentation basin. If the depth of basin is segmented by the positions where the sampling ports are located in Figure 13, then the suspended solids concentration in effluent can be approximated as

$$C_{eff} = \bar{C}_5 \frac{D-z_5}{D} + \bar{C}_4 \frac{z_5-z_4}{D} + \bar{C}_3 \frac{z_4-z_3}{D} + \bar{C}_2 \frac{z_3-z_2}{D} + \bar{C}_1 \frac{z_2-z_1}{D} + \bar{C}_0 \frac{z_1}{D}, \quad (12)$$

where

$\bar{C}_i$ = average suspended solids concentration of C_i and C_{i+1} at $t = t_d$, mg/l,

C_i = suspended solids concentration at $z = z_i$, mg/l.

$\bar{C}_i$ is obtained from Figure 16 by reading C_i and C_{i+1} at $(t_d - k_i z)$ and $(t_d - k_{i+1} z)$, respectively, after drawing a smooth curve to cover the settling data.

To invesigate the effect of initial concentration of suspended solids on settling, two additional experiments using different initial concentration (C_o) were performed and the results are shown in Figures 17, 18, 19, and 20, Although all these cases yielded straight lines in plots of suspended solids concentrations versus t - kz (Figures 16, 18, and 20), it was not possible to determine any general trend on the effect of C_o. A more extensive study is needed to determine this trend and express it in a mathematical relationship, which will allow prediction of the settling performance for a given initial suspended solids concentration. A qualitative analysis is described later in this report.

Similar experiments were conducted for the ashes collected by the electrostatic precipitators at plants A and E; the results and analyses are shown in Figures A-1 through A-12 in appendix A. The settling of these ashes showed piecewise straight lines on plots of suspended solids concentrations versus t - kz except in Figure A-12. Table 9 shows the values of constants that were obtained from the graphical methods and figures. These constants can be used to estimate the suspended solids concentration in effluent from the sedimentation basin by using Equations 7, 10, or 12.

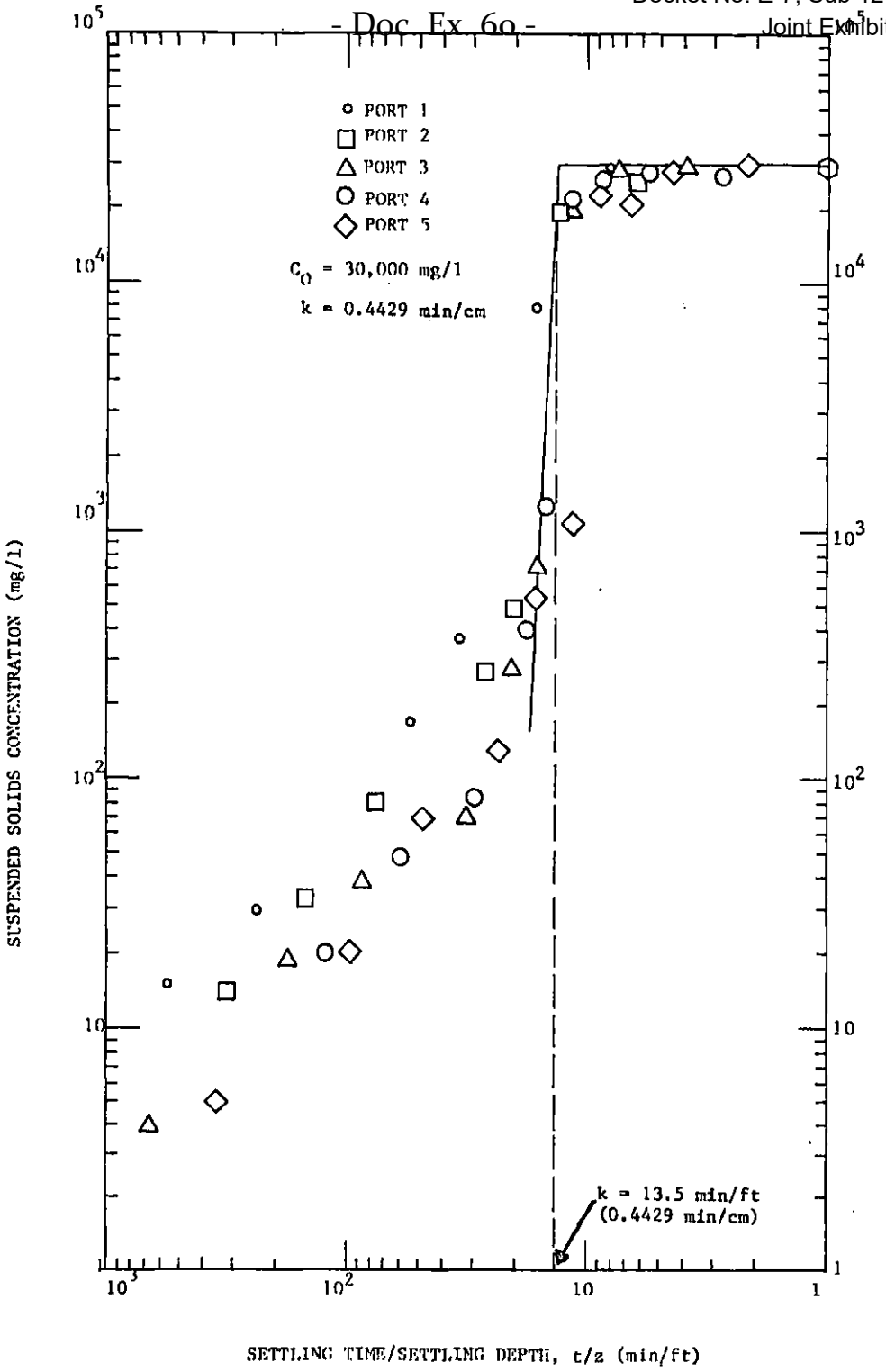

Figure 17. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 30,000 mg/1).

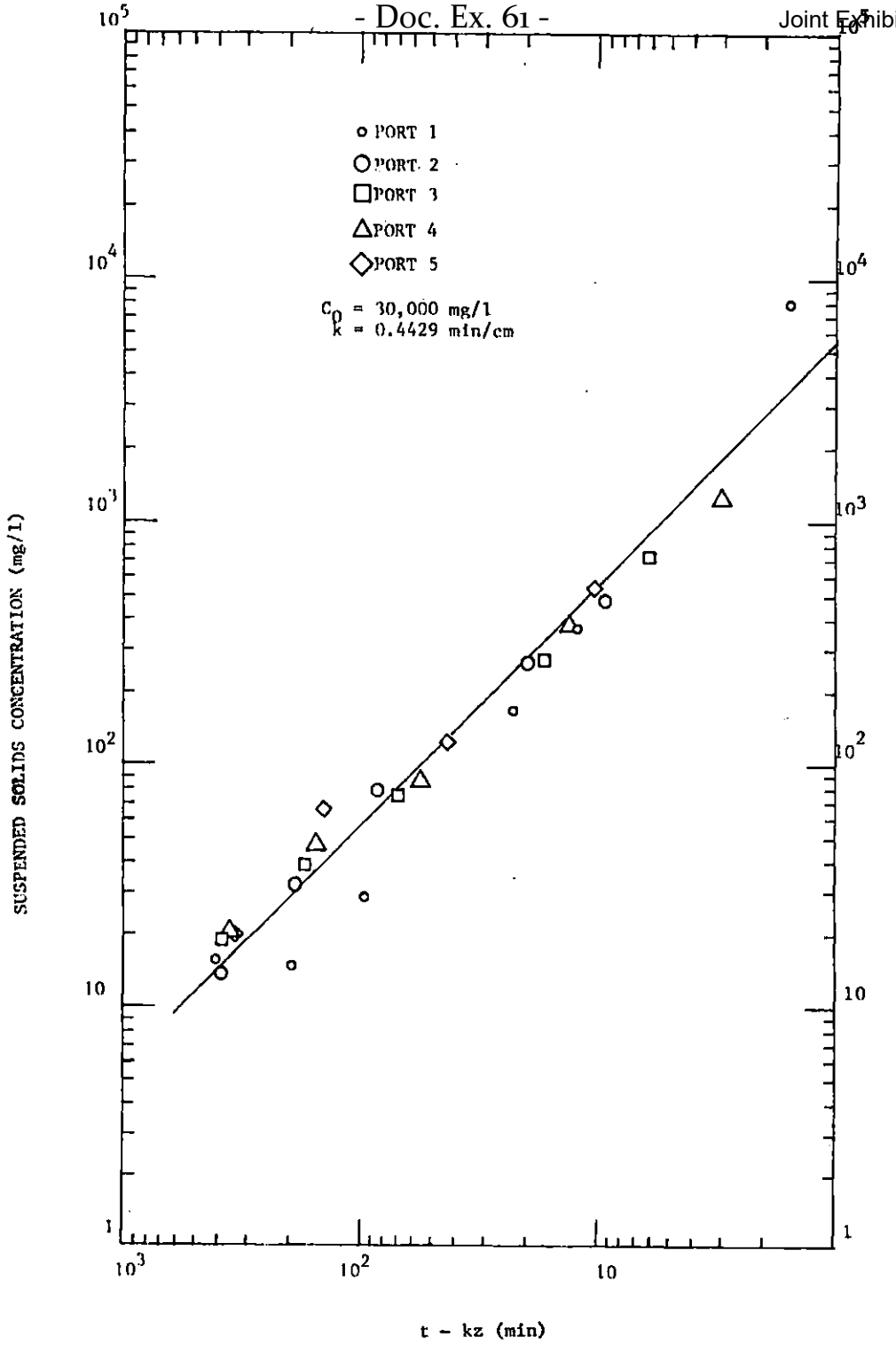

Figure 18. Suspended solids concentration vs t - kz (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 30,000 mg/l).

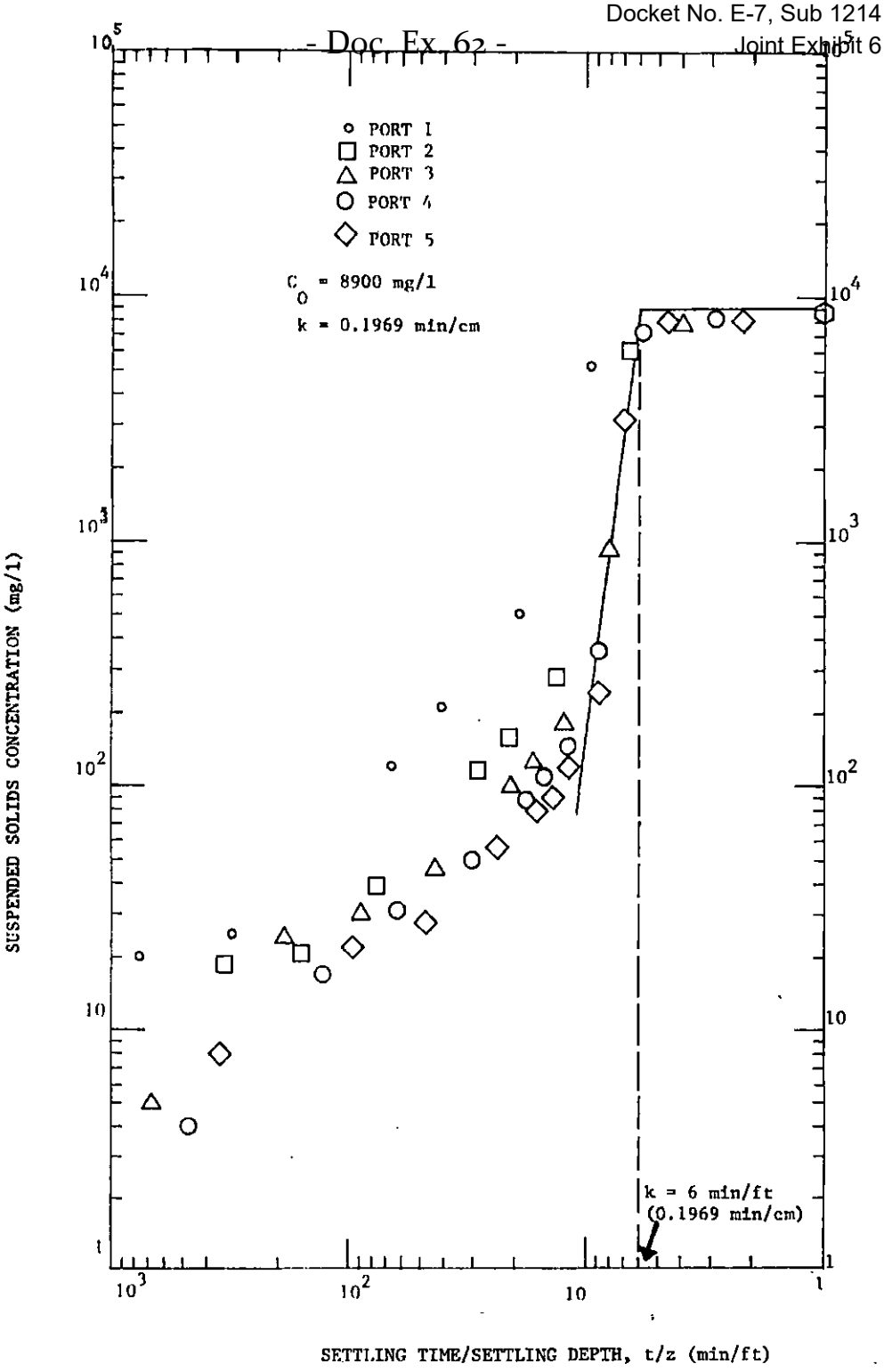

Figure 19. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_o = 8900 mg/l).

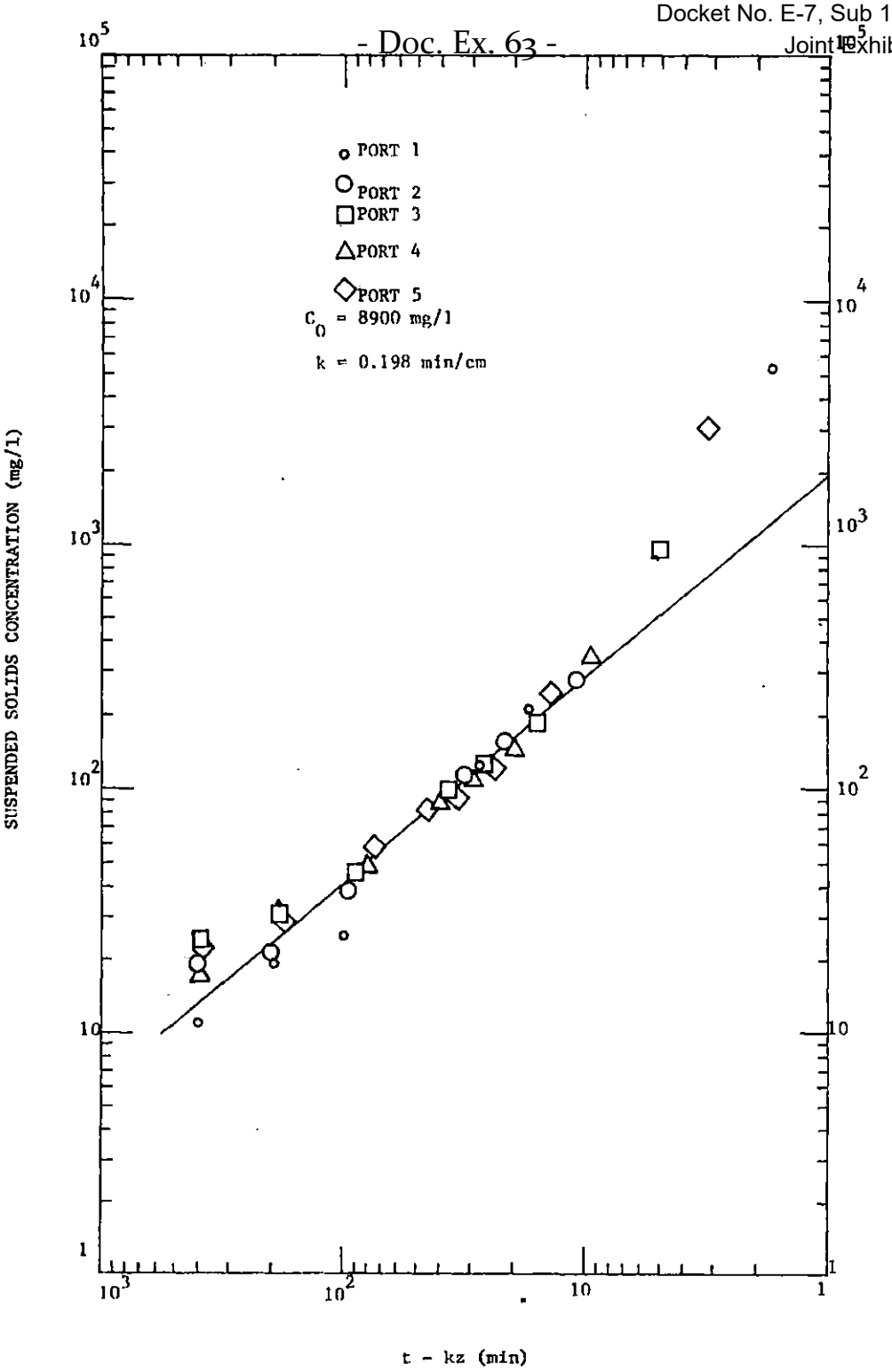

Figure 20. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 8900 mg/l).

TABLE 9. VALUES OF CONSTANTS FOR SETTLING CURVES

Plant	C_0 (mg/l)	Equation used	Range of R* (min)	k (min/cm)	Constant** a	Constant** b
J--electrostatic precipitator	48,000	(6)	R>10	0.6234	-1.0546	31,000
	30,000	(6)	R>10	0.4429	-0.9895	5,300
	8,900	(6)	R>10	0.198	-0.8373	1,950
E--electrostatic precipitator	35,000	(6)	60.5>R>5	0.3117	-0.5374	770
	35,000	(6)	R>60.5	0.3117	-0.2904	275
	22,000	(6)	200>R>10	0.2364	-0.8480	2,100
	22,000	(6)	R>200	0.2364	-0.0774	35
	5,800	(6)	70>R>10	0.1101	-0.6052	850
	5,800	(6)	R>70	0.1101	-0.2973	230
A--electrostatic precipitator	31,000	(6)	200>R>5	0.5414	-0.8722	9,100
	31,000	(6)	R>200	0.5414	-0.5321	1,500
	18,000	(6)	280>R>10	0.4593	-0.9064	11,000
	18,000	(6)	R>280	0.4593	-0.424	720
	6,000	(6)	R>5	0.1773	-0.8466	2,600
J--mechanical collector	30,000	(6)	180>R>10	0.2198	-1.1431	17,200
	30,000	(6)	R>180	0.2198	-0.4175	3,900
	17,500	(6)	250>R>10	0.1837	-1.0524	11,200
	17,500	(6)	R>250	0.1837	-0.5222	590
	4,500	(6)	R>5	0.16404	-0.9798	8,700
South Chickamauga Creek	140	(9)	R>10	0.19685	-18.559	174.9

*$R = t - kz$.

**Units for constants a and b are mg/l-min and mg/l, respectively.

Results of the settling studies on fly ash collected by mechanical collectors or cyclones at plant J are shown in Figures A-12 through A-18. The settling velocity of hindered zone of this fly ash was about twice as fast as that collected by electrostatic precipitators at C_o = 30,000 mg/l (compare k values in Figure 17 and A-13 and in Table 9). This increased velocity is expected because the larger and heavier particles are collected by cyclones. However, the mechanically collected fly ash showed a slower settling behavior in the clarified zone (the zone behind the hindered settling zone) than did the ash collected by the electrostatic precipitator (Figures 18 and A-14). This difference in settling behavior is quite interesting if the wide differences in particle size distribution (Figure 12) between the two ashes are considered.

The difference in settling behavior illustrates again that the very fine particles play a major role for achieving a low suspended solids concentration of the effluent from the clarification process, since the relatively heavier particles are removed at the initial stage through hindered-zone settling. In Figure 12, less than 30 percent of fly ash particles collected by electrostatic precipitators are greater than 20 μm, whereas more than 60 percent of fly ash particles collected by mechanical collectors are larger than 20 μm. The hindered-zone settling of ash collected by the electrostatic precipitators seems to entrap more fine particles than that of the ash collected by mechanical collectors, thus leaving a lower concentration of suspended solids behind the zone. This entrapment phenomenon could result from the fact that the coarser particles of mechanically collected ashes had less chance of interaction with the finer particles because of the fewer particles and the less contact time, or settling time, than did the ashes collected by electrostatic precipitators. Examination of Figures A-14, A-16, and A-18 for the settling of mechanically collected fly ash shows that the data do not differ much, except for the low suspended solids concentration, whereas data for the electrostatic precipitator fly ash vary significantly. This may indicate that the hindered settling zone only minimally affects the initial removal of fine particles in mechanically collected ash, whereas it significantly affects the settling of ash collected by electrostatic precipitators.

The velocity of hindered settling zone (reciprocal of k) decreased with the increase of initial suspended solids concentration, as shown in Figure 21.

To investigate the applicability of this graphical approach to the settling of suspended solids in river water, a sample was collected from the South Chickamauga Creek, Chattanooga, Tennessee, after a rainfall and a settling study was conducted by placing the sample in a settling column. The movement of hindered settling zone could hardly be observed in this case, as shown in Figure 22. The rate of sedimentation was relatively slow, probably because of the fine silt, clay materials, and other low-density materials present; it took more than two days to reduce the suspended solids concentration to 30 mg/l. By estimating

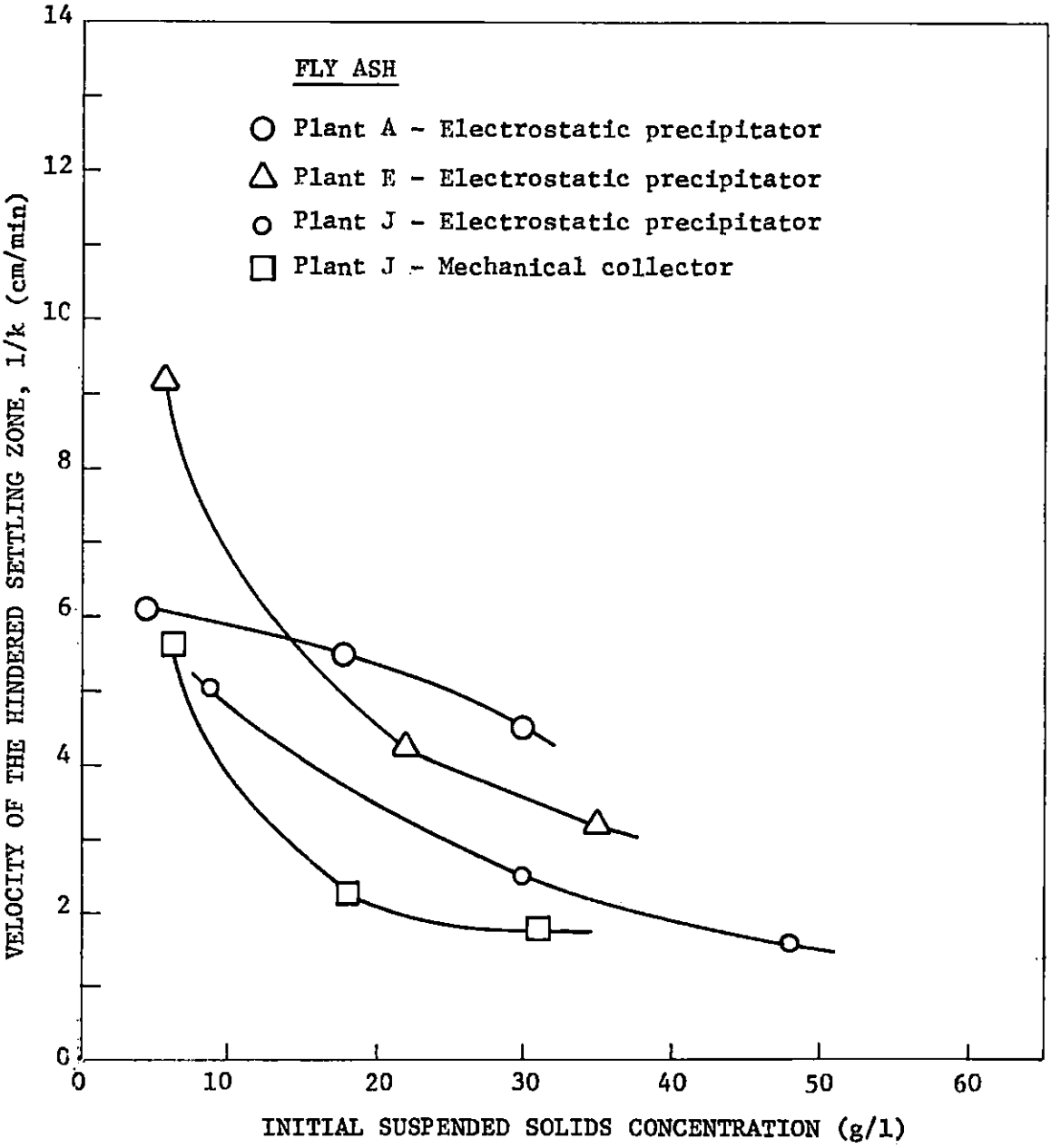

Figure 21. Velocity of the hindered settling zone vs. the initial suspended solids concentration of ash settling.

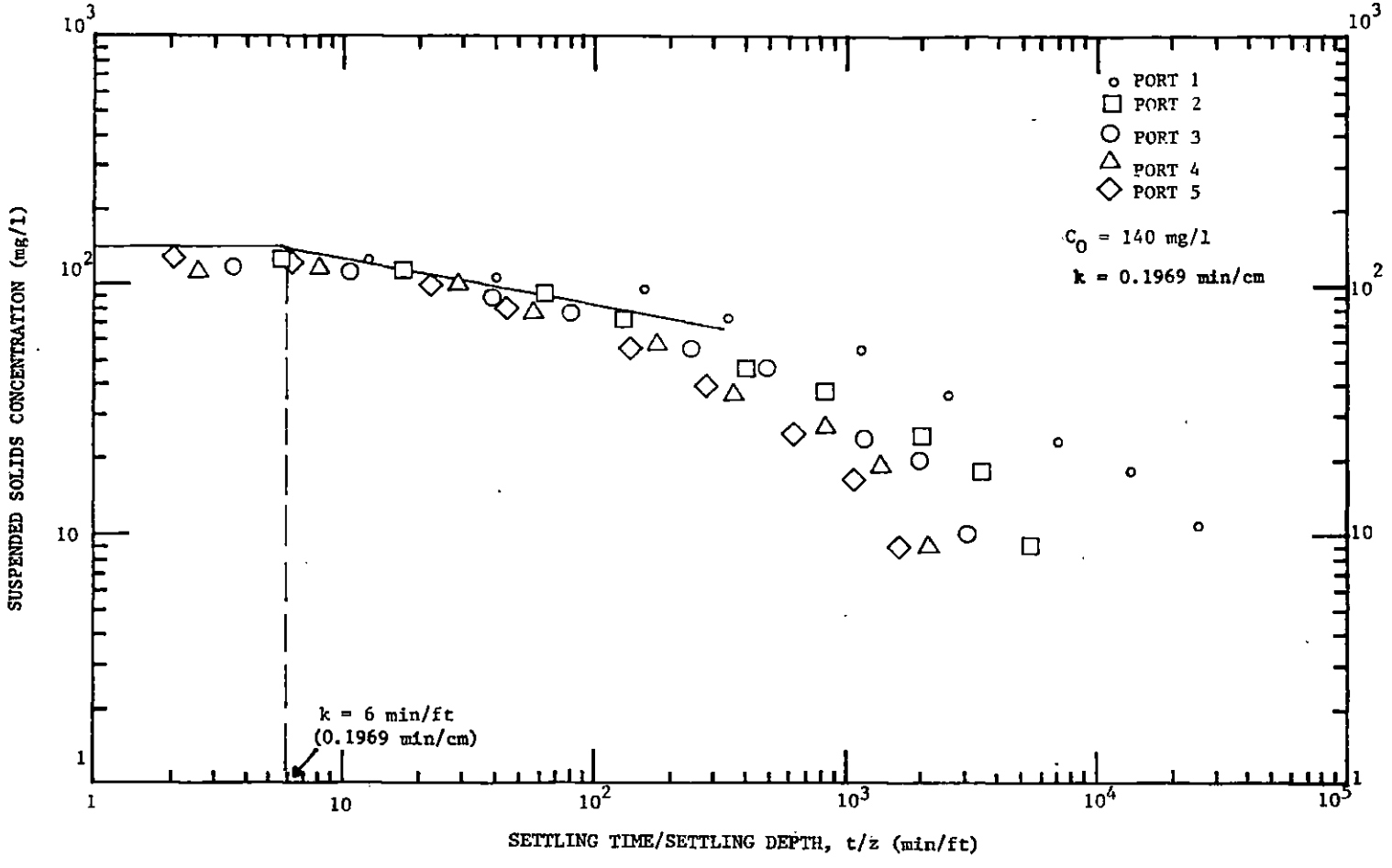

Figure 22. Suspended solids concentration vs. the reciprocal of settling velocity (river water from South Chickamauga Creek; initial suspended solids concentration C_0 = 140 mg/l).

the best k value (Figure 22), it was found that the suspended solids concentration followed Equation 9, as shown in Figure 23. Whether this slow settling resulted from the different nature of suspended solids present or from the very low initial suspended solids concentration (140 mg/l), or both, is not clear. The constants for Equation 9 are shown in Table 9, and the effluent concentration of the sedimentation basin can be estimated by Equation 10.

The effect of initial concentration of suspended solids on the behavior of zone settling was studied by conducting a series of experiments on the lower initial suspended solids concentrations (390 to 3800 mg/l) of electrostatic precipitator fly ash from plant J. The results are shown in Figures A-19 through A-24. The settling rate was greater for the higher than for the lower initial concentrations of suspended solids in this range (390 to 3800 mg/l); these results are opposite to the previous cases for which the initial suspended solids concentration was high (8900 to 48,000 mg/l) (Figures 15 through 20). The behavior of hindered zone settling seems to become less evident for initial concentrations of suspended solids less than 8900 mg/l.

Examination of settling data over the concentration range of 390 to 48,000 mg/l (Figures 15 through 20 and Figures A-19 through A-24) show the degrees and changes of particle interaction for different initial concentrations of suspended solids. Up to 8900 mg/l the increase in suspended solids concentration enhances the settling rate, probably because of the flocculating type of interaction in which large particles become even larger by colloiding with the small particles. However, the suspended solids concentration is still not high enough to form a hindered settling zone. As the suspended solids concentration increases further, however, the settling rate is reduced because of the increase in hindrance and the formation of a hindered zone. This is shown in Figures 16 and 18 for suspended solids concentrations of 48,000 and 30,000 mg/l, respectively.

At this higher concentration of suspended solids, (greater than 8900 mg/l), more water is displaced by settling in the hindered zone. Therefore, behind the hindered settling zone, the relatively high disturbances induced by the flow of displaced water can prevent the residual fine ash particles from settling. The poorer settling of fine particles for very high and very low initial suspended solids concentrations indicates that an optimum initial concentration gives the best settling. For the case of electrostatically precipitated fly ash from plant J, the optimum initial concentration for suspended solids seems to be about 8900 mg/l. This optimum initial concentration of suspended solids appears to be a point at which the suspended solids concentration is (1) high enough to provide the particle interaction necessary for the formation of larger particles, and (2) low enough to reduce the turbulence resulting from the rise of displaced water caused by the zone settling at high concentrations of suspended solids.

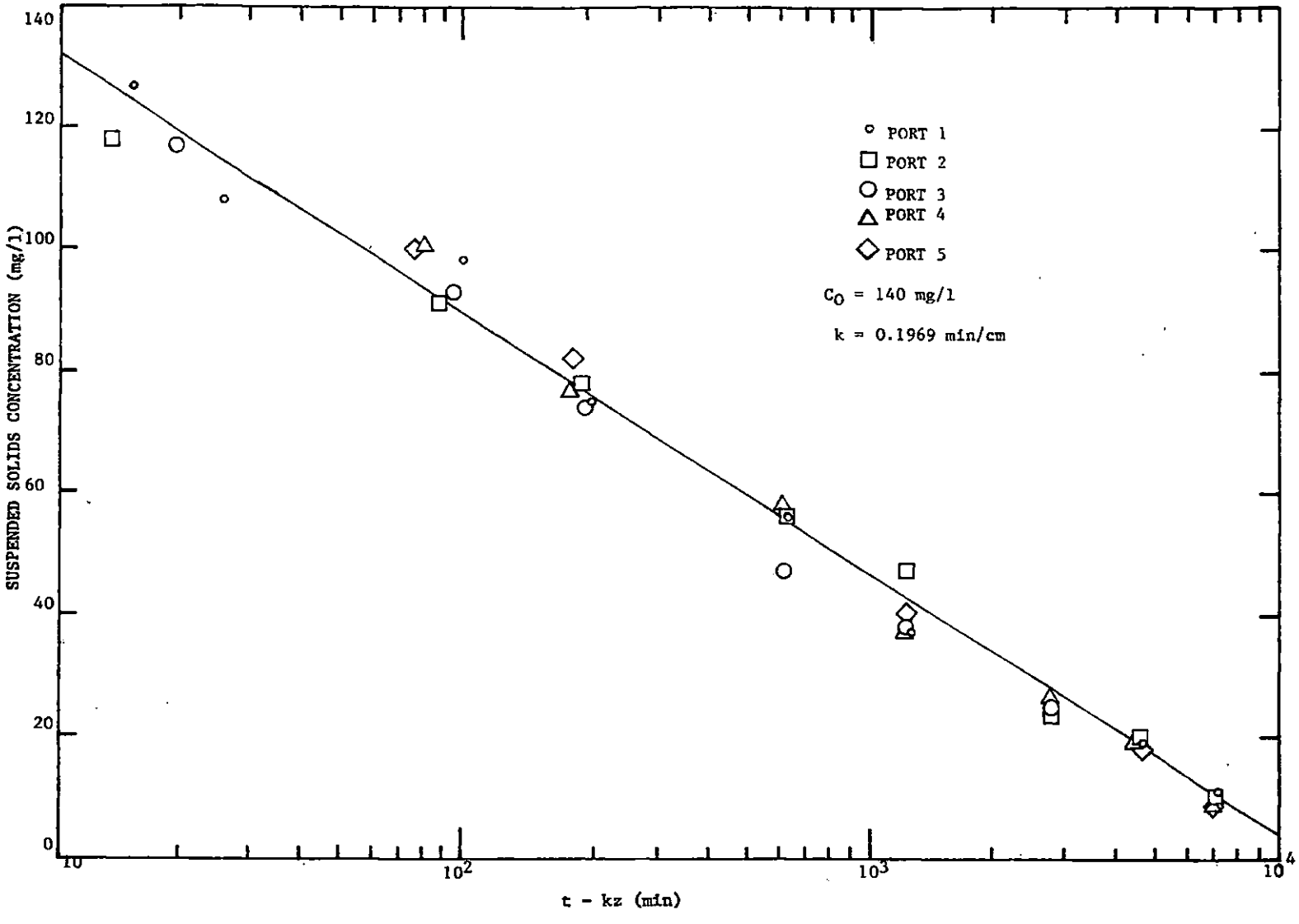

Figure 23. Suspended solids concentration vs. t - kz (river water from South Chickamauga Creek; initial suspended solids concentration C_0 = 140 mg/l).

A similar result was observed in settling of the mechanically collected fly ash from plant J, as shown in Figures A-25 and A-26. The degree of hindrance was reduced at an initial suspended solids concentration of 3000 mg/l (Figure A-25), as compared with the previous cases where the initial suspended solids concentrations were 30,000, 17,500, and 4500 mg/l (Figures A-13, A-15, and A-17). At the initial suspended solids concentration of 3000 mg/l, more fine particles escaped from the hindered settling zone (Figure A-26) than in the previous cases (Figures A-12, A-14, and A-16), probably due to the reason that was discussed earlier.

Bottom ash settling tests were performed at two initial ash concentrations, 30,000 and 10,000 mg/l. Results of the ash settling tests are presented in Figures A-27 and A-28. Bottom ash, due to its relatively large particle size, settled much faster than the fly ash. Also, the settling characteristics of bottom ash differed from that of fly ash; that is, no distinction was found between the behavior of high and low suspended solids concentrations in the hindered settling zone during bottom ash settling. After about two minutes of bottom ash settling, only the fine particles, representing about 2 percent of the initial ash weight, were suspended in the water. However, these fine bottom ashes behave like the fine fly ashes left behind the hindered zone.

SECTION 7

CHARACTERISTICS OF ASHES

Coals contain various elements found in the earth's crust, including various rare elements (Table 3). The mineral in coal comes from the (1) inherent matter in the plants from which the coal bed forms and (2) extraneous matter that is deposited in the coal bed from outside by mechanical means (e.g., dust deposited from the atmosphere or suspended and dissolved material carried by water). Most of the mineral matter of coal is extraneous. After combustion, many trace and rare elements have been found concentrated in the ashes of coals[27,29,31,35,39] despite the different chemical properties of coals. The chemical characteristics of ashes from individual pieces of coal may also vary widely, even when the pieces are selected from closely adjacent places in the same seam. Three mass balance studies have been conducted at three TVA steam plants.[24,29,58] Many toxic trace metals were found to be enriched to a significant extent in the combined particulate and vapor phases of stack gas. These toxic metals may leach into water when ash contacts water by ponding or landfill.

The distribution of major elements in fly and bottom ashes is approximately the same, but more trace metals are concentrated in fly ash than in bottom ash. Fly ash has been characterized within TVA. Table 10 presents the chemical properties of fly ashes from 11 TVA steam plants.

Fly ash contains cenospheres, which are thin-walled hollow spheres, 20 to 200 μm in diameter, that float on water. Some coarse-size cenospheres are either particles filled with smaller spheres (plerospheres) or particles that have a thicker wall with a porous and irregular surface. The formation of cenospheres is dynamic, and gases of CO_2 and N_2 are trapped inside the sphere.[59] The proportion of cenospheres in fly ash is probably affected by the nature of minerals in the coal being burned,[19,59] fusing temperature, type of boiler, and efficiency of fly ash collection. Almost all coal-fired power plants produce cenospheres. At some power plants, the cenospheres are sufficient to form a thick layer of floating material on the surface of ash ponds. Laboratory tests were conducted to determine the amounts of cenospheres produced at several TVA steam plants, and the cenospheres were defined as those fly ashes with a specific gravity less than one and floating on water for more than three days. The results in Table 11 indicate that the contents of cenospheres range from 0.02 to 0.13 percent by weight in fly ash collected by electrostatic precipitators and from 0.1 to 0.42 percent by weight in fly ash collected by mechanical collectors. To meet the effluent limitations guidelines for suspended solids, discharge of cenospheres into the ash pond effluent must be prevented at some ash ponds.

TABLE 10. CHEMICAL COMPOSITION OF FLY ASHES FROM TVA STEAM PLANTS[a,b]

	Plant A ESP	Plant C ESP	Plant D ESP	Plant E ESP	Plant E MC	Plant F ESP	Plant G ESP	Plant H MC	Plant I ESP	Plant I MC	Plant J ESP	Plant K ESP	Plant K MC	Plant L ESP
Alumina (Al_2O_3), %	20.4	22.7	29.6	16.2	16.6	17.5	23.7	25.7	24.7	20.9	26.5	25.1	20.6	21.6
Calcium (CaO), %	1.8	1.7	0.8	5.1	4.6	7.0	2.8	1.3	1.9	1.6	1.1	2.1	3.0	2.3
Iron (Fe_2O_3), %	21.1	11.3	3.8	23.0	29.0	20.3	13.7	12.3	12.9	18.4	12.2	12.4	24.3	4.9
Magnesium (MgO), %	0.9	0.93	0.9	1.1	1.0	1.3	1.1	1.1	1.3	1.0	0.9	1.2	1.0	0.9
Potassium (K_2O), %	2.9	-	2.7	2.3	2.4	2.9	2.8	3.1	3.3	2.6	2.8	3.0	2.2	2.3
Silica (SiO_2), %	47.4	47.6	57.5	47.6	42.5	47.9	48.6	51.2	51.8	51.5	48.7	52.4	45.2	48.3
Sodium (Na_2O), %	0.2	2.7	0.7	0.6	0.4	0.8	0.6	0.3	0.4	0.2	0.2	0.9	0.5	0.3
Sulfur (SO_3), %	1.6	-	0.4	1.4	1.2	1.5	2.6	0.5	1.4	0.4	0.7	1.0	0.5	0.7
Titanium (TiO_2), %	1.2	-	1.7	0.8	0.8	0.9	1.2	1.1	1.1	1.0	1.2	1.1	0.9	1.0
Beryllium (Be), ppm	14	-	12	8.7	8.4	5.5	12	11	13	7.3	8.5	12	8	7.3
Cadmium (Cd), ppm	5.3	8.0	<1	3.6	5.4	1.7	6.8	<1	5.1	<1	<1	9	<1	<1
Chromium (Cr), ppm	170	300	180	160	135	140	160	145	130	120	150	170	140	155
Copper (Cu), ppm	160	140	195	89	91	89	145	145	150	76	150	230	130	110
Lead (Pb), ppm	120	80	69	95	49	53	125	31	105	15	49	105	30	37
Manganese (Mn), ppm	285	298	51	328	395	635	255	240	250	255	230	70	245	345
Nickel (Ni), ppm	150	207	115	88	100	81	115	100	115	91	105	115	97	120
Vanadium (V), ppm	150	440	130	490	235	235	230	125	160	115	130	130	120	150
Zinc (Zn), ppm	965	740	97	398	435	395	790	190	550	140	175	920	310	300
Specific gravity	2.69	2.69	2.13	2.53	2.66	2.48	2.42	2.11	2.6	2.3	2.07	2.45	2.4	2.24
Mean fly ash particle diameter, μm	11.4	-	10.4	8.4	9.8	13.3	6.3	14.7	3.8	13.5	10.3	5.2	15.6	17.1

[a]ESP--electrostatic precipitator; MC--mechanical collector.

[b]Data based on one grab sample from each plant.

TABLE 11. PERCENTAGE OF CENOSPHERES IN FLY ASHES

Fly ashes	Cenospheres in fly ashes (%)
Plant A--electrostatic precipitator	0.022
Plant C--electrostatic precipitator	0.034
Plant E--electrostatic precipitator	0.042
Plant E--mechanical collector	0.094
Plant H--electrostatic precipitator	0.037
Plant H--mechanical collector	0.422
Plant J--electrostatic precipitator	0.132
Plant J--mechanical collector	0.173
Plant K--electrostatic precipitator	0.092
Plant K--mechanical collector	0.101
Plant L--electrostatic precipitator	0.080
Plant L--mechanical collector	0.177

Also, cenospheres were collected from two acid ash ponds and one alkaline ash pond, and samples were analyzed for both the principal and trace constituents. The results in Table 12 show that the chemical composition of cenospheres is similar to that of fly ash, except that the soluble constituents such as alkaline metals are lower in cenospheres than in dry fly ash because those cenospheres have already been in contact with water in the pond for several days. However, when cenospheres enter the discharges, they can contribute to both suspended solids concentration and total concentration of trace metals in ash pond effluents.

TABLE 12. CHEMICAL COMPOSITION OF CENOSPHERES

Constituent	Plant A[a]	Plant E[b]	Plant J[c]
Alumina (Al_2O_3), %	24.93	20.73	18.70
Calcium oxide (CaO), %	0.06	14.91	0.01
Iron oxide (Fe_2O_3), %	4.07	6.59	4.43
Magnesium oxide (MgO), %	0.50	0.98	0.73
Potassium oxide (K_2O), %	3.01	4.22	4.58
Silica (SiO_2), %	45.00	41.90	42.86
Sodium oxide (Na_2O), %	0.22	0.69	0.3
Sulfur oxide (SO_3), %	NA	0.19	NA
Titanium oxide (TiO_2), %	1.50	1.22	1.63
Arsenic, µg/g	45	10	94
Cadmium, µg/g	<1	<1	<5
Chromium, µg/g	<5	32.5	70
Copper, µg/g	45	41	85
Lead, µg/g	140	65	110
Mercury, µg/g	<0.1	<0.1	<0.1
Nickel, µg/g	100	140	80
Selenium, µg/g	8	8	<2
Zinc, µg/g	140	120	100

[a]Ash pond water--4.4 pH.

[b]Ash pond water--11.1 pH.

[c]Ash pond water--4.0 pH.

NA--Not Available.

SECTION 8

LEACHING OF MINERALS FROM ASHES

Inorganic materials, including trace elements, present in coal ash leach into water during ash sluicing and settling. Many trace elements apparently are located on the surface of ash particles and thus cause water quality problems at ash disposal sites. This section of the report is on laboratory leaching tests to assess the levels of minerals leached from ash into water and on mathematical analysis of mass transfer of chemical species leached from ash.

The rate of mass transfer of any chemical species from ash into water can be expressed as

$$N_A = k_m (C_i - C), \tag{13}$$

where

N_A = rate of mass transfer per unit area, g-mole/sec-cm^2,

k_m = coefficient of mass transfer between the surroundings and the surface of solids, cm/sec,

C_i = concentration of a species at the interface, g-mole/cm^3,

C = concentration of a species in the bulk liquid, g-mole/cm^3.

The concentration of a species at a given point of ash surface varies with time during leaching. The mass transfer coefficient for a single ash particle can be calculated by using the Chilton-Colburn analogy,[60] as

$$N_{Sh} = N_{Sho} + aN_{Re}^{m}N_{Sc}^{n}, \tag{14}$$

where

N_{Sh} = Sherwood number ($k_m Ly/D$),

where

L = characteristic length dimension, cm,

y = mole fraction of a species in the bulk liquid,

D = volumetric molecular diffusivity, cm^2/sec,

N_{Sho} = Sherwood number for molecular diffusion from a sphere,

N_{Re} = Reynolds number ($dV\rho/\mu$),

where

d = diameter of a sphere, cm,

V = mean velocity, cm/sec,

ρ = density of solvent, g/cm^3,

μ = viscosity, g/cm-sec,

N_{Sc} = Schmidt number ($\mu/\rho D$),

a, m, n = constants.

The N_{Sho} can be assumed to have a value of 2. Ranz and Marshall[61] obtained the following correlation for mass transfer of a component of mole fraction y in a fluid to free-falling solids:

$$N_{Sho} = 2 + 0.6N_{Re}^{1/2}N_{Sc}^{1/3}. \quad (15)$$

When ash materials are sluiced into the ash ponds or when water seeps into the ash landfills, correlations of the form of Equation 14 with or without N_{Sho} can be used to describe forced-convection rates of mass transfer only when the effects of free or natural convection are negligible. The effects of free or natural convection are negligible for Reynolds numbers that satisfy the expression,

$$N_{Re} \geq 0.4\ N_{Gr}^{1/2}\ N_{Sc}^{-1/6} \quad (16)$$

where

N_{Gr} = Grashof number for mass transfer $\{\rho^2\alpha gd\ (y_i - y)/\mu^2\}$,

where

α = concentration coefficient of volumetric expansion, dimensionless,

g = gravitational acceleration, cm/sec^2,

y_i = mole fraction of a species at the interface.

Twelve different correlations of Equation 14, with or without N_{Sho}, have been presented by various workers[62] for forced-convection mass transfer from single spheres. Recommendation of one correlation rather than another is somewhat difficult.

Reed et al.[63] determined the mass transfer coefficient of calcium ion from a Wyoming coal fly ash and produced the correlation equation,

$$N_{Sho} = 3.26 \times 10^{-5} (w/\rho_s)^{-0.78} N_{Re}^{0.21} N_{Sc}^{0.33} , \qquad (17)$$

where

w = weight concentration of solids in solvent, g/cm^3,

ρ_s = density of solids, g/cm^3.

The mass transfer coefficient was calculated as ranging from 1.3×10^{-3} to 8.3×10^{-5} cm/sec.

Based on the above theoretical analyses, many independent parameters in the dimensionless numbers can affect the mineral leaching rate of fly ash. However, principal factors may be the concentration and form of chemical species in ash, molecular diffusivity, particle size, and corresponding bulk flow velocity normal to the solid surface (or intensity of turbulence).

Kinetic studies were performed to investigate the mineral leaching rate of fly ash. Acid, neutral, and alkaline fly ashes were collected from TVA steam plants, and certain amounts of fly ash were put in beakers and mixed with water with two-blade impellers. The result of mineral leaching represented by conductivity and the corresponding pH for each of the 10 fly ashes with 3 percent ash concentration are presented in Figures 24 and 25 and Figures B-1 and B-8 in appendix B. The kinetic equilibrium curves of conductivity and pH for these ashes leveled off between 10 and 240 min after the ash and water were in contact.

In general, the rate of mass transfer of minerals for these fly ashes was rapid. This indicated that the dissolved material in the ash can leach into water within a very short period of contact time. For wet ash handling, most of the dissolved minerals will be leached out of ash during sluicing and transporting ash into ash pond. However, the ash in the bottom of the pond will continue to leach while the ash is in contact with water if the surrounding environment is changed, such as under anoxic and low-pH conditions. TVA has monitored ash pond leachate at two coal-fired power plants.[51] The interstitial water extracted from several soil core samples collected underneath the ash ponds was found to be acidic (pH about 4) even though the surface discharges of these two ash ponds were alkaline.

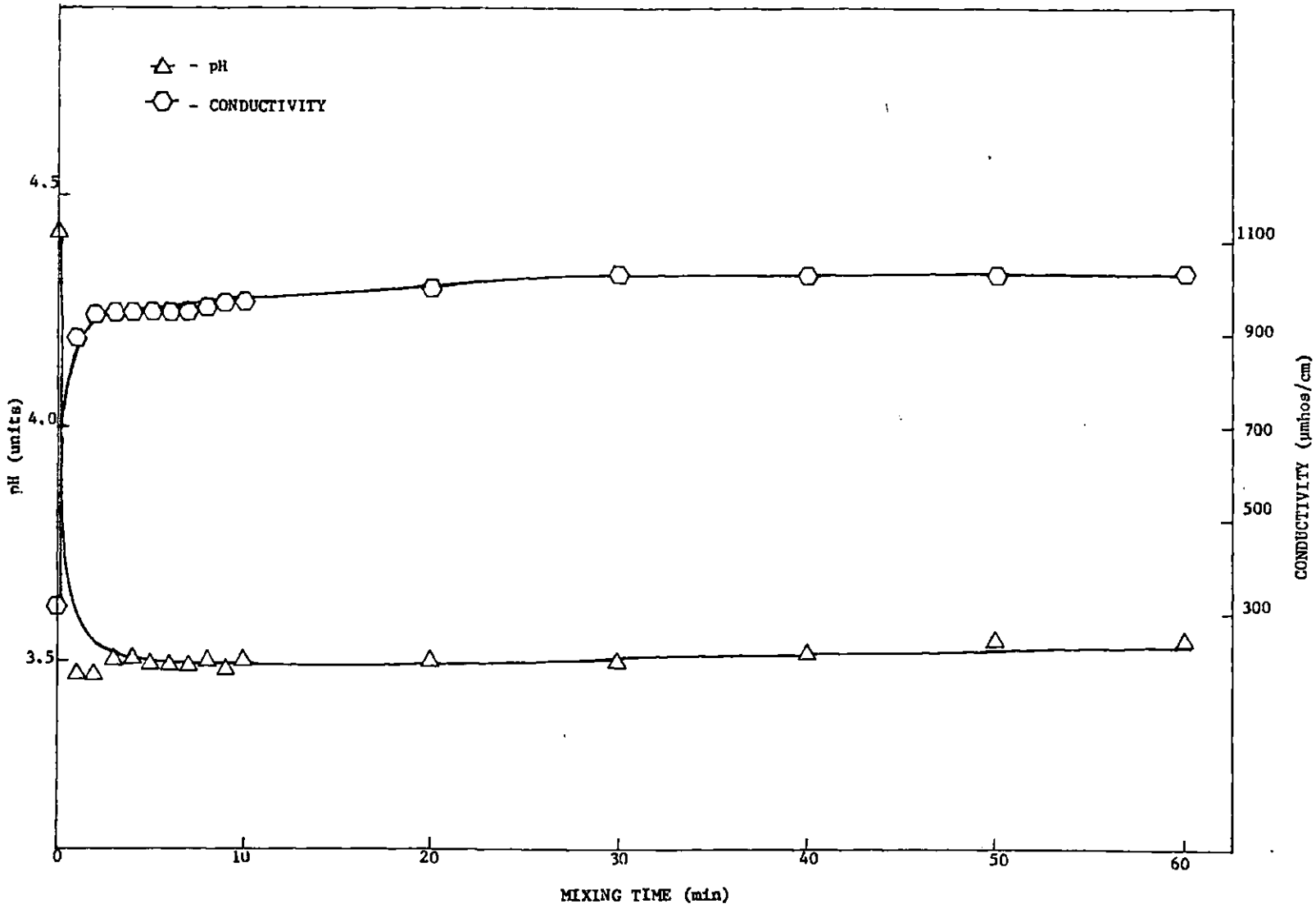

Figure 24. pH and mineral leaching rate of 3 percent electrostatic precipitator fly ash from plant A.

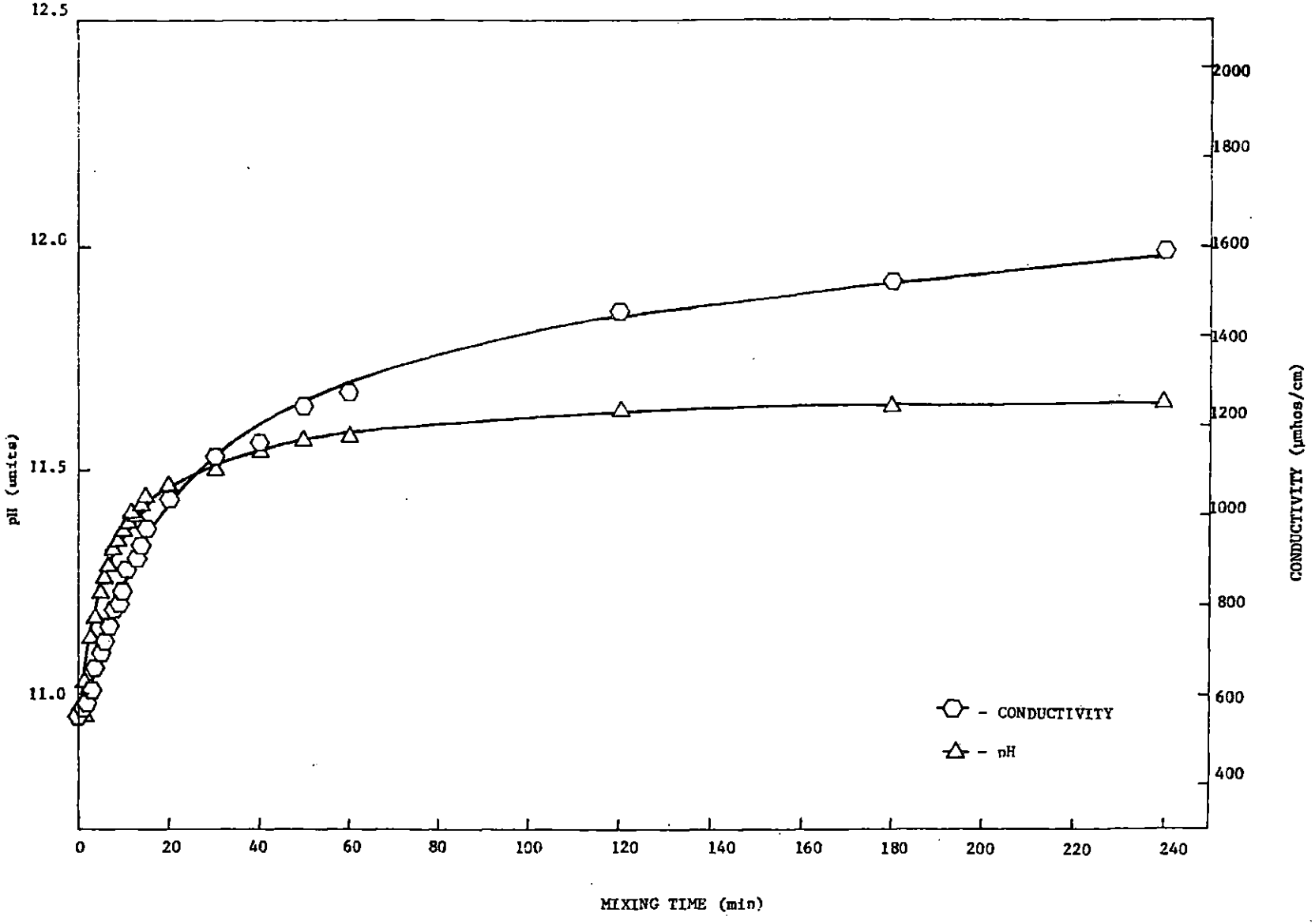

Figure 25. pH and mineral leaching rate of 3 percent electrostatic precipitator fly ash from plant E.

Laboratory leaching studies were also conducted at four different ash concentrations. The resulting kinetic equilibrium curves of conductivity and pH in Figures 26 and 27 and Figures C-1 through C-4 show that the ash concentration has a major effect on the concentration level of dissolved solids in water, but has little effect on the time of mineral leaching. Obviously, the concentration level of trace metals leaching to water significantly impacts water quality.

After the water has contacted the active sites on or in the ash particle and dissolved the soluble chemical species, the mathematical expression of the concentration of chemical species leaching from fly ash can be derived by unsteady-state molecular diffusion in a sphere. Therefore, three assumptions are made: (1) the concentration of solute is uniform at C_o through the sphere at the start of diffusion ($t = 0$); (2) the resistance to transfer in the medium surrounding the ash sphere is negligible, so that the surface concentration of the ash sphere is constant at C^* and is in equilibrium with the entire water phase; and (3) the diffusion is radial, there being no variation in concentration with angular position, and physical properties are constant. The partial differential equation for unsteady-state diffusion can be generally expressed by

$$\frac{\partial C}{\partial t} = D \left(\frac{\partial^2 C}{\partial r^2} + \frac{2}{r} \frac{\partial C}{\partial r}\right) . \tag{18}$$

The boundary conditions follow from the initial assumptions:

$$C(r,o) = C_o$$

$$C(r_s,t) = C^*,$$

$$\lim_{r \to o} C(r,t) = \text{bounded},$$

where r_s is the radius of the ash sphere.

Equation 18 can be solved by applying the methods of separating variables and Fourier series:

$$C = C^* + \frac{2r_s}{\pi} (C_o - C^*) \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{n} \frac{1}{r} \sin \left(\frac{n\pi r}{r_s}\right) \exp \left(\frac{-Dn^2\pi^2 t}{r_s^2}\right) . \tag{19}$$

The total transfer up to time t is N,

where

$$N = 4\pi r_s^2 \int_o^t - D\left(\frac{\partial C}{\partial r}\right)_{r=r_s} dt = \frac{8r_s^3}{\pi} (C_o - C^*) \sum_{n=1}^{\infty} \frac{1}{n^2} \left(1 - \exp \left(\frac{-Dn^2\pi^2 t}{r_s^2}\right)\right) \tag{20}$$

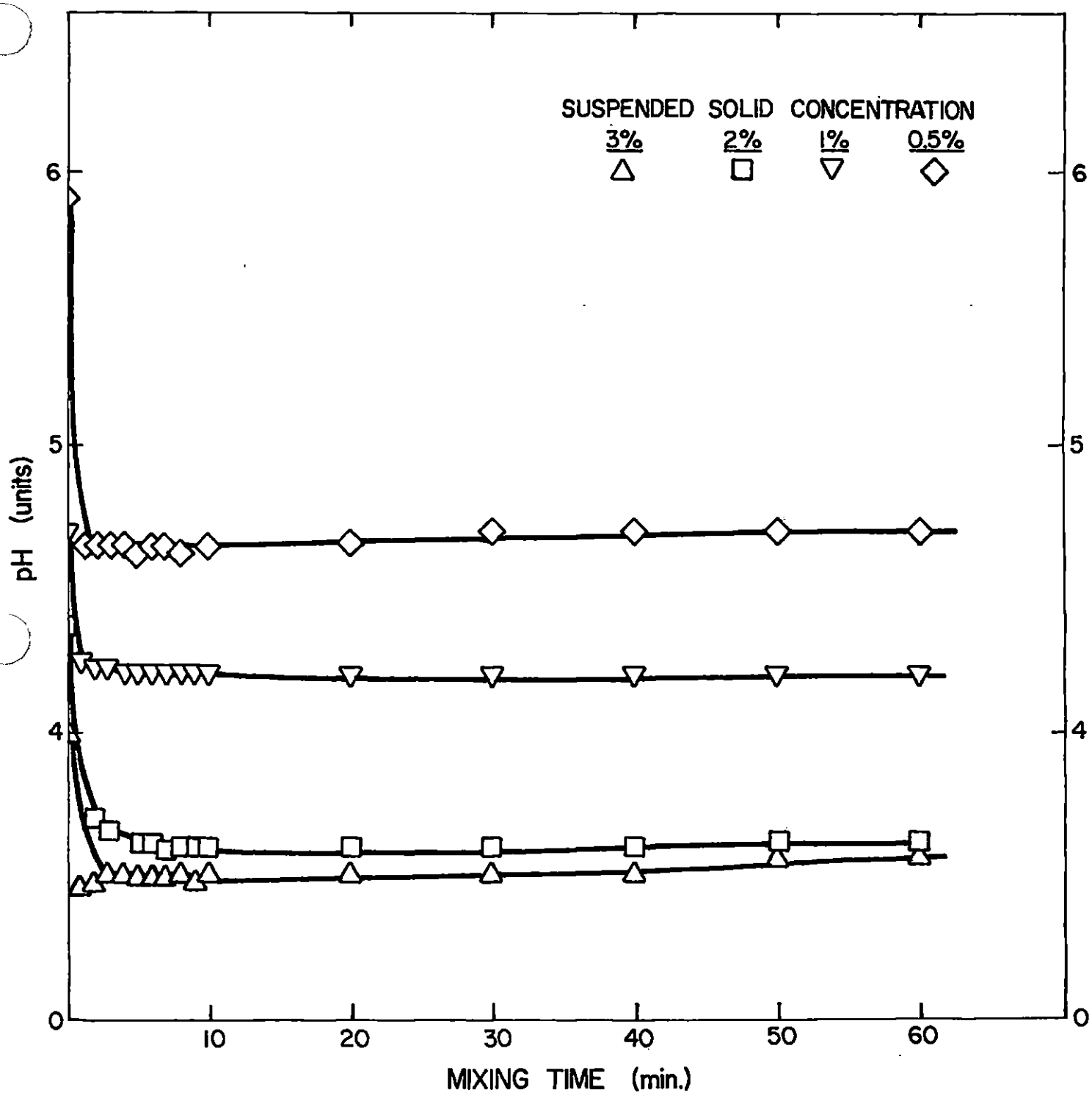

Figure 26. pH of ash transport water vs. mixing time for various ash concentrations (electrostatic precipitator fly ash from plant A).

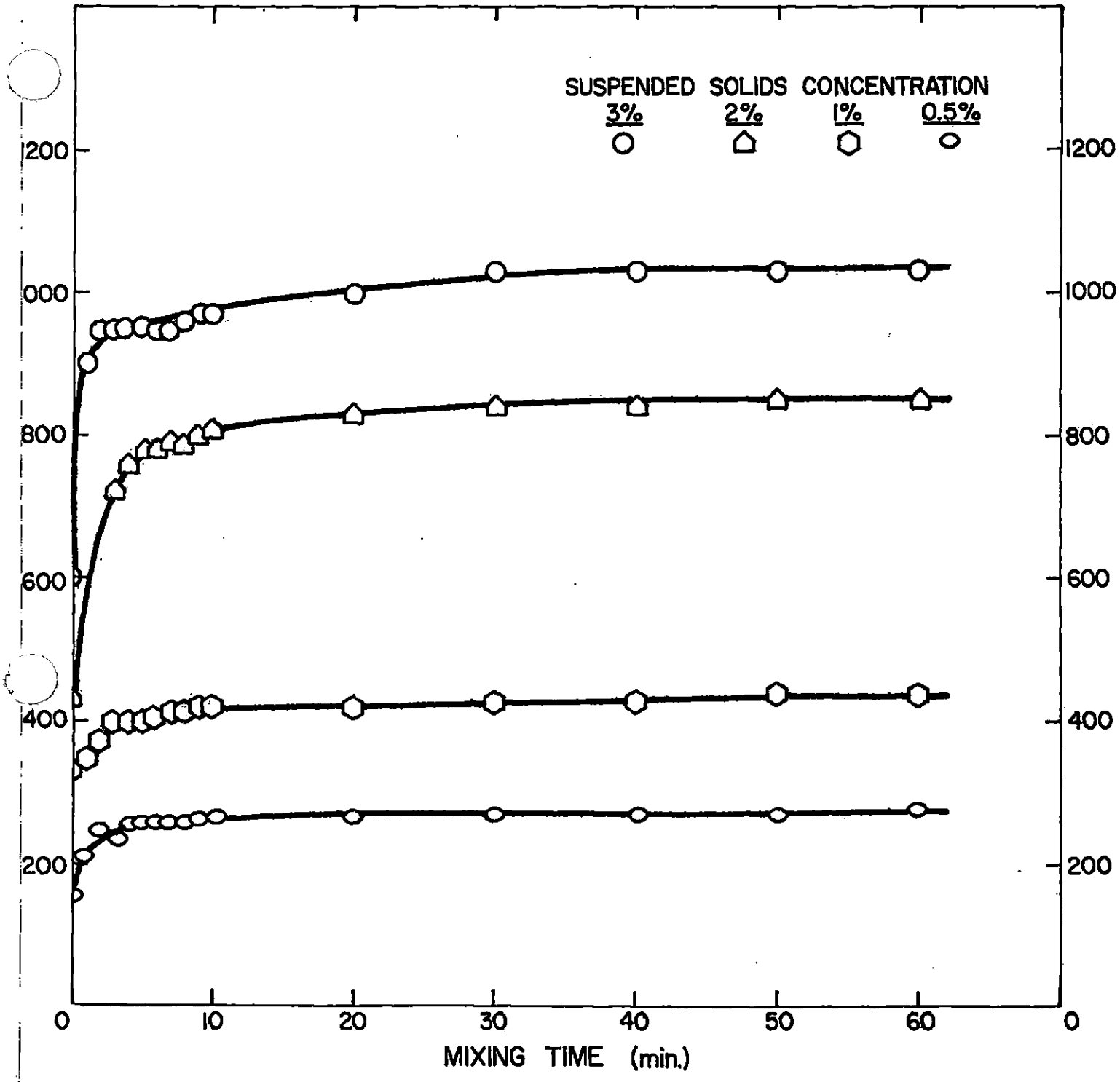

Figure 27. Conductivity of ash transport water vs. mixing time for various ash concentrations (electrostatic precipitator fly ash from plant A).

A mass balance on the transfer up to time t is:

$$(C_o - \bar{C}) \times \frac{4}{3} \pi r_s^3 = N, \tag{21}$$

in which $\bar{C}$ is the average concentration throughout the ash sphere at t. The fractional extraction from the ash sphere at time t may be defined as follows and combined with Equation 20:

$$\frac{C_o - \bar{C}}{C_o - C^*} = \frac{3N}{4\pi r_s^3 (C_o - C^*)} = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(\frac{-Dn^2\pi^2 t}{r_s^2}\right). \tag{22}$$

Skelland[62] indicated that the series in Equations 19 and 22 converge rapidly only for large times or large values of Dt/r_s^2. The previous kinetic studies show that the rate of mineral leaching from ash is rapid, or that the value of Dt/r_s^2 is small. Therefore, alternative solutions useful for small times can be derived by use of the Laplace transform. The results are in terms of an infinite series of error functions and associated functions:

$$\bar{C} = C_o + \frac{r_s}{r} (C^* - C_o) \sum_{n=0}^{\infty} \left(\operatorname{erfc} \frac{(2n+1)r_s - r}{2\sqrt{Dt}} - \operatorname{erfc} \frac{(2n+1)r_s + r}{2\sqrt{Dt}}\right), \tag{23}$$

and

$$\frac{C_o - \bar{C}}{C_o - C^*} = 6 \sqrt{\frac{Dt}{r_s^2}} \left(\frac{1}{\sqrt{\pi}} + 2 \sum_{n=1}^{\infty} \operatorname{ierfc} \frac{nr_s}{\sqrt{Dt}}\right) - 3 \frac{Dt}{r_s^2}. \tag{24}$$

where

$$\operatorname{ierfc} x = \int_x^{\infty} \operatorname{erfc} \theta d\theta = \frac{1}{\sqrt{\pi}} \exp(-x^2) - x \operatorname{erfc} x$$

Therefore, the amounts of chemical constituents leaching from fly ash depend on the available concentration and form of chemical species in ash, particle size of ash, and diffusivity of each individual species.

Laboratory studies were conducted to determine the level of mineral concentrations in ash sluice water resulting from the different ratios of ash to water in contact. The chemical composition of three fly ashes

used for this study are shown in Table 13, and these compositions are within the range of expected values reported in the literature. Representative weight fractions of ash samples were mixed with water at 20°C for 24 h and filtered. The soluble minerals leaching from ash into water should reach equilibrium levels under these conditions. The results of this study are plotted in Figures 28 through 33.

Results of the study indicated that sulfur oxides and alkaline metal oxides in the fly ash easily dissolved in water. The concentrations of sulfate and calcium built up rapidly in the water as ash concentrations increased, but their maximum concentrations depended on pH, carbonate alkalinity, and ionic strength of water. Potassium and sodium also were released readily into the sluice water and were independent of the pH value. Chlorides dissolved only slightly. The concentrations of dissolved potassium and sodium were less than the concentrations of calcium in sluice water, but the concentrations of potassium and sodium can increase linearly at high ash concentrations because of their high solubility limits. The leaching of magnesium and silicon oxides were continuously released into water, even though the silicon has a low solubility limit. However, neither magnesium nor silicon was leached from the alkaline fly ash.

According to Tables 10 and 13, silica, alumina, and iron oxides are the three major components of fly ash. The other principal components are calcium, potassium, magnesium, sodium, titanium oxides, and sulfur oxides. Among these principal components, iron and titanium were not released into the neutral and alkaline sluice waters, but were released into the acid sluice water. Aluminum was not released into the neutral sluice water; it dissolved only slightly in the alkaline sluice water, but dissolved greatly in the acid sluice water.

However, pH is not the only factor that governs the release of the components in fly ash. The total amount of dissolved salts released from fly ash also depends on (1) the content of elements in fly ash, especially the quantity of alkaline oxides and sulfur oxides in ash, and (2) the manner in which each element is held to the fly ash. These particular studies indicated that the concentrations of total dissolved solids and the conductivity in the acidic ash sluice water were higher than those in the neutral and alkaline ash sluice waters, and the concentrations of total dissolved solids and the conductivity in the alkaline ash sluice water were higher than those in the neutral ash sluice water.

The leaching of trace metals from ashes is of particular concern. Leachability of trace metals from ash is governed by the surface concentration of each trace metal in the ash matrix,[65] its chemical bonding in the ash, and pH of water with which it comes in contact. In the studies of neutral fly ash in contact with river water, chromium, lead,

TABLE 13. CHEMICAL COMPOSITION OF DRY FLY ASHES USED FOR LEACHING STUDY

Constituent	Plant A	Plant E	Plant J
Alumina (Al_2O_3), %	22.67	18.52	31.19
Barium oxide (BaO), %	0.06	0.22	0.16
Calcium oxide (CaO), %	1.68	5.74	1.82
Chloride (Cl), %	NA	0.25	0.35
Iron oxide (Fe_2O_3), %	20.02	20.79	8.76
Magnesium oxide (MgO), %	0.62	1.23	1.53
Potassium oxide (K_2O), %	0.27	3.37	4.34
Silica (SiO_2), %	44.91	46.28	49.70
Sodium oxide (Na_2O), %	0.35	0.66	0.32
Sulfur trioxide (SO_3), %	0.85	1.55	0.40
Titanium oxide (TiO_2), %	1.17	1.07	1.27
Arsenic, µg/g	72	55	170
Boron, µg/g	NA	1800	400
Cadmium, µg/g	12	6	<2
Chromium, µg/g	140	90	140
Copper, µg/g	NA	78	170
Lead, µg/g	460	75	100
Manganese, µg/g	250	410	220
Mercury, µg/g	0.15	0.1	0.42
Nickel, µg/g	280	100	100
Selenium, µg/g	4.8	6	8
Zinc. µg/g	1000	540	280

NA--Not Available

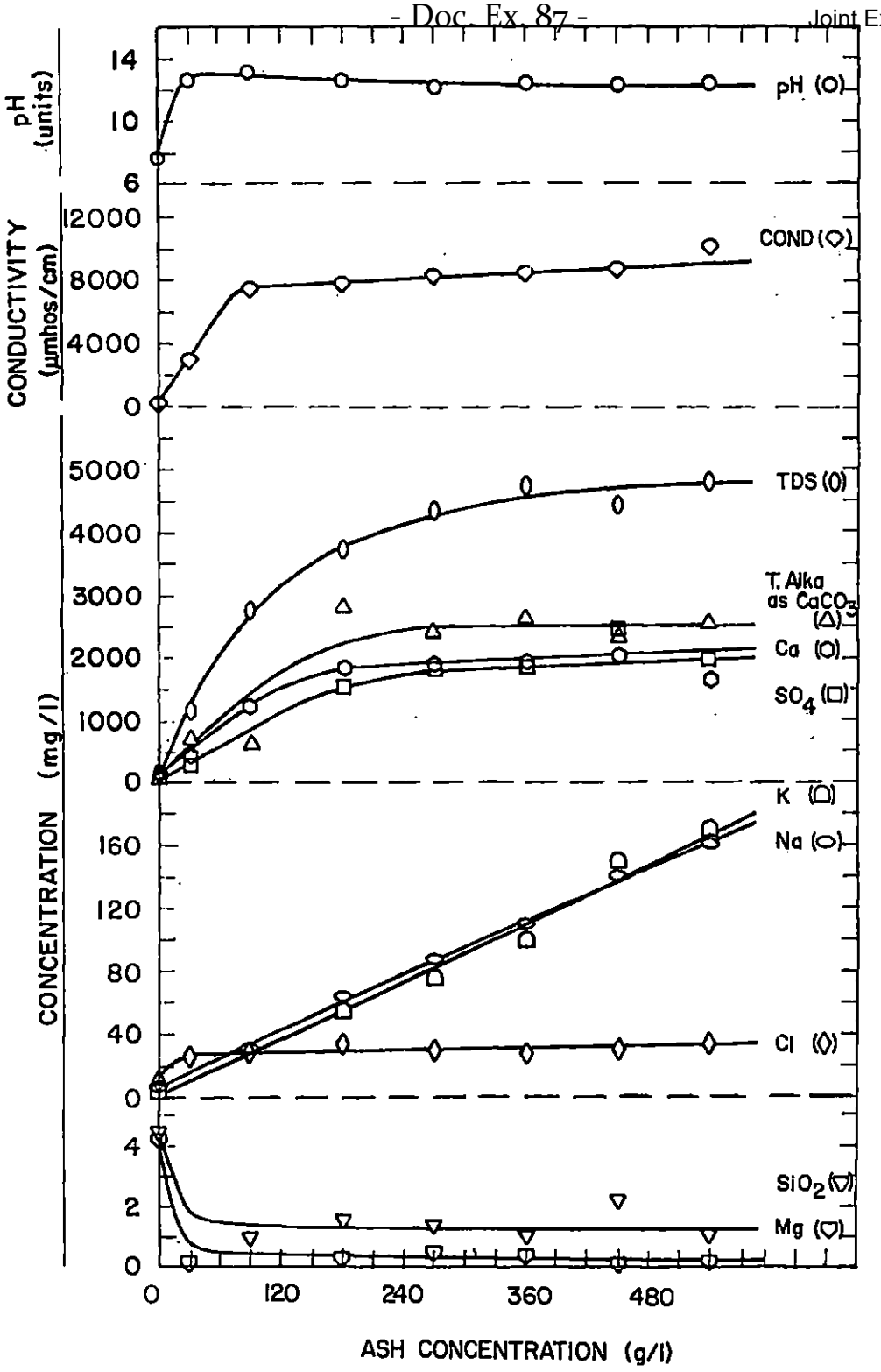

Figure 28. pH and leaching of principal constituents from an alkaline fly ash sample from plant F

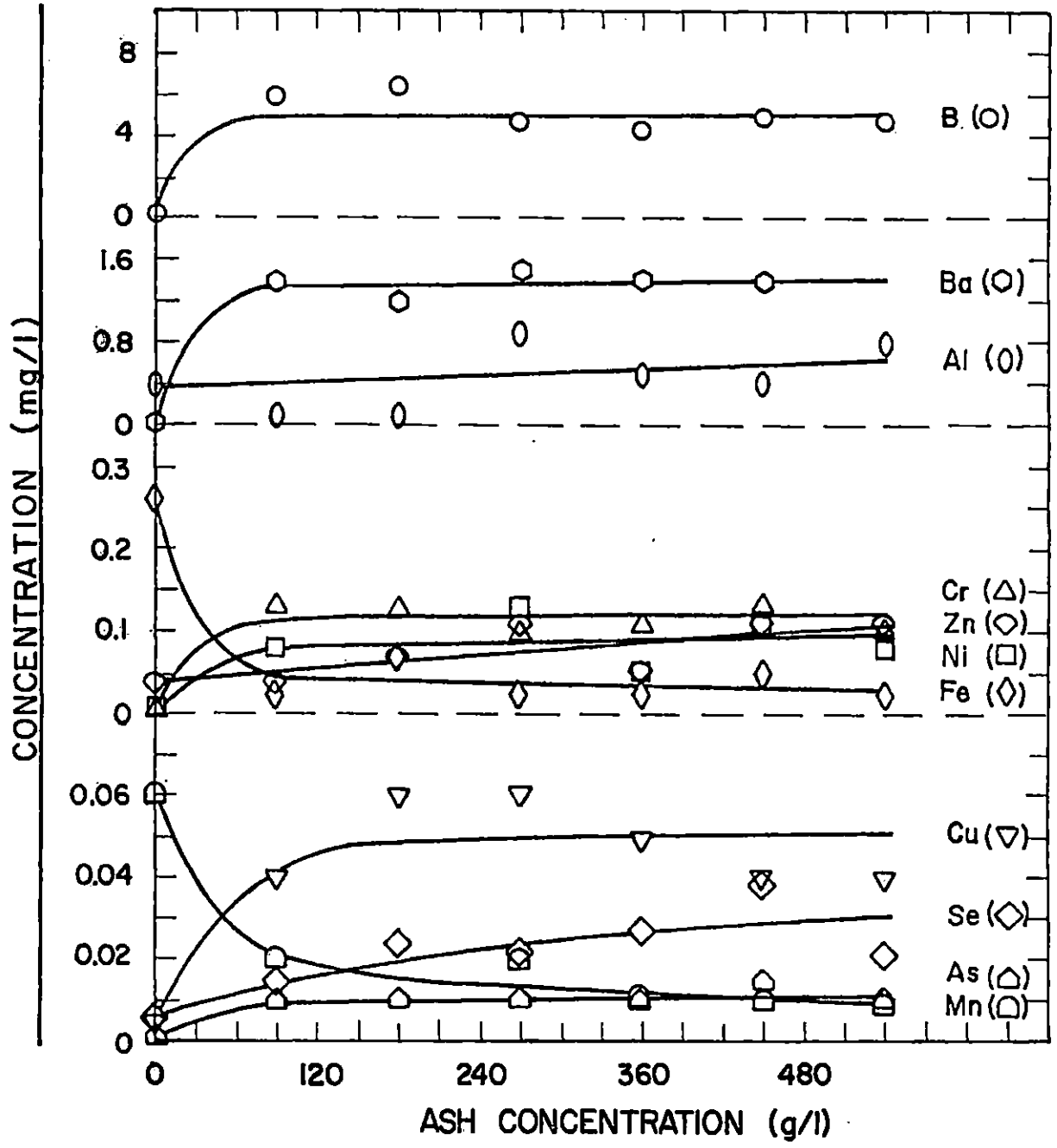

Figure 29. Leaching of trace metals from an alkaline fly ash sample from plant E.

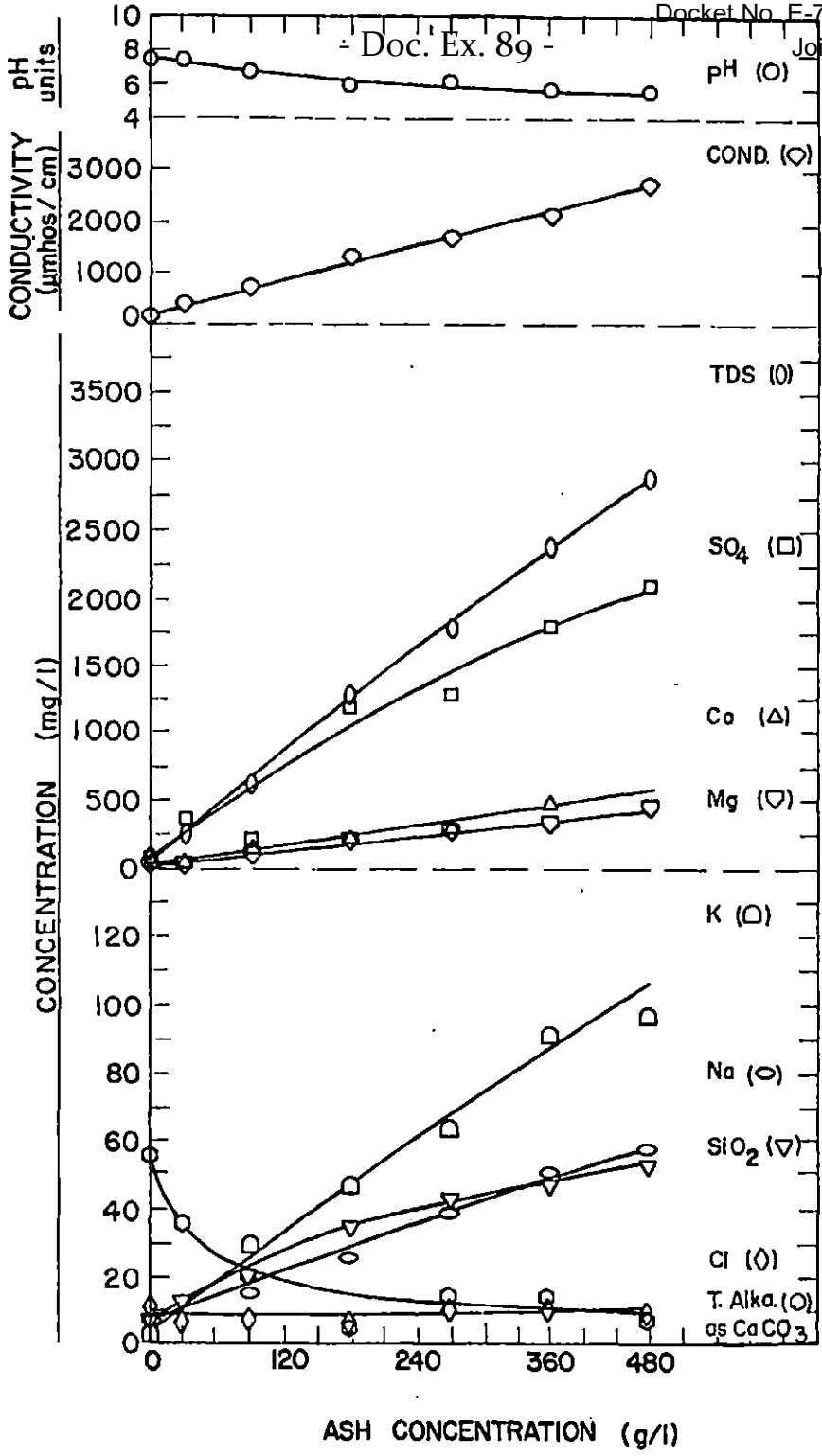

Figure 30. pH and leaching of principal constituents from a neutral fly ash sample from plant J.

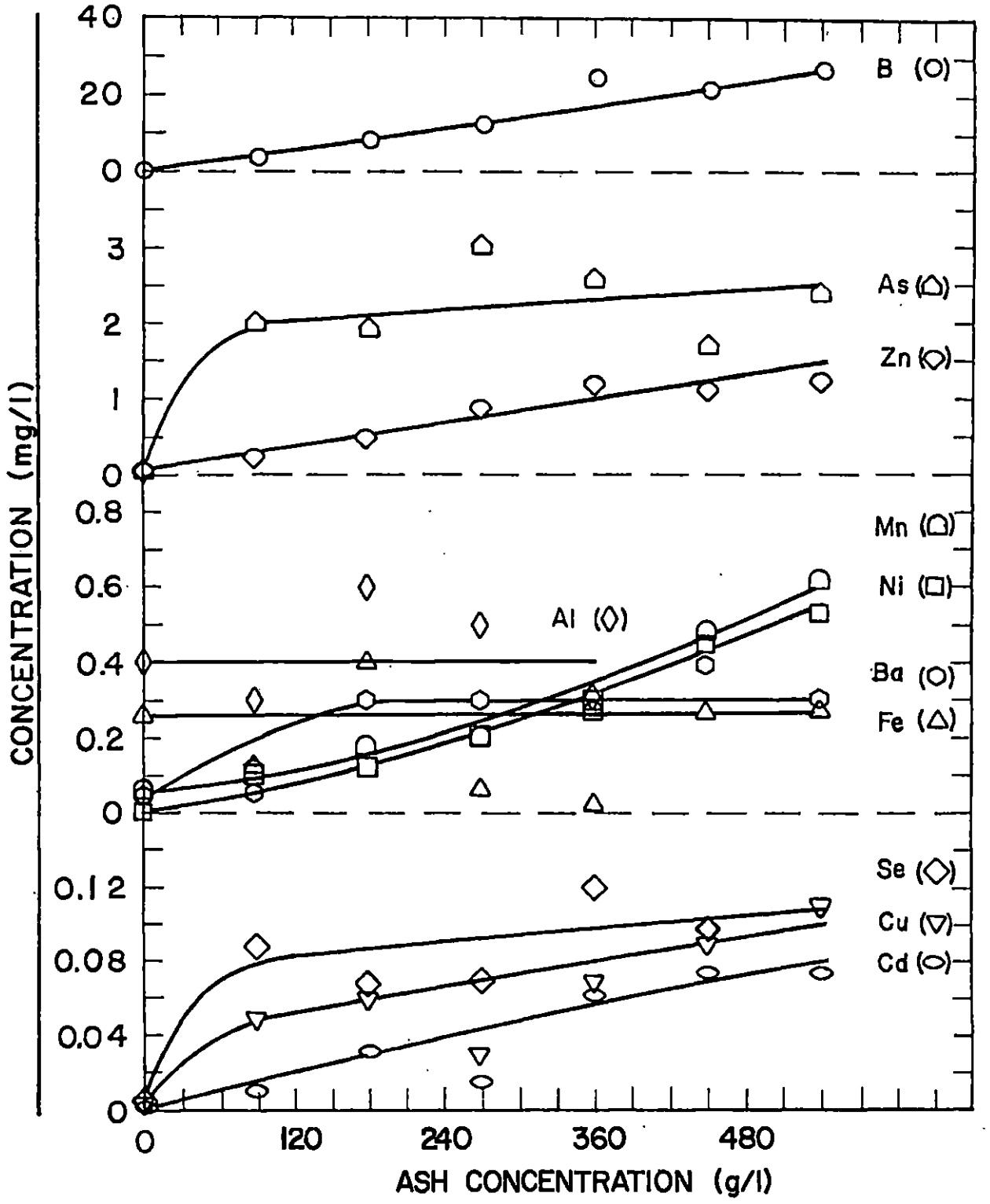

Figure 31. Leaching of trace metals from a neutral fly ash sample from plant J.

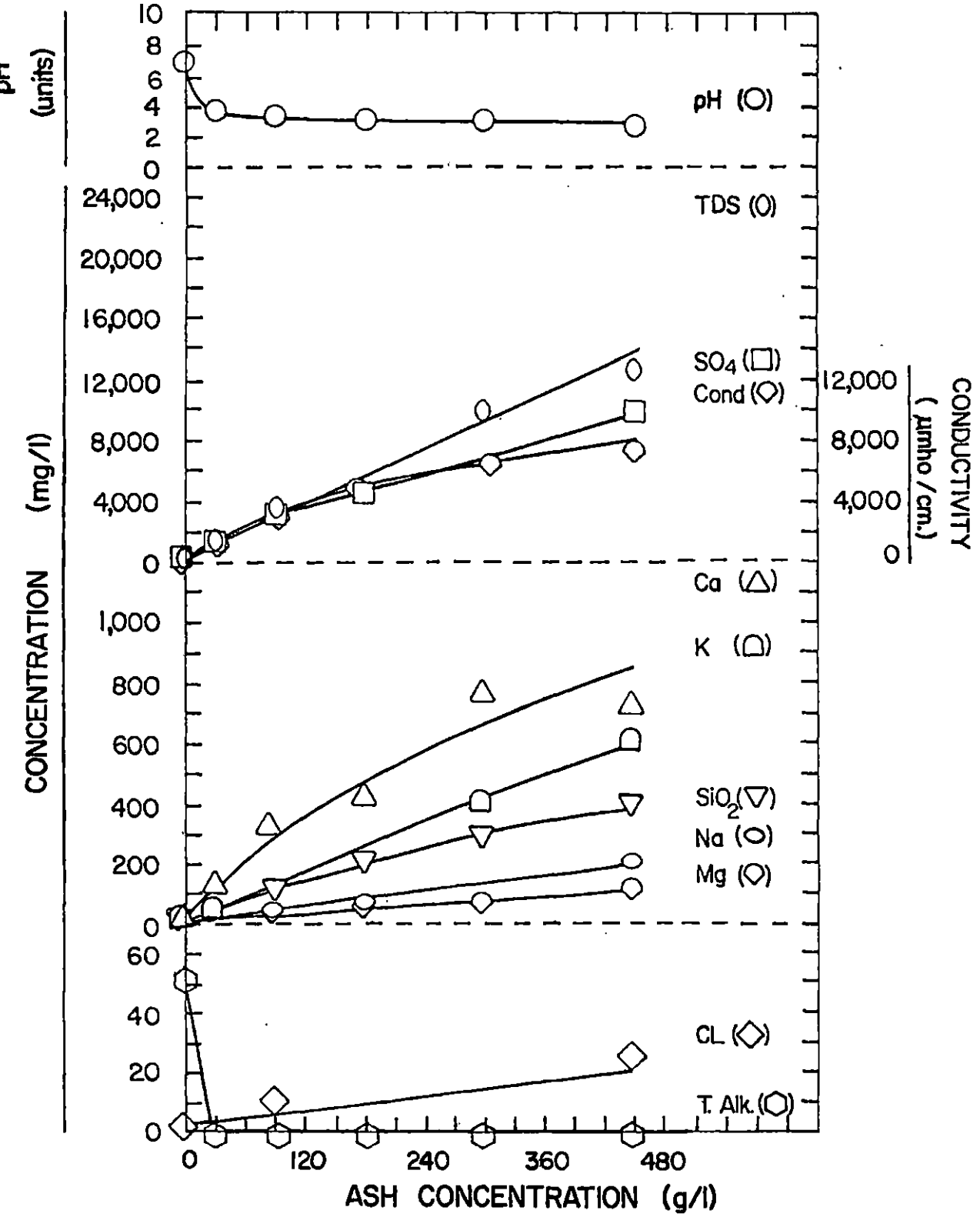

Figure 32. pH and leaching of principal constituents from an acidic fly ash sample from plant A.

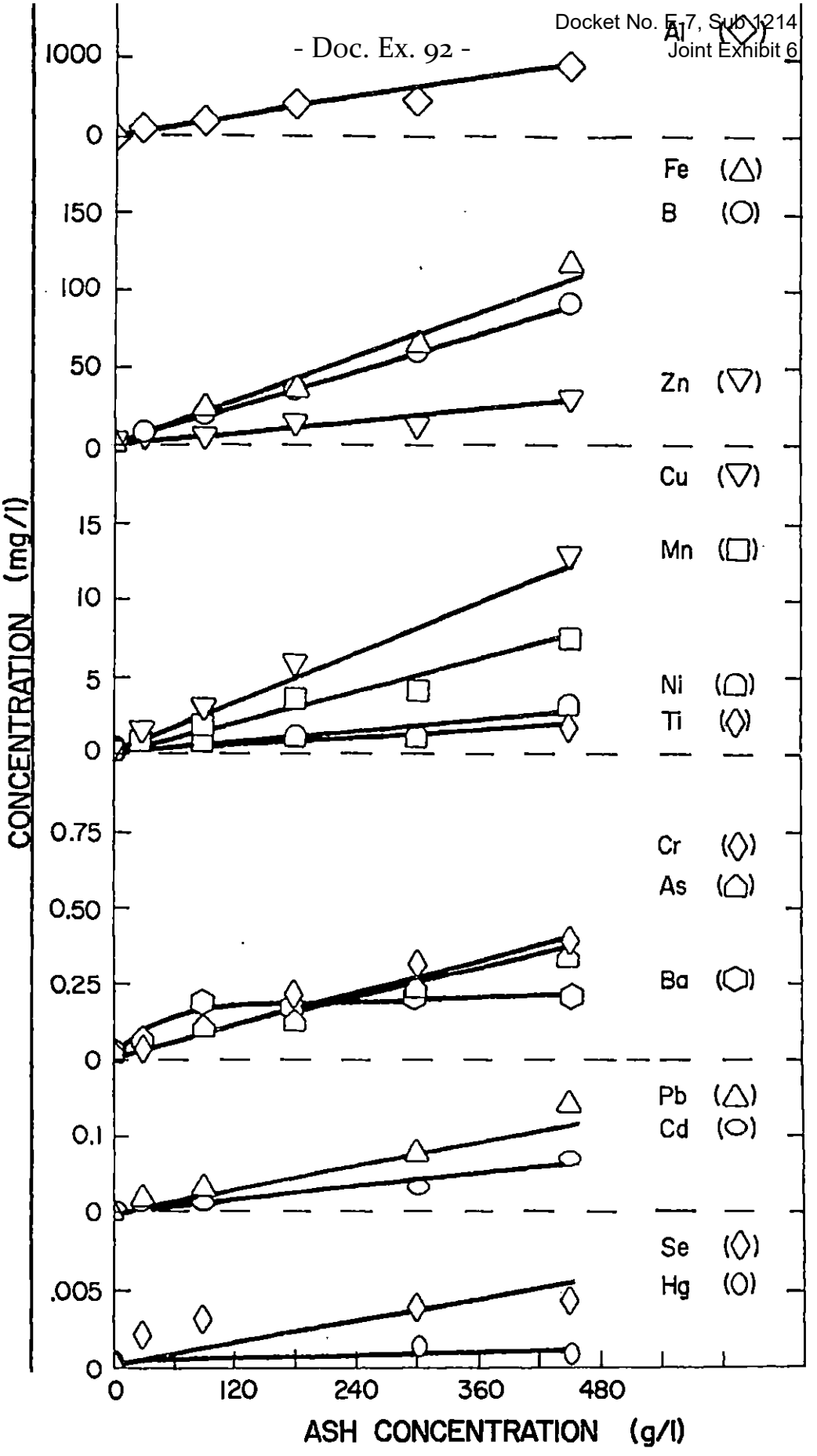

Figure 33. Leaching of trace metals from an acidic fly ash sa mple from plant A.

and mercury did not leach from the ash. This agrees with their solubility limits at neutral pH. Concentrations of arsenic, barium, boron, cadmium, copper, manganese, nickel, selenium, and zinc increased with increasing concentrations of ash (Figure 31). Concentrations of arsenic, boron, cadmium, manganese, and selenium greatly exceeded the quality criteria for water.[66] Copper and zinc apparently would have exceeded quality criteria for water if the ash concentration were higher than 60 percent by weight. Although these criteria (appendix E, Table E-1) are not applicable to ash pond effluents, they are used here and elsewhere in this report as a screening process to identify water quality constituents that may deserve environmental consideration.

Alkaline fly ash in contact with water did not release cadmium, iron, lead, manganese, and mercury into alkaline water because of the low solubilities of these trace metals. However, boron, barium, arsenic, chromium, copper, nickel, selenium, and zinc did leach into the sluice water, but their concentrations quickly leveled off somewhat (Figure 29). Concentrations of barium, boron, chromium, and selenium exceeded quality criteria for water.[66]

When acidic fly ash was in contact with water, almost all the metals mentioned above could have leached into the water (Figure 33). Concentrations of arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, and zinc exceeded the quality criteria for water.[66] In addition, the concentration levels of boron, chromium, copper, iron, manganese, nickel, and zinc in the acidic ash sluice water were much higher than those in the alkaline and neutral ash sluice waters. Therefore, according to these studies, low-pH water does favor the leaching of most trace metals; however, the leaching of boron and selenium does not depend significantly on pH. Of these trace metals, arsenic, barium, cadmium, chromium, lead, mercury, and selenium are toxic to humans, and boron is toxic to plants.

The rankings of trace metal concentrations resulting from leaching from these three particular ashes were: B>Ba>Se>Cr>Zn>Ni>Cu>Se>As in alkaline ash sluice water; B>As>Zn>Mn>Ni>Ba>Se>Cu>Cd in neutral ash sluice water; and Al>Fe>B>Zn>Cu>Mn>Ni>Ti>Cr>As>Ba>Pb>Cd>Se>Hg in acidic ash sluice water.

The laboratory testing results may provide a delineation of potential trace metal pollution resulting from ash disposal under various ash-to-water contact ratios. Field characterizations of ash pond effluents have also been conducted at TVA's 12 steam plants since 1967. TVA ash ponds are divided into three categories: (1) those that receive only fly ash, (2) those that receive only bottom ash, and (3) those that receive both types of ash. Table 14 lists data related to the chemical composition of ash pond effluents from TVA's 12 steam plants.

TABLE 14. CHARACTERISTICS OF ONCE-THROUGH ASH POND DISCHARGES

	Source[a]	Plant A		Plant B		Plant C		Plant D	Plant E	Plant F	Plant G	Plant H	Plant I	Plant J	Plant K	Plant
		Fly ash pond	Bottom ash pond	Fly ash pond	Bottom ash pond	East	West									
Flow, gpm[b]	EFF	6667.3	17798.7	NA	NA	7730	1651.7	8224	5857.5	30616.5	7391	2692.3	16872	14062.3	22447.3	14494
	RW	6441.7	17426.3	NA	3.8	7659	1633	8998	5384	30395	7429.7	2666.7	17447	14403.3	21085	14229
Total alkalinity,[b] mg/l as $CaCO_3$	EFF	18.7	71.7	84.3	55.7	70.7	69	61.7	141	96.5	46.3	67.7	121.7	40	99.7	86
	RW	110	86	56	84.5	70	66	56	194	82	38.3	67.3	121.7	35	77	86
Phen. alkalinity,[b] mg/l as $CaCO_3$	EFF	<1	<1	38	5	<1	<1	5	105.5	82.5	20	11.3	91	4.5	63.3	44
	RW	0	0	6	39	0	0	3	155	64.7	16	10.5	86	0.5	51.7	45
Conductivity,[b] µmhos/cm	EFF	811	322	788	223.5	495	329.5	265	819	915	366	392	652.5	311.5	472.5	359.5
	RW	811	322	221	769.1	495	330	258	947	717.5	393.5	406	651	311.5	469	313.3
Total hardness,[b] mg/l as $CaCO_3$	EFF	315	141.5	329	92.5	212.5	129	126.5	288	304	198	115.5	211.5	103	174	178
	RW	261	141.5	94	327.9	208.5	120	130	348.5	255	196	114	210.5	104	174	239
pH, units[b]	EFF	4.2	7.1	9.3	8.1	7.1	7.4	8.5	11.2	10.9	9.6	8.6	10.7	6.2	10.8	10.2
	RW	4.4	7.2	8.1	9.4	7.1	7.4	8.3	11.1	10.8	9.6	8.4	10.6	6.5	10.6	10.1
Dissolved solids,[b] mg/l	EFF	517	168.7	524.3	136.3	342.3	217	157.3	389.5	408.5	263	270	259	187.3	247.7	212.7
	RW	516	168	133	526.8	356.7	218	179.3	424	380.7	241	280	256	184.3	211.3	215.7
Suspended solids, mg/l	EFF	48.3	57	70.7	57	39.3	40	19	8	23	19.3	14.3	19	39	19.3	15
	RW	48	-	56.1	80	39.3	39	16	27	25	14.3	16.5	15	35	9.9	15
Aluminum, mg/l	EFF	7.9	3.2	1.6	2.2	1.5	3.4	1.4	2.5	1.7	1.7	1.6	1.5	2.6	1.8	2.0
	RW	2.6	2.6	0.8	0.8	4.7	5.2	0.5	2.9	1.4	1.2	1.0	1.6	0.7	2.0	1.2
Ammonia, mg/l as N	EFF	0.75	0.11	0.07	0.07	0.11	0.09	0.06	0.06	0.17	0.12	0.34	0.07	0.05	0.06	0.08
	RW	0.07	0.07	0.08	0.08	0.14	0.16	0.04	0.07	0.08	0.04	0.23	0.05	0.04	0.09	0.08
Arsenic, mg/l	EFF	0.011	0.007	0.029	0.014	0.013	0.022	0.034	0.028	0.008	0.030	0.123	0.036	0.041	0.033	0.052
	RW	<0.005	<0.005	<0.005	<0.005	0.008	0.009	<0.005	<0.005	<0.005	<0.005	0.006	<0.005	0.018	0.009	0.005
Barium, mg/l	EFF	0.2	0.1	0.1	0.1	0.2	0.14	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
	RW	0.2	0.2	<0.1	<0.1	0.1	0.14	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1

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TABLE 14 (continued)

		Plant A		Plant B		Plant C										
		Fly ash pond	Bottom ash pond	Fly ash pond	Bottom ash pond	East	West	Plant D	Plant E	Plant F	Plant G	Plant H	Plant I	Plant J	Plant K	Plant
Beryllium, mg/l	EFF	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium, mg/l	EFF	0.038	0.001	0.001	0.002	0.006	0.002	0.001	0.001	0.001	<0.001	0.001	<0.001	0.001	0.001	0.001
	RW	0.001	0.001	0.004	0.004	0.001	0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Calcium, mg/l	EFF	126	38	152	50	78	37	31	126	107	73	50	84	34	76	54
	RW	35	35	19	19	29	33	28	17	27	20	28	19	15	20	17
Chloride, mg/l	EFF	7	7	6	7	11	11	3	6	5	4	14	6	5	10	6
	RW	6	6	5	5	11	11	3	5	4	4	14	6	2	7	6
Chromium, mg/l	EFF	0.072	0.007	0.013	0.009	0.006	0.009	<0.005	0.017	0.033	0.011	0.006	0.017	0.005	0.019	0.009
	RW	0.010	0.010	<0.005	<0.005	0.012	0.013	0.005	<0.005	0.006	0.005	0.005	<0.005	0.005	0.009	0.009
Copper, mg/l	EFF	0.33	0.07	0.03	0.06	0.05	0.06	0.03	0.08	0.03	0.05	0.04	0.06	0.11	0.05	0.06
	RW	0.09	0.09	0.02	0.02	0.11	0.12	0.07	0.05	0.05	0.07	0.07	0.07	0.08	0.07	0.07
Cyanide, mg/l	EFF	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron, mg/l	EFF	2.3	5.2	1.4	4.7	1.7	6.0	0.32	0.16	0.22	0.53	0.56	0.26	2.4	0.39	0.56
	RW	2.7	2.7	0.57	0.57	6.5	7.2	0.51	1.0	1.1	1.3	1.1	1.7	0.7	1.9	1.03
Lead, mg/l	EFF	0.066	0.017	0.015	0.018	0.021	0.017	0.016	0.017	0.013	0.014	0.015	0.012	0.015	0.017	0.017
	RW	0.021	0.021	<0.01	<0.01	0.022	0.024	0.012	0.015	0.019	0.019	0.019	0.15	0.010	0.01	0.016
Magnesium, mg/l	EFF	14	6.0	3.6	6.2	10	10	8.3	0.3	1.57	2.4	7.4	1.2	6.7	1.6	2.6
	RW	6.1	6.1	4.3	4.3	9.5	6.6	8.0	3.4	4.2	4.0	7.4	3.3	4.5	4.3	3.9
Manganese, mg/l	EFF	0.49	0.17	0.12	0.40	0.20	0.18	0.02	0.01	0.01	0.02	0.06	0.05	0.38	0.02	0.03
	RW	0.13	0.13	0.06	0.06	0.31	0.31	0.07	0.05	0.07	0.10	0.14	0.01	0.07	0.10	0.07
Mercury, mg/l	EFF	0.0003	0.0005	0.0008	0.0009	0.0034	0.0070	0.0002	0.0002	0.0003	0.0024	0.0004	0.0003	0.0003	0.0003	0.0003
	RW	<0.0002	<0.0002	<0.0002	<0.0002	0.0004	0.0003	0.0002	<0.0002	0.0006	0.0049	0.0003	0.0002	0.0003	<0.0002	<0.0002

TABLE 14 (CONTINUED)

		Plant A		Plant B		Plant C										
		Fly ash pond	Bottom ash pond	Fly ash pond	Bottom ash pond	East	West	Plant D	Plant E	Plant F	Plant G	Plant H	Plant I	Plant J	Plant K	Plant
Nickel, mg/l	EFF	0.08	0.06	0.05	0.06	0.05	0.06	0.06	<0.05	0.05	<0.05	0.05	0.05	0.05	0.06	<0.05
	RW	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total phosphate, mg/l as P	EFF	0.03	0.07	0.06	0.06	0.04	0.12	0.03	0.01	0.02	0.07	0.12	0.06	0.06	0.05	0.06
	RW	0.07	0.08	0.02	0.02	0.22	0.25	0.02	0.07	0.13	0.09	0.14	0.17	0.02	0.10	0.03
Selenium, mg/l	EFF	0.002	0.002	0.015	0.007	0.010	0.003	0.070	0.007	0.014	0.010	0.017	0.012	0.004	0.010	0.010
	RW	<0.002	0.002	<0.002	0.002	0.002	0.002	0.002	<0.002	<0.002	0.002	0.002	<0.002	0.003	0.002	0.002
Silica, mg/l	EFF	13	7.4	7.1	6.4	7.4	6.7	4.0	7.0	6.0	4.4	4.9	7.1	6.4	6.7	5.7
	RW	5.6	5.6	5.4	5.4	6.1	6.2	5.2	4.7	4.5	4.4	4.9	5.4	3.9	4.6	5.1
Silver, mg/l	EFF	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	RW	<0.01	<0.01	0.02	0.02	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sulfate, mg/l	EFF	346	45	214	102	158	99	57	147	160	182	98	81	119	83	80
	RW	21	21	12	12	23	49	16	20	19	17	19	21	22	20	13
Zinc, mg/l	EFF	1.4	0.08	0.05	0.13	0.13	0.14	0.03	0.05	0.05	0.05	0.05	0.08	0.07	0.05	0.04
	RW	0.09	0.09	0.02	0.02	0.08	0.08	0.04	0.08	0.12	0.09	0.11	0.07	0.06	0.07	0.06

[a] EFF--ash pond effluent (data from 1973 to 1975); RW--raw water for ash sluicing (data from 1974 to 1975).

[b] Average values of weekly grab samples; all other numbers are average values of quarterly grab samples.

The quantity of water for ash handling is generally high at TVA steam plants because of the large available quantity of water in the Tennessee Valley. Therefore, the ash concentrations in the ash transport water during sluicing at TVA steam plants range from 5.6 to 25.2 g per liter; these values are much lower than the nationwide range of 6 to 200 g per liter.[5]

Although the ash concentration in the ash transport water is low at TVA steam plants, various trace metals were found to have concentrations exceeding the water quality criteria. Based on quarterly ash pond monitoring for a 3-year period, the percentage of each trace element equal to or exceeding a given concentration are presented in Figures D-1 to D-15. Boron was not included in the monitoring, but the quantity of boron in ash pond effluents would be high because the coal fly ash contains significant levels of boron and the leaching of boron is not limited by pH. The results from laboratory leaching tests and ash pond monitoring indicate that many trace metals are present in ash pond effluents in potentially toxic quantities.

SECTION 9

EFFECT OF pH AND SUSPENDED SOLIDS ON TRACE METAL CONCENTRATIONS IN ASH POND EFFLUENTS

Trace metals may occur in ash pond discharges in both dissolved and suspended forms. The dissolved trace metals in the ash transport water are governed by their leachability from the ash materials (see section 8). The suspended trace metals in ash pond effluents may be associated with unsettled ash and colloid particles which contain undissolved trace elements.

A field survey was conducted at the plant E alkaline ash pond to investigate the distribution of dissolved and suspended trace elements in the intake water, ash transport water, and ash pond effluent. The average concentrations of chemical species and their relative forms of existence are presented in Table 15. The intake water, which was pumped from the once-through cooling water discharge channel, contained very low concentrations of total suspended solids (3 mg/l) as well as dissolved and suspended trace metals.

During the survey, the average ash sluicing times per day were 240 min for fly ash collected by electrostatic precipitators, 93 min for fly ash collected by mechanical collectors, 20 min for bottom ash, and 44 min for pyrite.

The total suspended solids concentrations in ash slurries were quite high, and trace metals were mostly in the undissolved forms. For instance, 8.5 mg/l suspended lead and 0.017 mg/l dissolved lead were found in fly ash slurry from electrostatic precipitators, 1.8 mg/l suspended lead and 0.047 mg/l dissolved lead were found in fly ash slurry from mechanical collectors, 14.7 mg/l suspended lead and 0.016 mg/l dissolved lead were found in bottom ash slurry, and 0.12 mg/l suspended lead and 0.02 mg/l dissolved lead were found in pyrite slurry. Because most of the ash particles settled in the ash pond and only 11 mg/l suspended solids was found in ash pond effluent, the suspended trace metals were not observed in significant quantities. Also the dissolved trace metal concentrations were low in the alkaline effluent. Concentrations of some trace metals, such as copper, iron, lead, and zinc were found to be lower in the effluent than in the intake water.

Laboratory studies were conducted to investigate the effects of pH adjustment between 6 and 9 and reduction of suspended solids concentration to 30 mg/l on the forms and concentrations of trace metals in ash transport water after settling.

TABLE 15. AVERAGE CONCENTRATIONS (mg/l) OF DISSOLVED AND SUSPENDED CHEMICAL SPECIES IN INTAKE WATER, ASH SLUICE WATER, AND ASH POND EFFLUENT

Constituent	Intake water	Fly ash slurry		Bottom ash slurry	Pyrite slurry	Ash pond effluent
		Electrostatic precipitator	Mechanical collector			
Solids						
Dissolved	104	-	-	-	-	413
Suspended	3	46,000	21,500	115,500	1,700	11
Aluminum						
Dissolved	0.3	3.1	1.1	0.6	0.3	2.48
Suspended	0.5	4,330	1,750	9,730	93	0.28
Calcium						
Dissolved	27	500	520	83	71	158
Suspended	6	1,330	795	180	63	20
Chromium						
Dissolved	<0.005	0.022	0.007	<0.005	<0.005	0.022
Suspended	<0.005	4.3	2.0	0.1	0.1	0.018
Copper						
Dissolved	0.06	0.01	0.01	<0.01	<0.01	0.01
Suspended	0.06	3.1	0.71	5.6	0.06	0.03
Iron						
Dissolved	0.06	0.1	0.8	<0.05	<0.05	0.05
Suspended	0.26	5,457	3,830	19,850	220	0.17
Magnesium						
Dissolved	4.7	<0.1	<0.1	4.0	5.1	0.25
Suspended	<0.1	323	135	740	8.5	<0.1
Lead						
Dissolved	0.01	0.017	0.047	0.016	0.02	0.007
Suspended	0.01	8.5	1.8	14.7	0.12	0.005
Zinc						
Dissolved	0.03	0.02	0.02	<0.01	<0.01	0.023
Suspended	0.01	29	7.8	88	0.34	0.008
Silica						
Dissolved	2.3	1.3	1.1	3.6	2.1	3.1
Suspended	0.5	10,030	4,240	24,250	210	0.2
Sulfate						
Dissolved	10	360	133	99	135	147
Suspended	<1	260	147	77	42	<1
pH of water	7.8	12.4	12.4	9.9	7.7	11.3

Study 1--Reducing Suspended Solids Concentrations to 30 mg/l and Then Adjusting pH to 6 and 9

Dry fly ash samples, representing acidic, neutral, and alkaline characteristics, were collected from six TVA steam plants. Each ash sample was weighed and then soaked in river water for about 3 h. The water quality of the river water is shown in Table 16. Ash slurry samples were prepared so as to contain 30 g/l suspended solids, and each slurry was poured into a column for settling tests, as described previously. The concentration of suspended solids in the supernatant was determined by measuring the sample withdrawn from the top portion of the settling column at various time intervals. When the suspended solids concentration reached about 30 mg/l, a large quantity of sample was then taken, and the sample was analyzed for dissolved and suspended trace metals. All acid and alkaline samples were adjusted to pH 6 or 9 by using sodium hydroxide or hydrochloric acid solution before they were analyzed for dissolved and suspended trace metals. The results of the effect of pH on the settled ash transport water are presented in Tables 17 through 22.

The electrostatical precipitator fly ash transport waters at two plants (plants A and H) were originally acidic. For the acidic ash transport water sample at plant A, containing 30 mg/l suspended solids (Table 17), total concentrations of boron, cadmium, iron, manganese, and lead exceeded water quality criteria for domestic water supply and long-term irrigation.[66] The concentration of suspended iron, which is associated with unsettled fly ash particles, was quite high (4.2 mg/l). Although the concentration of suspended lead was not high, the concentration of total lead exceeded the 0.05-mg/l level of water quality criterion. A high concentration of dissolved aluminum was leached from the fly ash, but aluminum is not regulated in the quality criteria for water by EPA.

After the pH was raised to 6, most of the dissolved aluminum and iron were transformed to their suspended forms as aluminum and iron hydroxides. Other trace metals did not change significantly at pH 6.

After the pH of the water was raised to 9, the aluminum slightly redissolved, and arsenic, boron, barium, cadmium, magnesium, and selenium remained mostly in their dissolved forms. The other dissolved trace metals were precipitated at pH 9. Therefore, for this particular fly ash transport water, boron, cadmium, and manganese concentrations exceeded the water quality criteria for domestic water supply and long-term irrigation after pH had been adjusted to 6 and 9 and suspended trace metals had been removed.

For the acidic ash transport water sample from plant H (electrostatic precipitator), containing 30 mg/l suspended solids (Table 19), the total concentrations of boron, cadmium, iron, and manganese exceeded water quality criteria for domestic water supply. The concentration of

TABLE 16. CONCENTRATIONS OF DISSOLVED AND SUSPENDED TRACE METALS IN TENNESSEE RIVER WATER[a]

Trace metal	Concentrations (mg/l) Dissolved	Suspended
Aluminum	0.4	0.3
Arsenic	<0.005	<0.005
Boron	0.16	<0.1
Barium	<0.1	<0.1
Cadmium	<0.001	<0.001
Chromium	<0.005	<0.005
Copper	0.05	0.01
Iron	<0.05	0.26
Mercury	<0.0002	<0.0002
Manganese	0.01	<0.01
Nickel	<0.05	<0.05
Lead	<0.01	<0.01
Selenium	<0.002	<0.002
Zinc	<0.01	<0.01

[a]pH of river water was 7.2.

TABLE 17. EFFECT OF pH ADJUSTMENT ON TRACE METAL CONCENTRATIONS IN ELECTROSTATIC PRECIPITATOR ASH TRANSPORT WATER OF PLANT A[a]

	Trace metal concentration (mg/l) in ash transport water with varying pH					
	pH 3.5		pH 6		pH 9	
Trace metal	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Aluminum	27	1.6	0.9	27.7	1.6	27
Arsenic	0.05	<0.005	0.04	0.01	0.04	0.01
Boron	4.6	<0.1	4.5	0.1	4.7	<0.1
Barium	0.3	<0.1	0.3	<0.1	0.2	<0.1
Cadmium	0.077	<0.001	0.077	<0.001	0.05	0.02
Chromium	0.023	<0.005	0.02	<0.005	<0.005	0.02
Copper	0.5	0.02	0.5	0.02	<0.01	0.5
Iron	3	4.2	0.9	6.3	0.6	6.5
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Manganese	0.47	<0.01	0.47	<0.01	0.3	0.1
Nickel	0.12	<0.05	0.12	<0.05	0.07	0.05
Lead	0.047	0.01	0.045	0.01	0.01	0.04
Selenium	0.002	<0.002	0.002	<0.002	0.002	<0.002
Zinc	1.3	0.03	1.3	0.03	0.09	1.2

[a]Before settling, the ash concentration of the slurry was 30 g/l. After settling test, the suspended solids concentration of the collected water sample was 30 mg/l and the pH was 3.5. The pH of the unfiltered water sample was then adjusted to pH 6 and 9 by adding sodium hydroxide.

TABLE 18. EFFECT OF pH ADJUSTMENT ON TRACE METAL CONCENTRATIONS IN ELECTROSTATIC PRECIPITATOR ASH TRANSPORT WATER OF PLANT E[a]

	Trace metal concentration (mg/1) in ash transport water with varying pH					
	pH 11.1		pH 9		pH 6	
Trace metal	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Aluminum	9.2	2.4	8.8	<0.8	0.4	11.2
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Boron	7.1	<0.1	7.2	<0.1	6.7	0.4
Barium	0.3	<0.1	0.4	<0.1	0.4	<0.1
Cadmium	0.002	<0.001	0.002	<0.001	0.002	<0.001
Chromium	0.07	<0.005	0.04	0.03	0.07	<0.005
Copper	<0.01	0.07	<0.01	0.07	0.07	<0.01
Iron	0.1	0.4	0.09	0.4	0.15	0.4
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Manganese	<0.01	0.01	0.01	<0.01	0.01	<0.01
Nickel	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	0.012	<0.01	0.01	<0.01	0.01	<0.01
Selenium	0.046	<0.002	0.04	<0.002	0.04	<0.002
Zinc	0.04	0.02	0.04	0.02	0.04	0.02

[a]Before settling, the ash concentration of the slurry was 30 g/1. After settling test, the suspended solids concentration of the collected water sample was 30 mg/1 and the pH was 11.1. The pH of the unfiltered water sample was then adjusted to pH 9 and 6 by adding hydrochloric acid solution.

TABLE 19. EFFECT OF pH ADJUSTMENT ON TRACE METAL CONCENTRATIONS IN ASH TRANSPORT WATER OF PLANT H

	Trace metal concentration (mg/l) in electrostatical precipitator ash transport water with varying pH						Trace metal concentration (mg/l) in mechanical collector ash transport water with varying pH					
	pH 4.3		pH 6		pH 9		pH 9.8		pH 9		pH 6	
Trace metal	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Aluminum	13.6	2.03	0.8	14.8	1.7	13.93	1.9	3.59	1.8	3.6	0.9	2.8
Arsenic	0.039	0.005	0.043	0.005	0.046	0.005	0.12	0.05	0.11	0.05	0.08	0.06
Boron	2.2	<0.1	2.0	<0.1	2.1	<0.1	0.96	<0.1	0.98	<0.1	1.2	<0.1
Barium	0.2	<0.1	0.2	<0.1	0.2	<0.1	0.2	<0.1	0.2	<0.1	0.2	<0.1
Cadmium	0.037	<0.001	0.029	<0.001	0.01	0.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	0.013	<0.01	0.012	<0.01	<0.005	0.01	0.026	0.008	0.024	0.008	0.035	<0.005
Copper	0.48	<0.01	0.47	0.01	<0.01	0.4	0.01	<0.01	0.01	<0.01	0.01	<0.01
Iron	1.8	3.66	0.7	4.5	0.1	5.0	<0.05	2.92	<0.05	2.9	1.2	1.6
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Manganese	0.5	<0.01	0.49	<0.01	0.1	0.4	<0.01	0.01	0.01	<0.01	0.02	<0.01
Nickel	0.2	<0.05	0.2	<0.05	0.05	0.15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	0.007	<0.002	0.008	<0.002	0.010	<0.002	0.014	<0.002	0.016	<0.002	0.016	<0.002
Zinc	0.73	<0.01	0.71	<0.01	0.1	0.62	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Note: Before settling, the ash concentrations of both slurries were 30 g/l. After settling test, the suspended solids concentrations of both collected water samples were 30 mg/l; the pH of the electrostatical precipitator fly ash transport water was 4.3, and the pH of the mechanical collector fly ash transport water was 9.8. The pH of both water samples was then aijusted by adding sodium hydroxide or hydrochloric acid solution.

TABLE 20. EFFECT OF pH ADJUSTMENT ON TRACE METAL CONCENTRATIONS IN ASH TRANSPORT WATER OF PLANT J[a]

Trace metal	Trace metal concentration (mg/l) in electrostatical precipitator ash transport water with varying pH				Trace metal concentration (mg/l) in mechanical collector ash transport water with varying pH					
	pH 8		pH 9		pH 9.3		pH 9		pH 6	
	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Aluminum	0.9	4.9	1.8	3.7	1.7	3.9	1.6	4.1	0.7	4.8
Arsenic	0.26	0.005	0.23	0.005	0.11	0.007	0.12	0.007	0.06	0.009
Boron	2	<0.1	1.8	<0.1	0.57	<0.1	0.54	<0.1	0.7	<0.1
Barium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001
Chromium	0.026	<0.005	0.025	<0.005	<0.005	0.01	<0.005	0.01	0.011	<0.005
Copper	0.05	<0.01	0.02	0.03	<0.01	0.01	<0.01	0.01	0.01	<0.01
Iron	0.19	4.4	0.2	4.0	<0.05	3.5	<0.05	3.5	0.9	2.5
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Manganese	0.01	<0.01	0.01	<0.01	<0.01	0.02	0.01	0.01	0.02	<0.01
Nickel	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	0.048	<0.002	0.068	<0.002	0.021	<0.002	0.023	<0.002	0.021	<0.002
Zinc	0.04	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a]Before settling, the ash concentrations of both slurries were 30 g/l. After settling, the suspended solids concentrations of both collected water samples were 30 mg/l; the pH of the electrostatical precipitator fly ash transport water was 8, and the pH of the mechanical collector fly ash transport water was 9.3. The pH of both water samples was then adjusted to 9 or 6 by adding sodium hydroxide or hydrochloric acid solution.

TABLE 21. EFFECT OF pH ADJUSTMENT ON TRACE METAL CONCENTRATIONS IN ASH TRANSPORT WATER OF PLANT K[a]

	Trace metal concentration (mg/l) in electrostatical precipitator ash transport water with varying pH						Trace metal concentration (mg/l) in mechanical collector ash transport water with varying pH					
	pH 10.8		pH 9		pH 6		pH 11.2		pH 9		pH 6	
Trace metal	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Aluminum	1.9	3.6	1.7	3.7	0.9	4.7	1.1	2.9	1.0	3.0	0.6	3.4
Arsenic	0.16	0.1	0.18	0.1	0.16	0.1	0.12	0.05	0.11	0.05	0.12	0.05
Boron	5	<0.1	4.5	<0.1	5	<0.1	1.3	<0.1	1.5	<0.1	<0.1	<0.1
Barium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
Chromium	0.018	0.005	0.018	0.005	0.02	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	<0.005
Copper	<0.01	0.01	<0.01	0.01	0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01	<0.01
Iron	<0.05	2.56	<0.05	2.6	0.6	2.1	<0.05	5.0	<0.05	5.0	0.8	4.2
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Manganese	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.01	<0.01
Nickel	<0.05	<0.05	<0.05	<0.05	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	0.22	<0.002	0.16	<0.002	0.24	<0.002	0.029	<0.0002	0.026	<0.0002	0.022	<0.0002
Zinc	<0.01	0.03	0.01	0.03	0.03	<0.01	<0.01	0.01	<0.01	0.01	0.01	<0.01

[a]Before settling, the ash concentration of both slurries were 30 g/l. After settling, the suspended solids concentrations of both collected water samples were 30 mg/l; the pH of the electrostatical precipitator fly ash transport water was 10.8, and the pH of the mechanical collector fly ash transport water was 11.2. The pH of both water samples was then adjusted to 9 and 6 by adding hydrochloric acid solution.

TABLE 22. EFFECT OF pH ADJUSTMENT ON TRACE METAL CONCENTRATIONS IN ASH TRANSPORT WATER OF PLANT L[a]

	Trace metal concentration (mg/l) in electrostatical precipitator ash transport water with varying pH						Trace metal concentration (mg/l) in mechanical collector ash transport water with varying pH					
	pH 11.7		pH 9		pH 6		pH 10.4		pH 9		pH 6	
Trace metal	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Aluminum	1.1	4.3	1.0	4.4	0.7	4.7	1.7	3.2	1.6	3.4	0.8	4.1
Arsenic	0.074	<0.005	0.069	<0.005	0.071	<0.005	0.053	<0.005	0.052	<0.005	0.060	<0.005
Boron	7.1	<0.1	7.3	<0.1	7.7	<0.1	1.0	<0.1	1.2	<0.1	1.0	<0.1
Barium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.002	<0.001	0.003	<0.001
Chromium	0.03	0.01	0.03	0.01	0.04	0.05	0.01	<0.005	0.01	<0.005	0.01	<0.005
Copper	0.01	0.01	<0.01	0.01	0.03	<0.01	<0.01	0.01	<0.01	0.01	0.01	<0.01
Iron	<0.05	3.9	<0.05	3.9	1.0	2.9	<0.05	3.5	<0.05	3.5	1.1	2.5
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Manganese	<0.01	0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Nickel	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	0.03	<0.002	0.022	<0.002	0.027	<0.002	0.058	<0.002	0.056	<0.002	0.268	<0.002
Zinc	0.01	0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01

[a]Before settling, the ash concentrations of both slurries were 30 g/l. After settling, the suspended solids concentrations of both collected water samples were 30 mg/l; the pH of the electrostatical precipitator fly ash transport water was 11.7, and the pH of the mechanical collector fly ash transport water was 10.4. The pH of both water samples was then adjusted to 9 and 6 by adding hydrochloric acid solution.

total dissolved aluminum in the acid solution (13.6 mg/l) was higher than any other trace metal concentration. Except for suspended aluminum and iron, all other suspended trace metal concentrations were relatively low and insignificant. After the pH was raised to 6, most of the dissolved aluminum and iron became suspended. Dissolved and suspended concentrations of arsenic, boron, barium, and selenium did not change after pH was adjusted to 6 and 9; but the other dissolved trace metals were completely or partly changed to their suspended forms. However, dissolved boron, cadmium, and manganese concentrations still exceeded water quality criteria after pH adjustment.

The fly ash transport water at plant J (electrostatic precipitator fly ash) was neutral (Table 20), and the concentrations of total arsenic, iron, and selenium exceeded water quality criteria for domestic water supply. The iron was mainly in suspended form and associated with fly ash. This finding may indicate that suspended solids must be reduced to a concentration of less than 30 mg/l to decrease total iron concentration to 1 mg/l or less. Raising pH from 8 to 9 resulted in little change in dissolved and suspended forms of trace metals.

The other three electrostatic precipitator fly ash transport waters (plants E, K, and L) and all four mechanical precipitator fly ash transport waters (plants H, J, K, and L) were alkaline. In these alkaline water samples containing 30 mg/l suspended solids, concentrations of total trace metals exceeding water quality criteria for domestic water supply and long-term irrigation were boron, chromium, iron, and selenium in transport water (electrostatic precipitator fly ash) of plant E; arsenic, boron, iron, and selenium in transport water (mechanical collector fly ash) at plant H; and arsenic, iron, and selenium in transport water (mechanical collector fly ash) of plant J. Also, in alkaline water samples, the concentrations of total trace metals exceeding these water quality criteria were arsenic, boron, iron, and selenium in transport waters (electrostatic precipitator fly ash and mechanical collector fly ash) of plant K; and arsenic, boron, iron, and selemium in transport waters (electrostatic precipitator fly ash and mechanical collector fly ash) of plant L.

Aluminum was also leached from alkaline fly ashes, but the amount of aluminum leaching varied between ashes. After pH adjustments to 6 and 9 for those alkaline fly ash transport waters, the behavior of trace metals was about the same as that after pH adjustment for acidic fly ash transport water. The change of concentrations of arsenic, boron, and selenium were not sensitive to the change of pH. Suspended iron remained undissolved at pH 9 and 6, and dissolved chromium concentrations were somewhat lower at pH 9 than either at pH 6 or at pH above 9. Therefore, chromium in ash transport water may be in the trivalent form, because solubility of hexavalent chromium is also pH-independent.

Study 2--Spiking Trace Metals into Composite Alkaline Ash Pond Effluent and Adjusting pH to 9 and 7

To investigate the behavior of trace metals in ash transport water further, field samples of acidic and alkaline ash pond effluents were collected from five TVA steam plants. The effluents from alkaline combined ash ponds at 4 different plants were equally mixed, and the mixture was spiked with 11 trace metals in the dissolved form 100 times in excess of their analytical detection limits. The pH of the composite was then adjusted to 11 using sodium hydroxide and subsequently reduced to 9 and 7 by neutralizing with CO_2. The results are given in Table 23. Of the 11 trace metals, cadmium, chromium, copper, iron, lead, nickel, and zinc were generally found in undissolved forms at pH 11, 9, and 7. These seven trace metals may be precipitated as metal hydroxides, except the lead may be precipitated as lead carbonate at pH 9 and 7. Although the spiked concentrations of these trace metals were quite high, only the dissolved concentrations exceeded water quality criteria at pH 7, whereas dissolved chromium, copper, iron, lead, and zinc were below their water quality criteria. Arsenic, mercury, and selenium were found in both dissolved and undissolved forms. Aluminum was found in dissolved forms at pH 11 and 9 and in undissolved form at pH 7.

Study 3--Adjusting Acidic Ash Pond Effluent Using Lime and Investigating Suspended Trace Metals Settling

The acidic ash pond effluent from plant A was neutralized by adding lime from original pH 3.8 to 6, 7.3, 8.1, 9.0, and 10. After each pH adjustment, a homogeneous sample was taken and analyzed for dissolved and suspended cadmium, copper, iron, lead, and zinc. Then the mixture was allowed to settle in the beaker, and the supernatant was carefully sampled at several subsequent settling times to study the sedimentation of metal precipitates. Examination of the data in Table 24 reveals that suspended solids, as well as cadmium, copper, iron, lead, and zinc, are removed best by adjusting pH to about 9 with lime and settling for several hours. Therefore, some of the trace metals apparently were in the forms of metal hydroxides or metal carbonates (not contained in fly ash particles) and precipitated after several hours.

Study 4--Investigation of Dissolved and Suspended Trace Metals in TVA Ash Pond Discharges

Because the pH of TVA ash pond effluents varies from acidic to alkaline, grab samples were also collected from 14 ash pond discharges at 12 steam plants to investigate the dissolved and suspended nature of trace metals in ash pond discharges. The results are shown in Table 25. The concentrations of mercury, nickel, and silver were less than the general minimum detectable limits (0.0002, 0.05, and 0.02 mg/l, respectively) in all samples and, therefore, are not listed in the table. Boron was not included in the chemical analysis.

TABLE 23. COMPOSITION OF DISSOLVED AND UNDISSOLVED TRACE METALS IN ALKALINE COMBINED ASH POND EFFLUENTS[a]

Ash Pond Effluent	pH	Concentrations in µg/l																						
		Aluminum		Arsenic		Cadmium		Chromium		Copper		Iron		Lead		Mercury		Nickel		Selenium		Zinc		Solids
		Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss. S
Plant E	10.9	1.5	<0.2	0.01	<0.005	<0.001	<0.001	0.013	<0.005	<0.01	<0.01	<0.05	0.04	<0.01	0.012	<0.0002	<0.0002	0.008	<0.005	0.008	<0.002	<0.01	<0.01	330
Plant F	10.7	0.5	<0.2	0.01	<0.005	<0.001	<0.001	0.042	<0.005	<0.01	<0.01	<0.05	0.02	<0.01	0.015	<0.0002	<0.0002	<0.005	<0.005	0.008	0.007	<0.01	<0.01	400
Plant H	9.6	1.2	0.4	0.04	0.015	<0.001	<0.001	0.009	<0.005	<0.01	<0.01	<0.05	0.21	<0.01	0.012	<0.0002	<0.0002	0.007	<0.005	0.01	<0.002	<0.01	<0.02	170
Plant L	9.4	1.5	0.4	0.025	0.015	<0.001	<0.001	0.012	<0.005	0.01	<0.01	0.07	0.2	<0.01	0.014	<0.0002	<0.0002	<0.005	<0.005	0.01	<0.002	<0.01	<0.01	180
Composite	11	18	<0.2	0.25	0.18	<0.001	0.092	<0.005	0.465	0.05	0.95	<0.05	4.8	<0.01	0.94	0.0096	0.0044	<0.005	0.46	0.07	0.04	<0.01	1	1800
Composite	9	16	<0.2	0.28	0.18	<0.001	0.092	<0.005	0.465	0.05	0.9	<0.05	4.1	<0.01	0.94	0.0069	0.0071	<0.005	0.45	0.07	0.04	<0.01	1	1900
Composite	7	0.4	20	0.25	0.2	0.012	0.074	<0.005	0.465	0.05	0.84	0.06	4.3	<0.01	0.9	0.0069	0.0071	0.014	0.44	0.04	0.04	0.06	0.94	1800

[a]Metals were added to a composite consisting of one quarter of each of the above four ash pond effluents, so that the spiked sample would have the following total metals concentrations; 21 µg/l aluminum; 0.51 µg/l arsenic; 0.098 µg/l cadmium; 0.51 µg/l chromium (III); 0.98 µg/l copper; 4.87 µg/l iron; 0.97 µg/l mercury; 0.49 µg/l nickel; 0.11 µg/l selenium; and 0.97 µg/l zinc. The pH of the composite was then adjusted to 11.0 by adding sodium hydroxide and subsequently reduced to 9.0 and 7.0 by neutralizing with CO_2.

TABLE 24. EFFECT OF pH ADJUSTMENT USING LIME ON SUSPENDED AND DISSOLVED SOLIDS AND TRACE METALS IN ACID FLY ASH POND EFFLUENT FROM PLANT A

pH	CaO added (mg/l)	Settling time (h)	Solids (mg/l)		Cadmium (mg/l)		Copper (mg/l)		Iron (mg/l)		Lead (mg/l)		Zinc (mg/l)	
			Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved
3.8	0	0	8	600	0.0008	0.0451	<0.01	0.3	1.4	0.68	0.013	0.102	0.04	1.3
3.8	0	6	4	580	0.0007	0.0459	0.01	0.31	0.53	0.79	<0.001	0.105	0.06	1.8
3.8	0	23	2	610	<0.0001	0.0507	0.01	0.33	0.36	0.74	<0.001	0.102	0.06	1.7
6.0	36.2	0	42	560	0.0008	0.0428	0.21	0.09	1.9	<0.05	0.061	0.008	0.2	1.3
6.0	36.2	2.5	8	570	0.0004	0.0404	0.04	0.05	0.15	0.06	0.001	0.004	0.06	1.3
6.0	36.2	19	2	580	<0.0001	0.0406	0.01	0.05	<0.05	<0.05	<0.001	<0.001	0.05	1.2
7.3	41.9	0	40	580	0.0004	0.0327	0.28	0.01	1.8	<0.05	0.072	0.003	0.94	0.41
7.3	41.9	4	10	570	0.0013	0.0197	0.05	<0.01	0.37	<0.05	0.011	<0.001	0.17	0.11
7.3	41.9	20.5	2	580	0.0007	0.0251	0.02	0.02	0.13	0.05	<0.001	<0.001	0.08	0.22
8.1	46.4	0	40	580	0.0336	0.0090	0.27	<0.01	1.8	<0.05	0.085	<0.001	1.4	0.04
8.1	46.4	3.5	5	570	0.0067	0.0045	0.02	<0.01	0.1	<0.05	<0.001	<0.001	0.1	<0.01
8.1	46.4	20	3	570	0.0015	0.0061	0.02	0.02	0.08	<0.05	<0.001	<0.001	0.06	0.02
9.0	53.6	0	47	580	0.0376	0.0009	0.27	0.01	2.1	<0.05	0.074	<0.001	2.1	<0.01
9.0	53.6	3.5	5	570	0.0024	0.0009	0.02	0.01	0.17	<0.05	0.003	<0.001	0.15	<0.01
9.0	53.6	19.5	2	580	0.0005	0.0023	0.01	0.02	0.12	<0.05	<0.001	<0.001	0.06	0.01
10.0	67.0	0	72	560	0.0371	0.0005	0.25	<0.01	1.9	<0.05	0.068	<0.001	1.9	<0.01
10.0	67.0	3	13	550	0.0011	0.0004	0.02	0.02	0.1	<0.05	0.003	<0.001	0.11	0.02
10.0	67.0	19.5	5	560	0.0008	0.0001	<0.01	0.02	0.05	<0.05	<0.001	<0.001	0.05	<0.01
CaO blank	67.0	0	11	120	0.0009	<0.0001	<0.01	<0.01	0.11	0.05	<0.001	<0.001	0.08	<0.01
Deionized water blank	0	0	-	-	0.0013	<0.001	0.01	0.01	0.05	<0.05	<0.001	<0.001	<0.04	0.01

TABLE 25. TRACE ELEMENT CONCENTRATIONS (mg/l) OF DISSOLVED AND SUSPENDED FRACTIONS IN ASH POND EFFLUENTS FROM PLANTS A THROUGH L

Plant[a]	pH	Susp. solids	Arsenic		Cadmium		Chromium		Copper		Iron		Lead		Manganese		Selenium		Zinc	
			Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.
A-b	7.0	40	<0.005	0.005	<0.001	<0.001	<0.005	0.005	<0.01	0.03	<0.05	4.0	<0.01	<0.01	0.02	0.09	<0.002	<0.002	0.04	0.02
A-f	4.0	24	<0.005	0.010	<0.001	<0.001	0.076	0.040	0.28	<0.01	0.79	4.0	0.03	<0.01	0.49	<0.01	<0.002	<0.002	0.79	<0.01
B	6.0	20	0.045	0.145	0.003	<0.001	<0.005	0.010	0.04	<0.01	0.10	5.0	<0.01	<0.01	0.37	<0.01	<0.002	<0.002	0.20	<0.01
C	7.1	15	<0.005	0.01	0.012	<0.001	<0.005	0.006	0.09	0.02	<0.05	1.4	<0.01	<0.01	0.13	<0.01	<0.002	<0.002	0.28	0.02
D	7.7	13	0.04	0.005	<0.001	<0.001	<0.005	<0.005	<0.01	<0.01	<0.05	0.33	<0.01	<0.01	0.06	<0.01	0.010	<0.002	0.01	<0.01
E	11.4	20	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005	<0.01	<0.01	<0.05	0.66	<0.01	<0.01	0.02	0.02	<0.002	<0.002	<0.01	<0.01
F	10.8	7	<0.005	<0.005	<0.001	<0.001	<0.005	<0.005	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	0.007	<0.002	<0.01	<0.01
G	9.7	32	0.050	<0.005	<0.001	<0.001	0.035	<0.005	<0.01	<0.01	<0.05	0.29	0.01	<0.01	<0.01	0.02	0.007	<0.002	<0.01	<0.01
H-b	8.8	29	0.140	<0.005	<0.001	<0.001	<0.005	<0.005	<0.01	<0.01	<0.05	1.1	<0.01	<0.01	<0.01	0.04	0.002	<0.002	0.01	<0.04
H-f	7.0	34	0.140	0.05	0.007	<0.001	<0.005	0.020	0.02	0.12	<0.05	0.97	<0.01	<0.01	0.07	0.01	0.004	<0.002	0.05	0.02
I	9.1	34	0.140	0.020	0.002	<0.001	0.007	<0.005	<0.01	<0.01	<0.05	0.92	<0.01	<0.01	<0.01	<0.01	0.002	<0.002	<0.01	<0.01
J	3.6	23	0.050	0.090	0.032	<0.001	<0.005	<0.005	0.05	<0.01	0.05	2.6	<0.01	<0.01	0.23	<0.01	<0.002	<0.002	0.05	<0.01
K	11.4	37	0.120	0.100	0.003	<0.001	0.006	<0.005	<0.01	<0.01	0.54	0.75	<0.01	<0.01	<0.01	<0.01	0.002	<0.002	<0.01	<0.01
L	10.9	4	<0.005	<0.005	<0.001	<0.001	0.012	<0.005	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	0.002	<0.002	<0.01	<0.01

[a] b = bottom ash pond only; f = fly ash pond only; all other plants of combined ash pond.

In the grab samples, concentrations of arsenic, cadmium, chromium, iron, manganese, and selenium exceeded water quality criteria for domestic water supply. Dissolved arsenic concentrations exceeded the 0.05-mg/l level at five ash ponds (bottom ash and fly ash ponds at plant H and combined ash ponds at plants I, J, and K), and suspended arsenic concentrations exceeded the 0.05-mg/l level at four ash ponds (fly ash pond at plant H and combined ash ponds at plants B, J, and K). The high concentrations of arsenic occurred in these ash pond effluents in spite of the water being acid, neutral, or alkaline.

Dissolved cadmium exceeded the 0.01-mg/l level at one combined ash pond (plant J), where the effluent was acidic (pH 3.6). Dissolved chromium exceeded the 0.05-mg/l level at one fly ash pond (plant A), where the effluent was also acidic (pH 4.0).

Dissolved iron exceeded the 0.3-mg/l level at one acid fly ash pond (plant A) and at one alkaline combined ash pond (plant K). The pH of this alkaline ash pond effluent was 11.4; at this pH, the dissolved ferric iron is no longer at minimum solubility level. The suspended iron exceeded the 0.3-mg/l level at 11 ash ponds (bottom ash and fly ash ponds at plants A and H and combined ash ponds at plants B, C, D, E, I, J, and K). The suspended iron may be associated with unsettled ash or cenospheres in effluents, because the content of iron, one of the three principal constituents (aluminum, iron, and silicon) in fly and bottom ashes, in ash ranges from 5 to 30 percent.[7]

Dissolved manganese exceeded the 0.05-mg/l level at two fly ash ponds (plants A and H) and four combined ash ponds (plants B, C, D, and J). The pH of these six ash ponds was either acidic or neutral. Suspended manganese exceeded 0.05 mg/l at one bottom ash pond (plant A). Dissolved selenium exceeded the 0.01-mg/l level at one combined ash pond (plant D).

Summary

Based on the laboratory tests, field surveys, and literature reviews, conclusions may be drawn from the data for the trace metals that exist in significant amounts in ash pond effluents: arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, selenium, and zinc.

ARSENIC

Arsenic exists in aquatic systems in the 3-, 0, 3+, and 5+ oxidation states.[67] The pentavalent state (H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$) is stable in aerated water, and elemental arsenic and arsine (AsH_3) can exist in highly reducing sediments or ashes. In more moderately

reducing environments, the trivalent state (H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$) can exist.[67] Although the pentavalent form is thermodynamically much more stable in air-saturated water, about equal amounts of As(III) and As(V) seem to occur in ocean water. The distribution of As(III) and As(V) in ash pond effluents and ash pond leachate needs further investigation. However, the solubility of total dissolved arsenic is independent of pH. For As(V), $H_2AsO_4^-$ is the predominant species in the pH range of 3 to 7; $HAsO_4^{2-}$ is predominant in the pH range of 7 to 11.5; and AsO_4^{3-} predominates at pH above 11.5. For As(III), H_3AsO_3 is the predominant species in the pH range of 0 to 9.2; $H_2AsO_3^-$ is predominant in pH range between 9.2 to 12, and $HAsO_3^{2-}$ predominates at pH above 12.

Therefore, dissolved arsenic cannot be reduced to any great degree by pH adjustment alone. Dissolved arsenic can be removed by complexation with polyvalent metal species, coprecipitation with metal hydroxide adsorption onto a coagulant floc, sulfide precipitation, adsorption onto activated carbon and alumina, and ion exchange.[68-80] Some of these processes for reducing arsenic from ash pond effluents need to be demonstrated. Although removal of suspended solids could reduce suspended arsenic, the suspended arsenic concentration may exceed 0.1 mg/l when total suspended solids concentration is 30 mg/l (Table 24).

BORON

Boron(III) does not form a simple cation in solution.[67] The hydrolysis products of boric acid are $B(OH)_4^-$, $B_2O(OH)_5^-$, $B_3O_3(OH)_4^-$, and $B_4O_5(OH)_4^{2-}$. The solubility of boron is independent of pH, and boron was found mostly in the dissolved form in ash pond water (Tables 17 to 22). Therefore, the boron content of an ash pond effluent cannot be controlled by adjusting pH of the ash pond system. Reported treatment methods for boron removal include evaporation, reverse osmosis, and ion exchange.[80]

CADMIUM

Cadmium exhibits only the 2+ valence in aqueous solution. Mononuclear hydrolysis products appear above pH 8, but the low solubility of the hydroxide limits the concentration of cadmium ($CdOH^+$, $Cd(OH)_2$) to $<10^{-5}$ M until pH 13 is reached. In the presence of carbonate ions, the concentration of cadmium in solution is limited to even lower values by the insolubility of $CdCO_3$. The formation of $(Ca\text{-}Cd)CO_3$ is to be expected because Cd^{2+} and Ca^{2+} ions are nearly the same size.[67] This may be an important mechanism for the removal of trace concentrations of cadmium from water in contact with $CaCO_3$. Cadmium cannot be greatly

removed from ash pond effluents by adjusting pH and reducing suspended solids unless the pH value is 9 or more (Tables 17 to 25). Suspended cadmium can be readily settled within several hours (Table 24). Other treatment processes for removing cadmium are coprecipitation with, or adsorption on, iron or aluminum hydroxide, sulfide precipitation, ion exchange, and reverse osmosis.[80]

CHROMIUM

Chromium occurs in the 2+, 3+, and 6+ oxidation states in water. The divalent state is unstable with respect to evolution of hydrogen, the trivalent state has broad stability, and hexavalent chromium occurs under highly oxidized conditions.[67] The minimum solubility of hydrated $Cr(OH)_3$ is in the pH range of 8 to 9.5, but chromium(VI) is extensively hydrolyzed yielding species of $HCrO_4^-$, CrO_4^{2-}, and $Cr_2O_7^{2-}$. Neutralization of acidic or alkaline ash ponds to a pH between 8 and 9 can cause chromium precipitation (Tables 17 to 22). Therefore, it is likely that chromium(III) ions predominately exist in ash pond water.

COPPER

Only small amounts of copper(I) ion can exist in water unless it is stabilized by complexing agents. The copper(II) ion at ordinary concentrations begins to hydrolyze above pH 4 and precipitates the oxide or hydroxide soon thereafter.[67] The minimum solubility of Cu^{2+} occurs at pH between 8 and 11. Therefore, dissolved cupric ion can be removed effectively by adjusting pH to neutral values (Tables 17 to 25) and precipitating in ash ponds (Table 24).

IRON

Iron in the 2+ and 3+ oxidation states is stable over broad regions of potential and pH.[67] In ash sluice water, the ferric ion is probably predominant. The minimum solubility of the ferric ion occurs at pH between 6 and 9. Therefore, neutralization of acidic ash pond effluents can result in soluble iron converting to the suspended form. However, because of the high iron content in coal ash, reduction of suspended solids to 30 mg/l might not reduce suspended iron to the 1-mg/l level (Tables 17 to 25). The highest concentration of suspended iron was found as 5 mg/l at a suspended solids concentration of 20 mg/l (Table 25).

LEAD

Lead(II) is the most common form of lead and has the most complex hydrolysis behavior. The minimum solubility for hydrolyzed lead(II) is at pH about 11. Lead carbonate is often the insoluble form of lead(II).

Neutralization of acidic ash pond effluents to pH between 8 and 9 may precipitate dissolved lead(II) as $Pb_3(CO_3)_2(OH)_2$, if sufficient carbonate species is available in water.[67-68]

MANGANESE

Manganous ion, Mn^{2+}, is the most stable aqueous oxidation state for the element.[67] The 3+ to 7+ states also occur in solution, but are not likely to occur in ash pond water. The manganous ion is not readily oxidized to the manganic form, other than at elevated pH. The +3 state (manganic) is quite unstable, being easily reduced to Mn^{+2} or disproportionating to Mn^{2+} and MnO_2. The minimum solubility of manganous ion is at a pH above 10. Adjustment of pH between 6 and 9 may not reduce the concentration of manganese to a level of 0.05 mg/l (Tables 17 to 22). The most common general approach seems to involve oxidation of the soluble manganous form to insoluble manganous hydroxide or oxide at high pH, with subsequent precipitation. Ion exchange treatment has proven effective.[80]

SELENIUM

Selenium(IV) and selenium(VI) are very soluble in water.[67] Selenium(IV) may be the most common form of selenium in ash pond water. The predominant species of selenium(IV) in water below pH 2 is H_2SeO_3, selenous acid. The anions $HSeO_3^-$ and SeO_3^{2-} form at pH between 3 and 8, respectively. Therefore, adjustment of pH for ash pond systems will not remove selenium (Tables 17 to 23, and Table 25). Selenite ions can form complexes with several metal ions. For removal from wastewater, iron would be preferred as the precipitant.[81] Selenium treatment by precipitation after adding a sulfide salt at slightly acid pH (pH 6.5) has been suggested.[79] The likely treatment mechanism involved is reduction of the selenite ion, precipitating elemental selenium. Sulfide would be cooxidized in the process. However, the cost-effective treatment processes for removing selenium from ash pond effluents need further investigation.

ZINC

Zinc(II) hydrolyzes only sparingly in acidic media to produce $ZnOH^+$ and Zn_2OH^{3+} before precipitation begins in the neutral region. In basic media, $Zn(OH)_4^{2-}$ and perhaps $Zn_2(OH)_6^{2-}$ are formed.[67] The minimum solubility of zinc(II) occurs between pH 9 and 11. Adjustment of pH to about 9 may control the zinc in ash pond effluents (Tables 17 to 25).

In summary, some trace metals in ash pond effluents were present in both dissolved and suspended forms. The distribution of specific trace metals between the dissolved and suspended forms is site-specific, but it is important to analyze both forms for monitoring trace metals in ash pond discharges. Adjustment of pH between 6 and 9 and reduction of suspended solids concentrations to 30 mg/l reduced total concentration of many trace metals such as chromium, copper, lead, and zinc. However, pH adjustment did not appreciably reduce total concentrations of arsenic, boron, cadmium, iron, manganese, and selenium. The solubilities of arsenic, boron, and selenium are independent of pH. Dissolved cadmium and manganese can be greatly removed at pH above 9 and 12, respectively. Total iron concentrations could not be reduced to the 1-mg/l level at neutral pH, even though suspended solids in some ash pond effluents were reduced to 30 mg/l, because the high iron content in the suspended ash particles.

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APPENDIX A

EFFECTS OF INITIAL CONCENTRATIONS OF SUSPENDED SOLIDS ON SETTLING OF ASHES

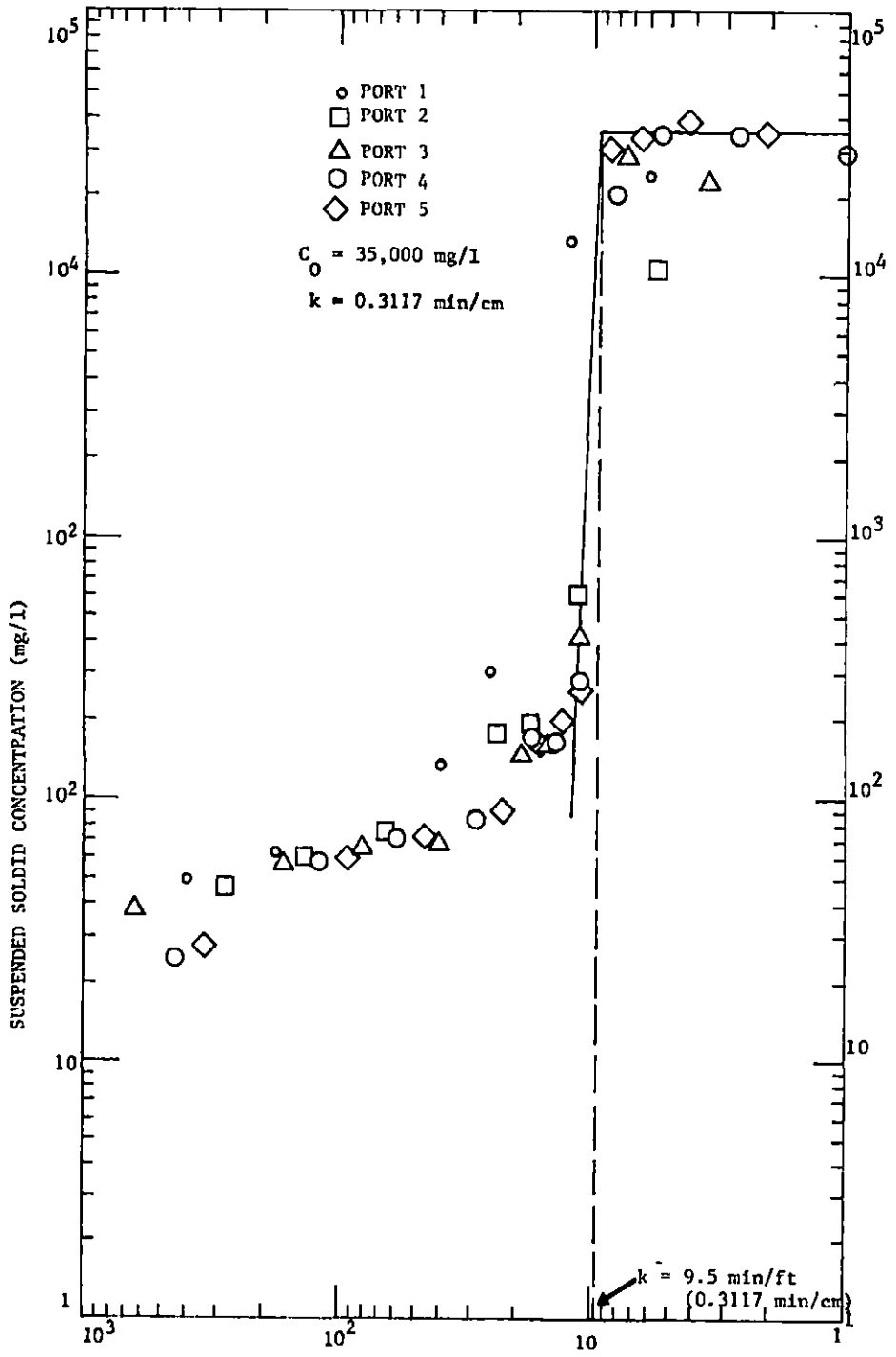

Figure A-1. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant E; initial suspended soldis concentration C_0 = 35,000 mg/l).

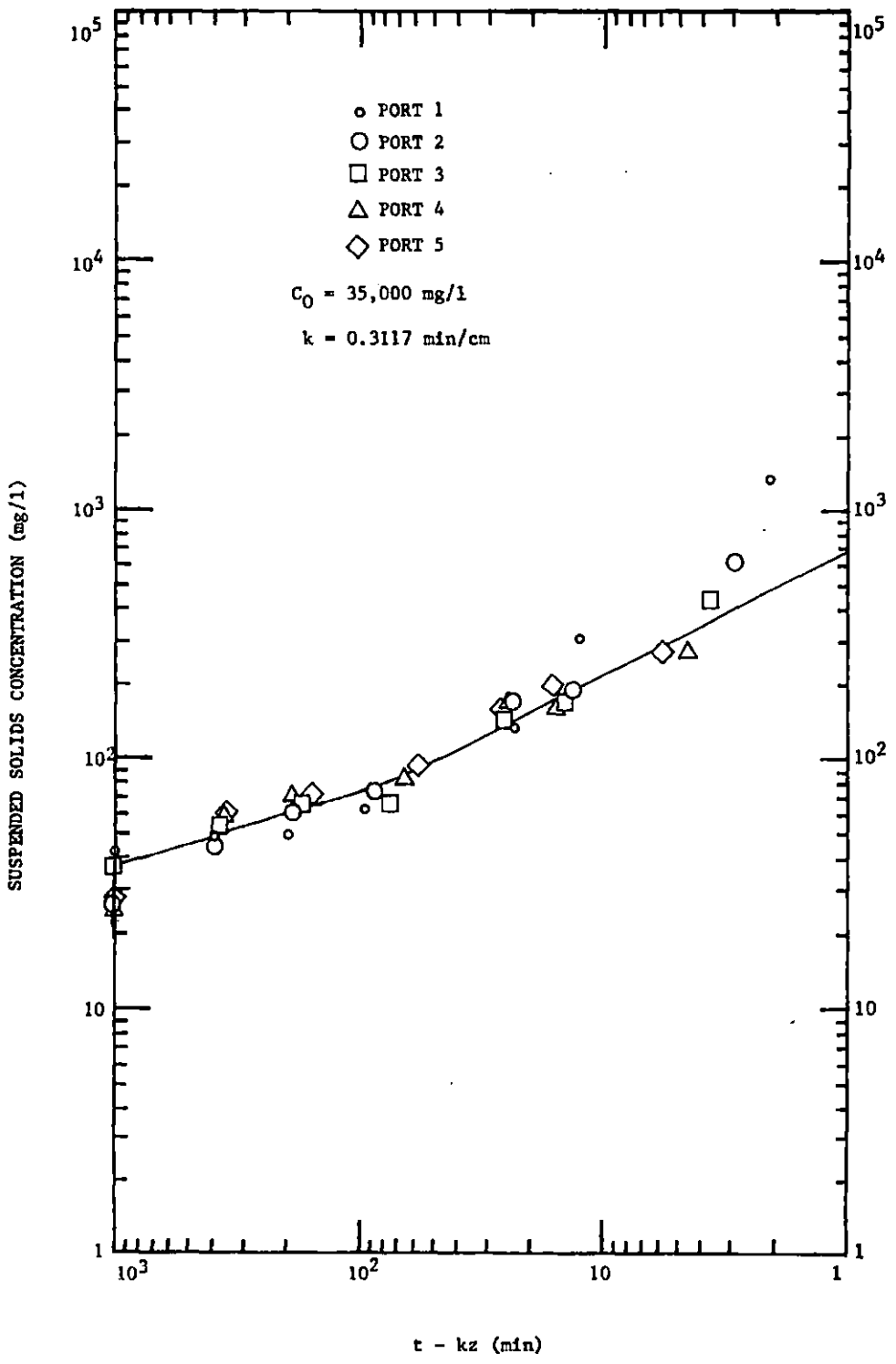

Figure A-2. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant E; initial suspended solids concentration C_0 = 35,000 mg/l).

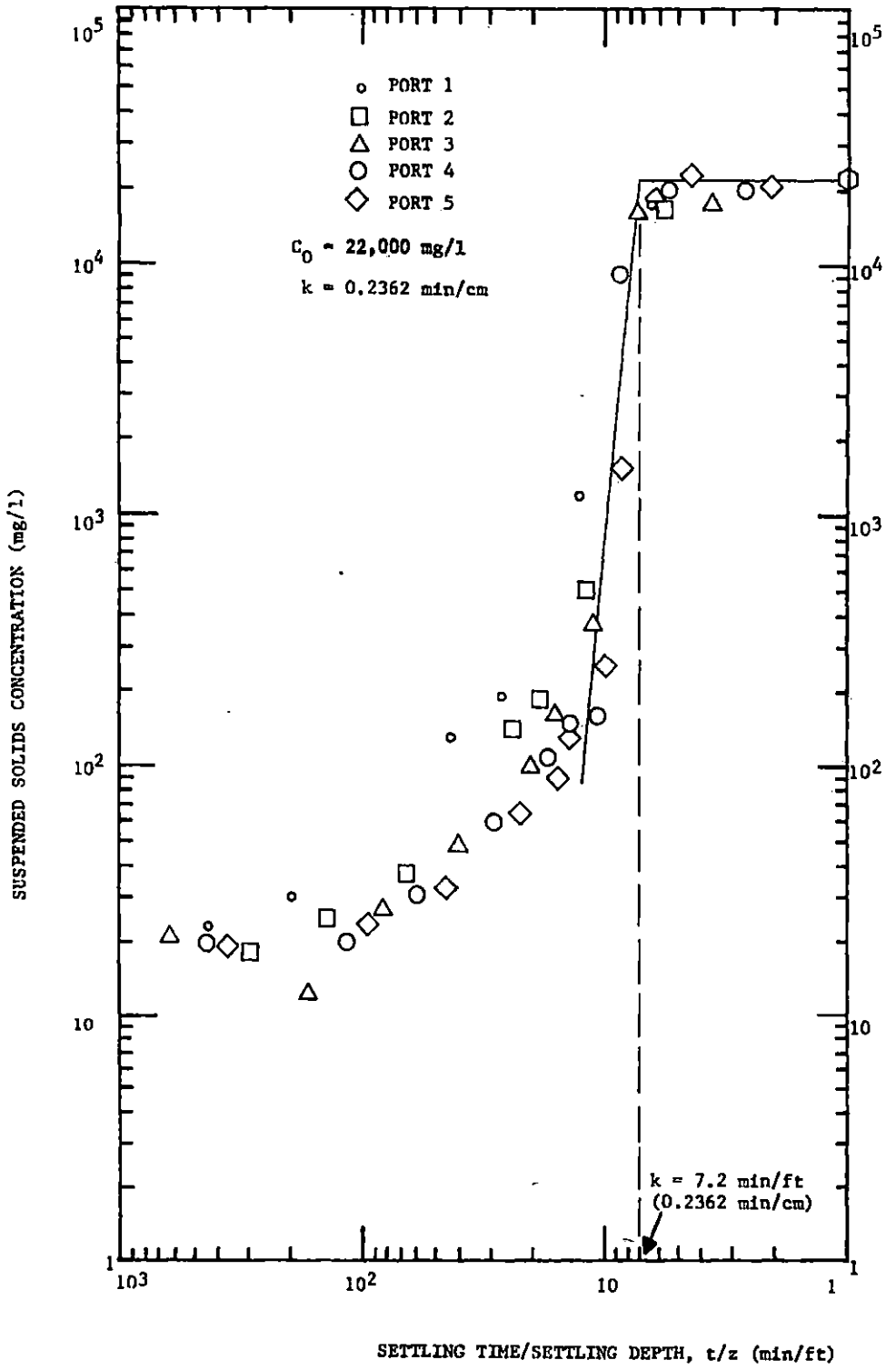

Figure A-3. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant E; initial suspended solids concentration C_0 = 22,000 mg/l).

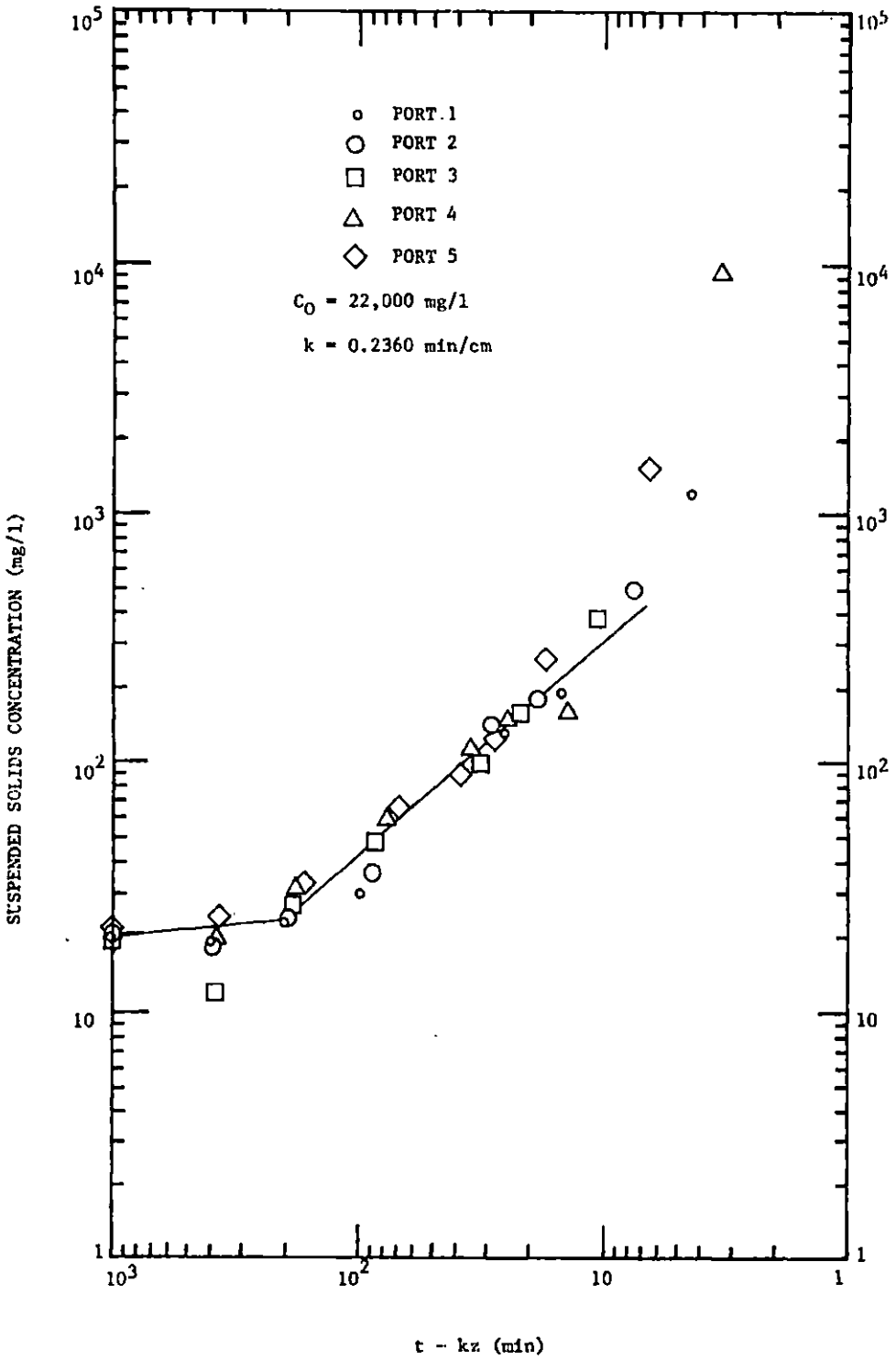

Figure A-4. Suspended solids concentration vs. t - kz (electrostatic precipitator from plant E; initial suspended solids concentration C_0 = 22,000 mg/l).

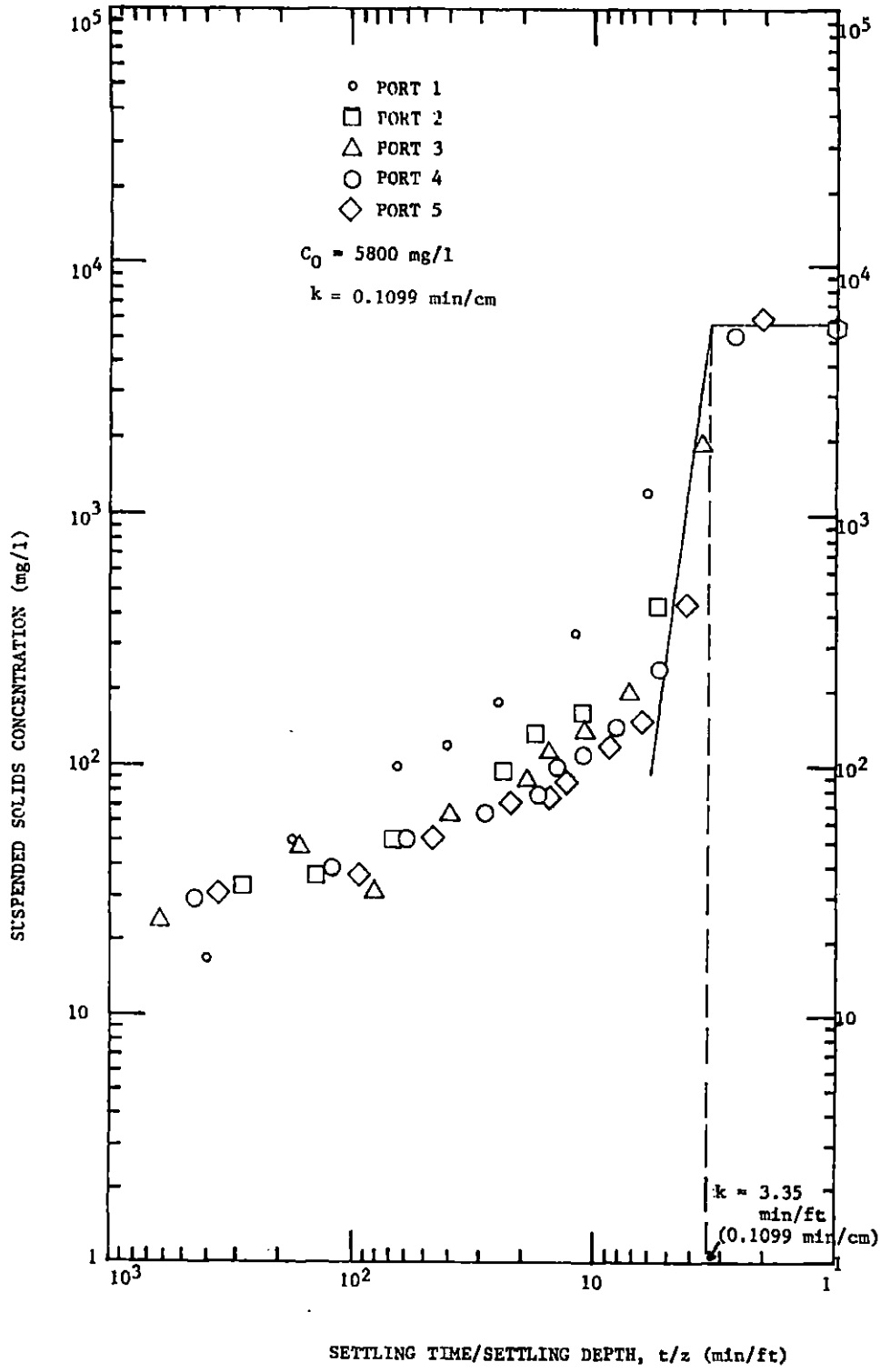

Figure A-5. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant E; initial suspended solids concentration C_0 = 5800 mg/l).

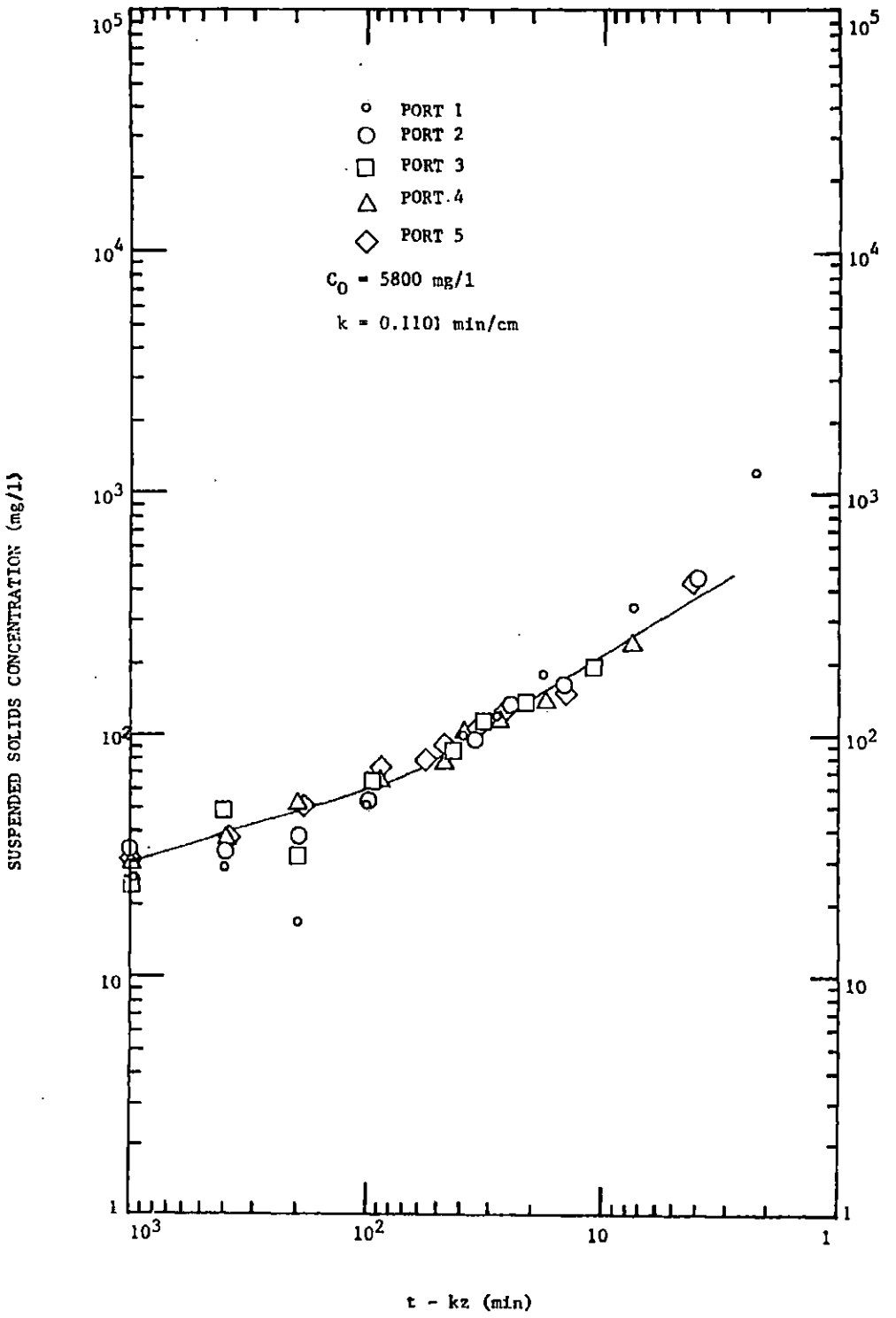

Figure A-6. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant E; initial suspended solids concentration C_0 = 5800 mg/1).

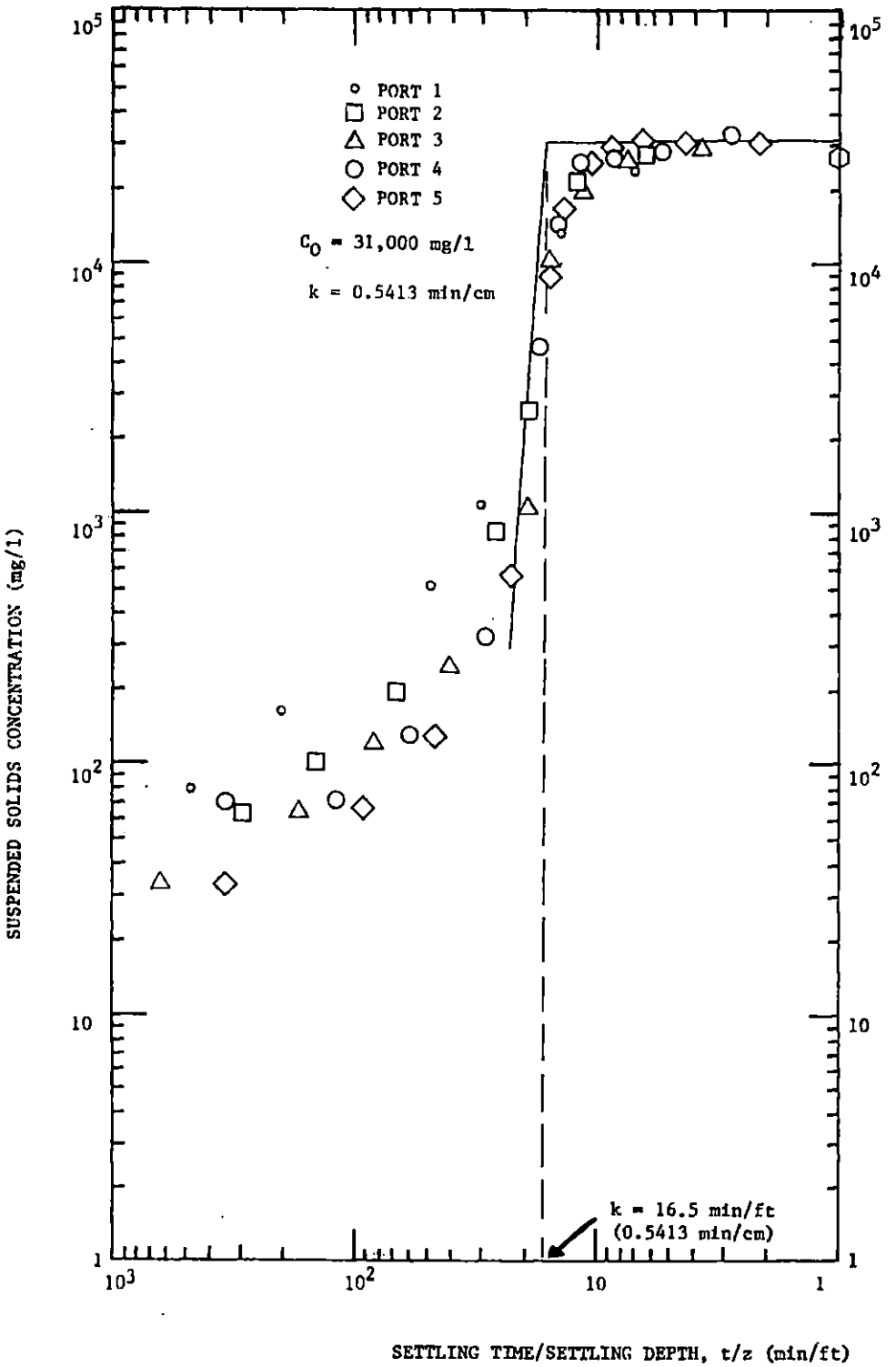

Figure A-7. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant A; initial suspended solids concentration C_0 = 31,000 mg/l).

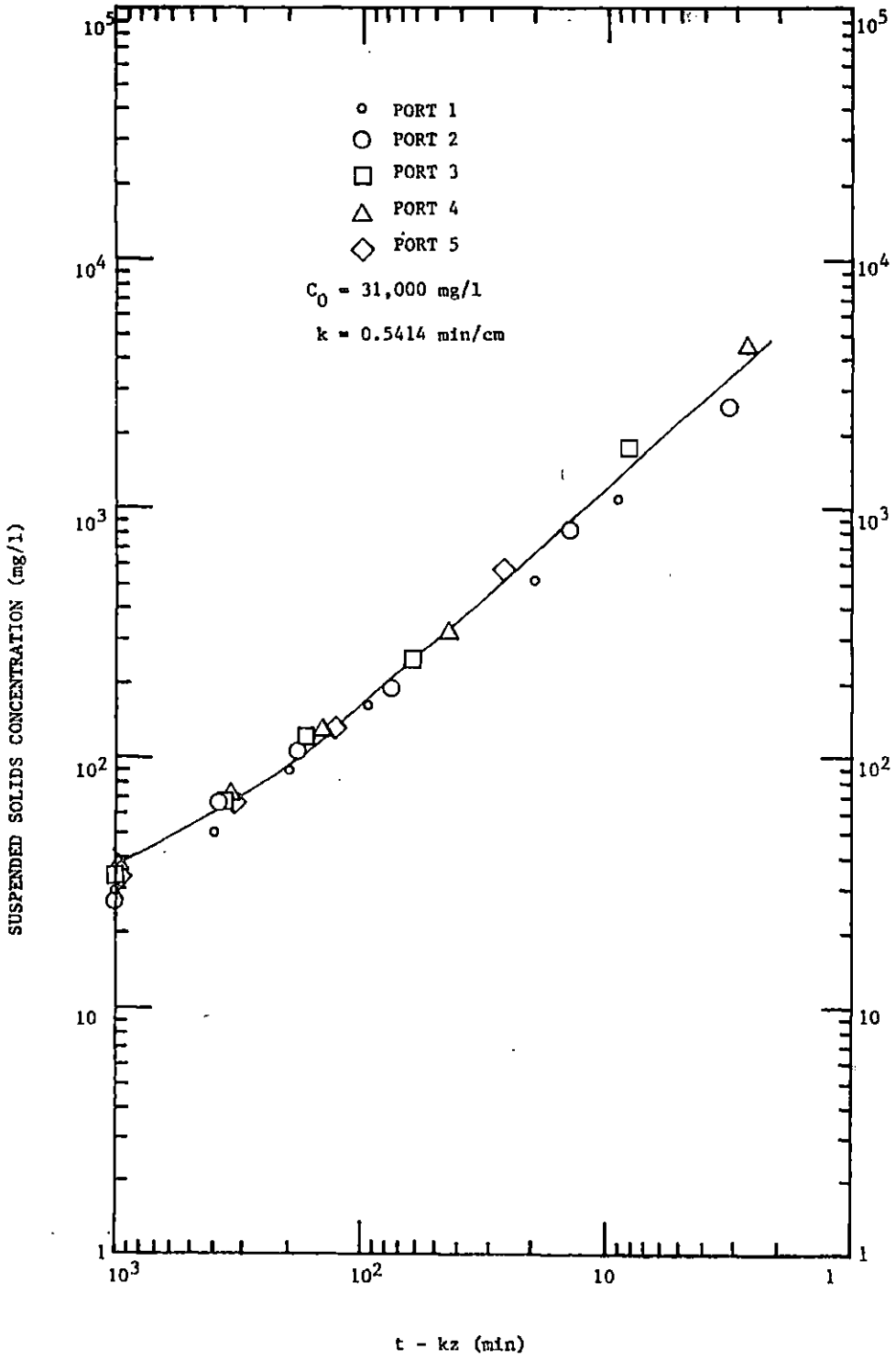

Figure A-8. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant A; initial suspended solids concentration C_0 = 31,000 mg/l).

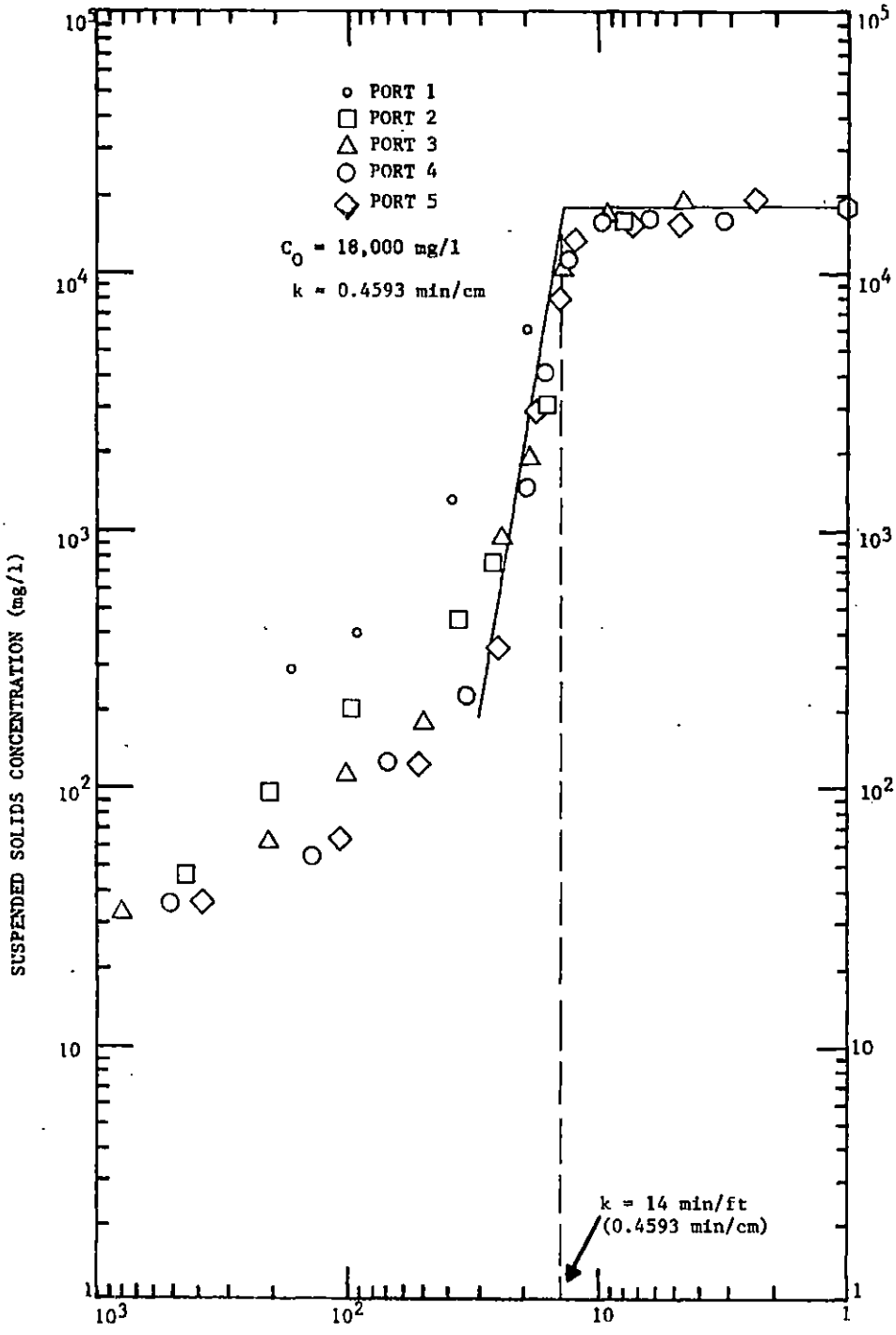

Figure A-9. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant A; initial suspended solids concentration C_0 = 18,000 mg/l).

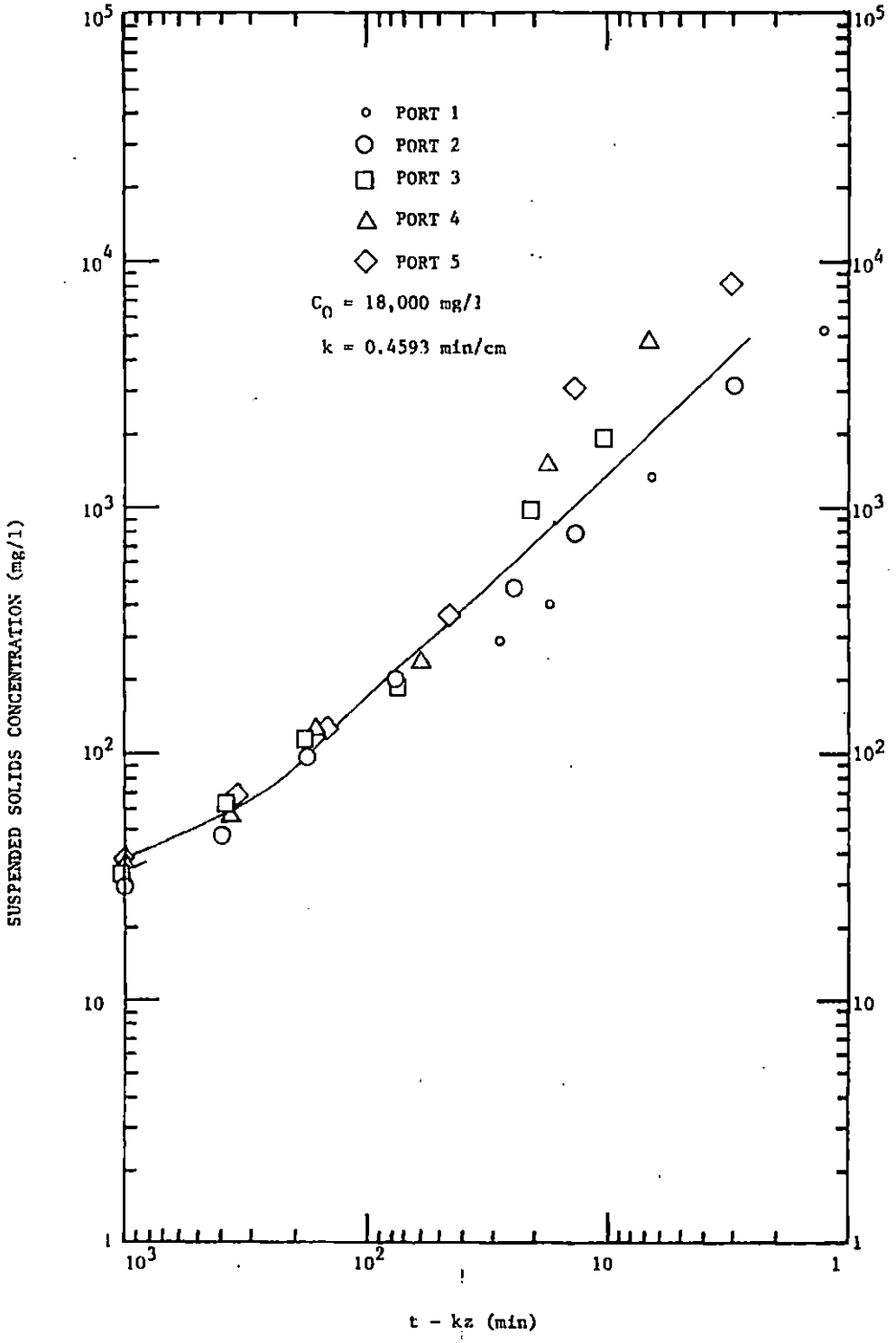

Figure A-10. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant A; initial suspended solids concentration C_0 = 18,000 mg/l).

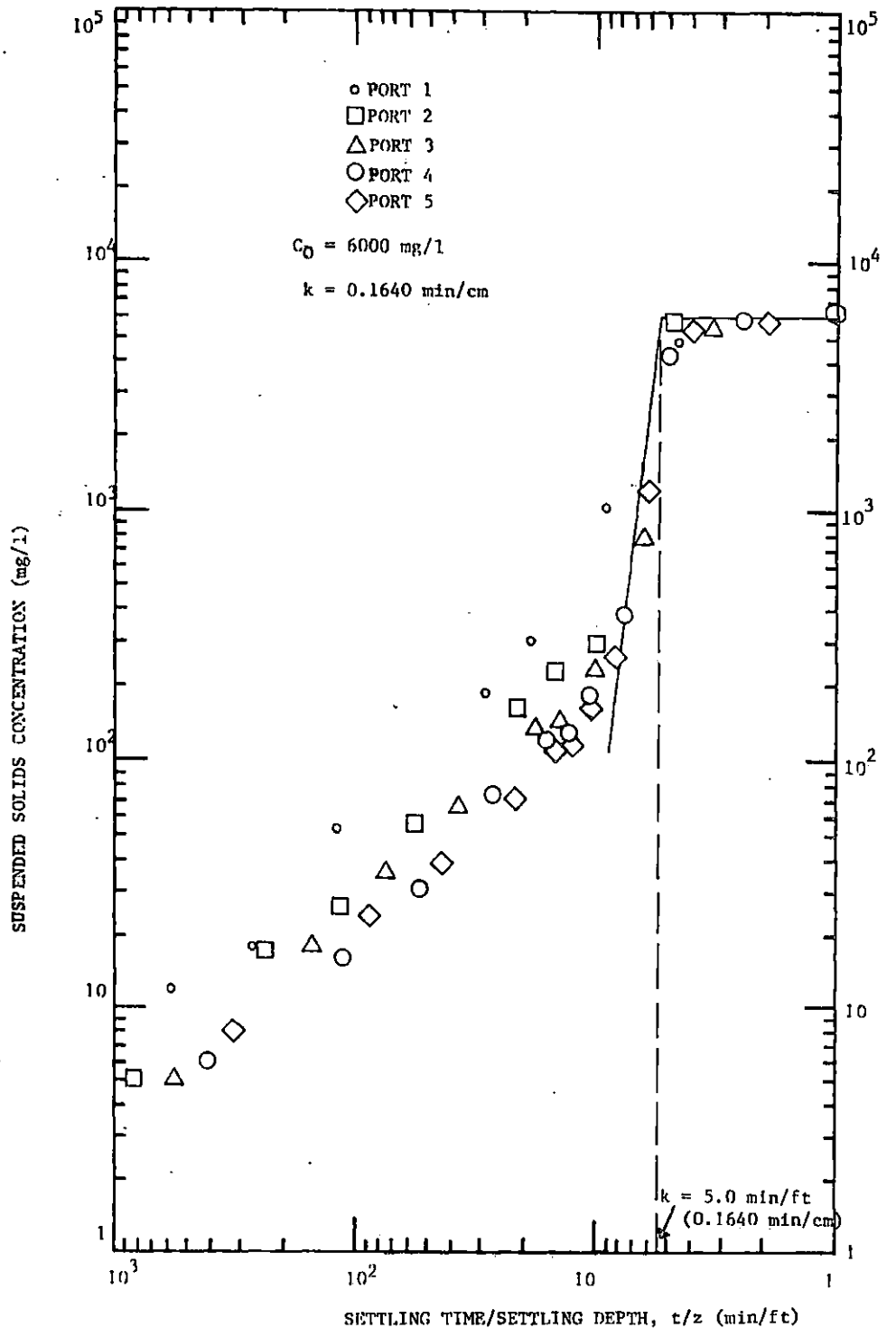

Figure A-11. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant A; initial suspended solids concentration C_0 = 6000 mg/l).

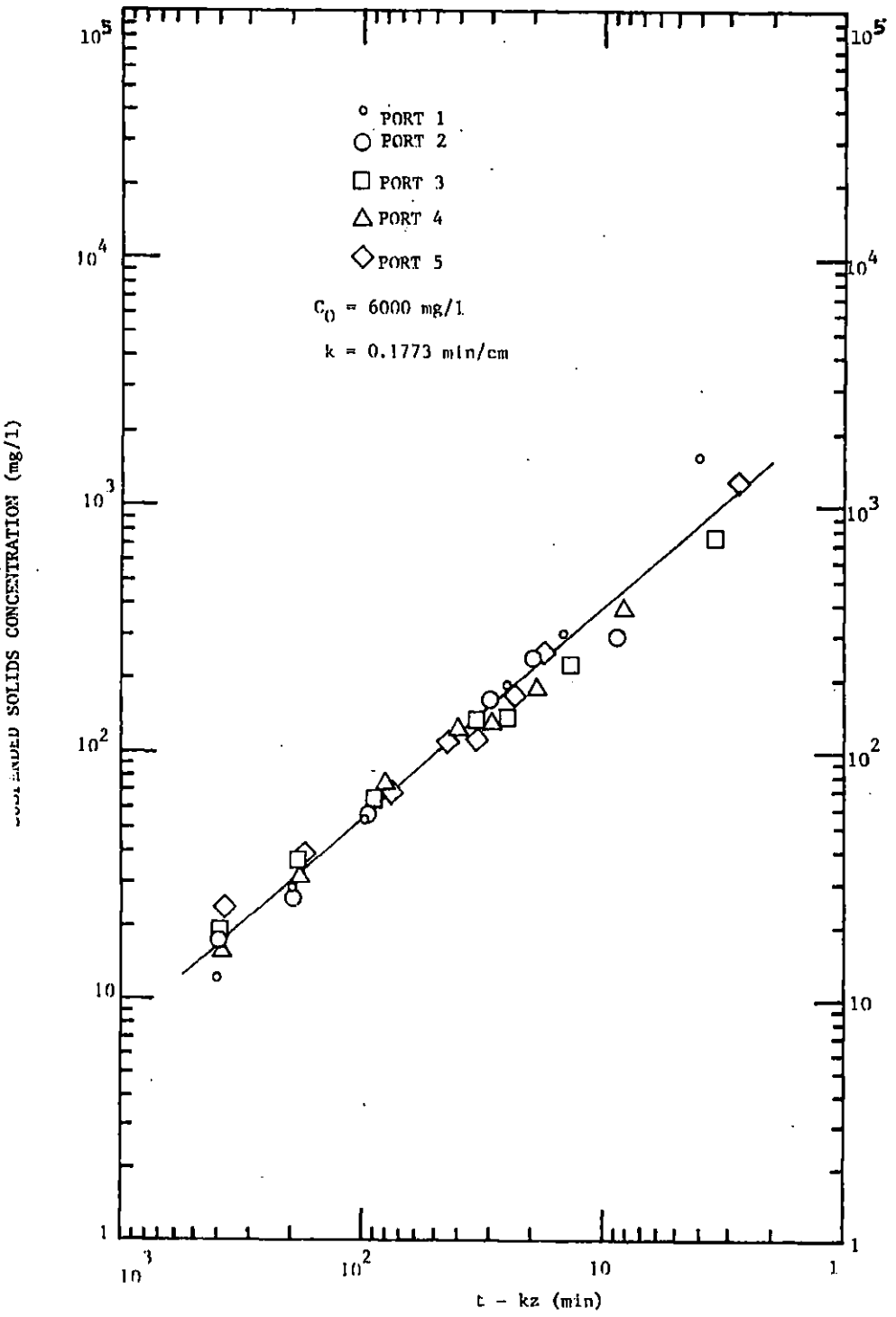

Figure A-12. Suspended solids concentration vs. t-kz (electrostatic precipitator fly ash from plant A; initial suspended solids concentration C_0 = 6000 mg/1).

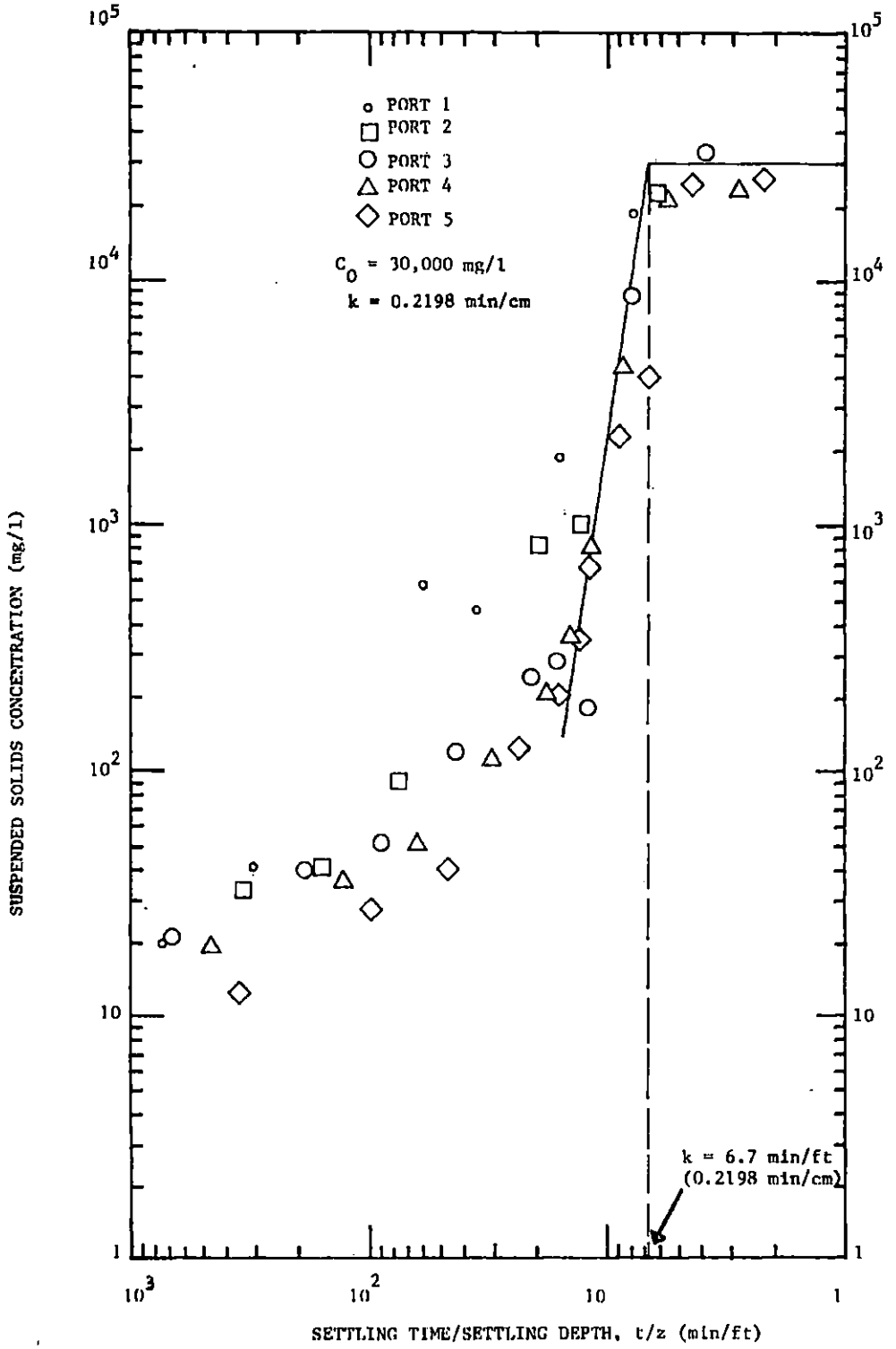

Figure A-13. Suspended solids concentration vs. the reciprocal of settling velocity (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 30,000 mg/l).

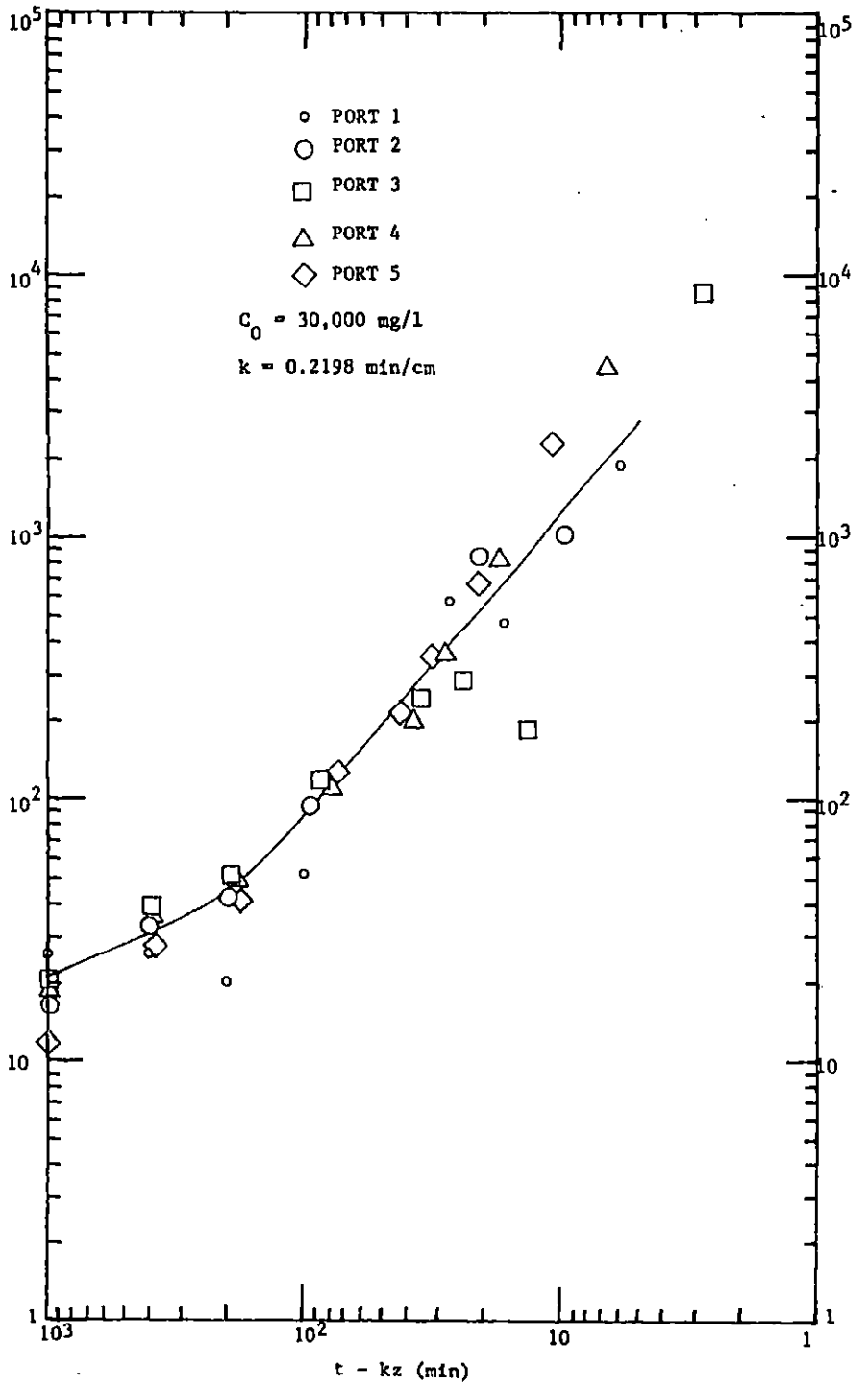

Figure A-14. Suspended solids concentration vs. t - kz (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 30,000 mg/l).

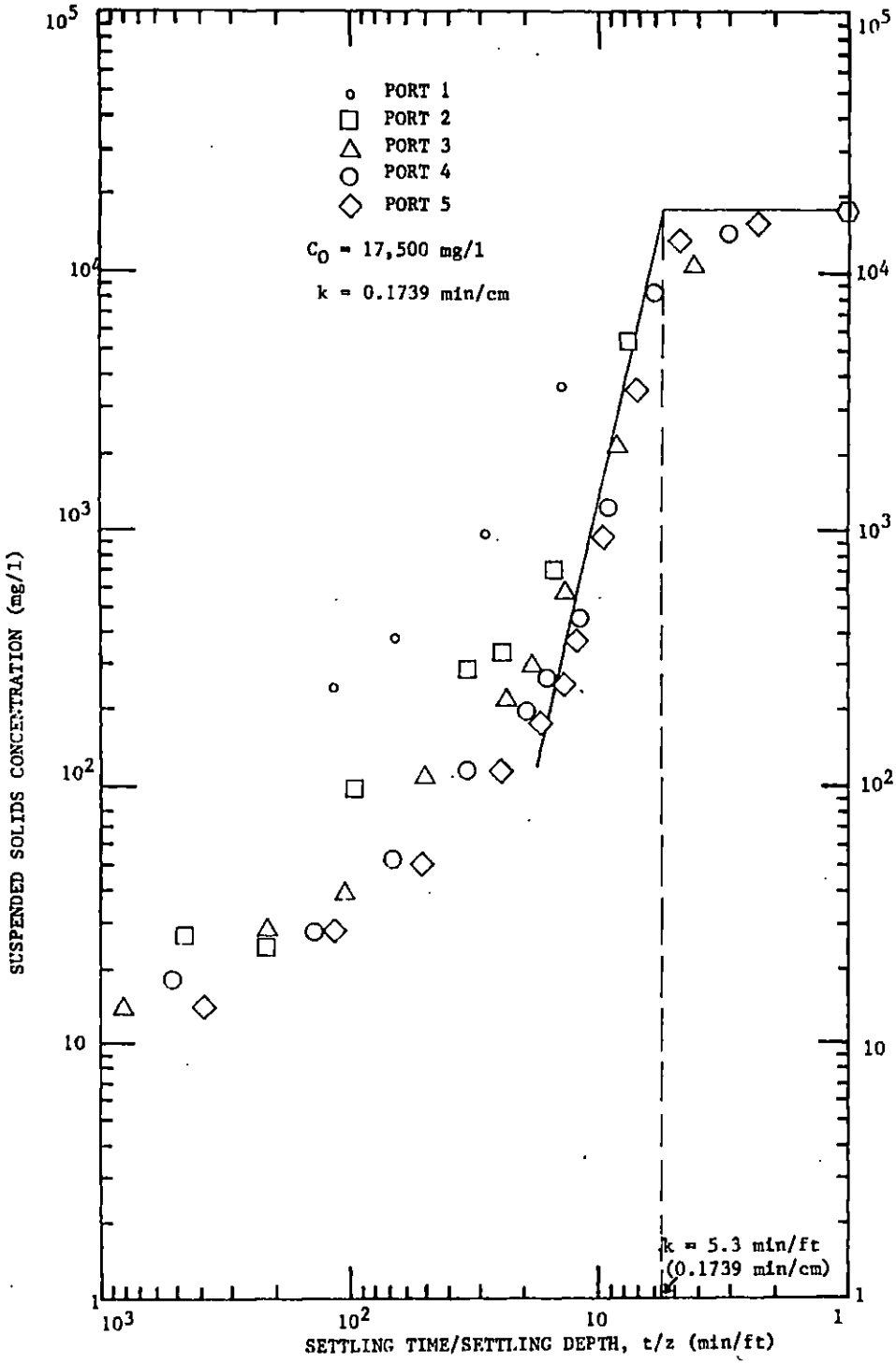

Figure A-15. Suspended solids concentration vs. the reciprocal of settling velocity (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 17,500 mg/1).

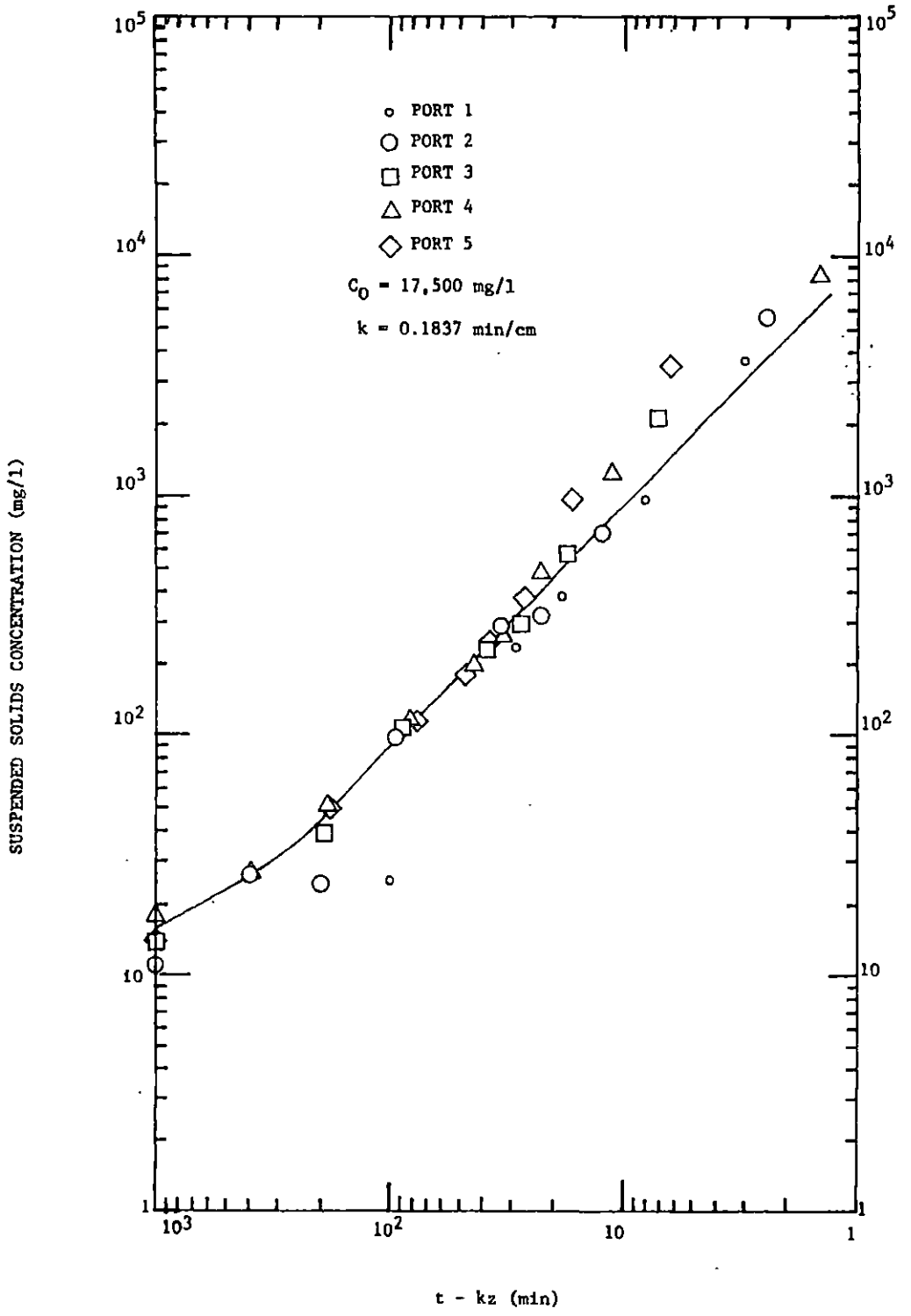

Figure A-16. Suspended solids concentration vs. t - kz (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 17,500 mg/l).

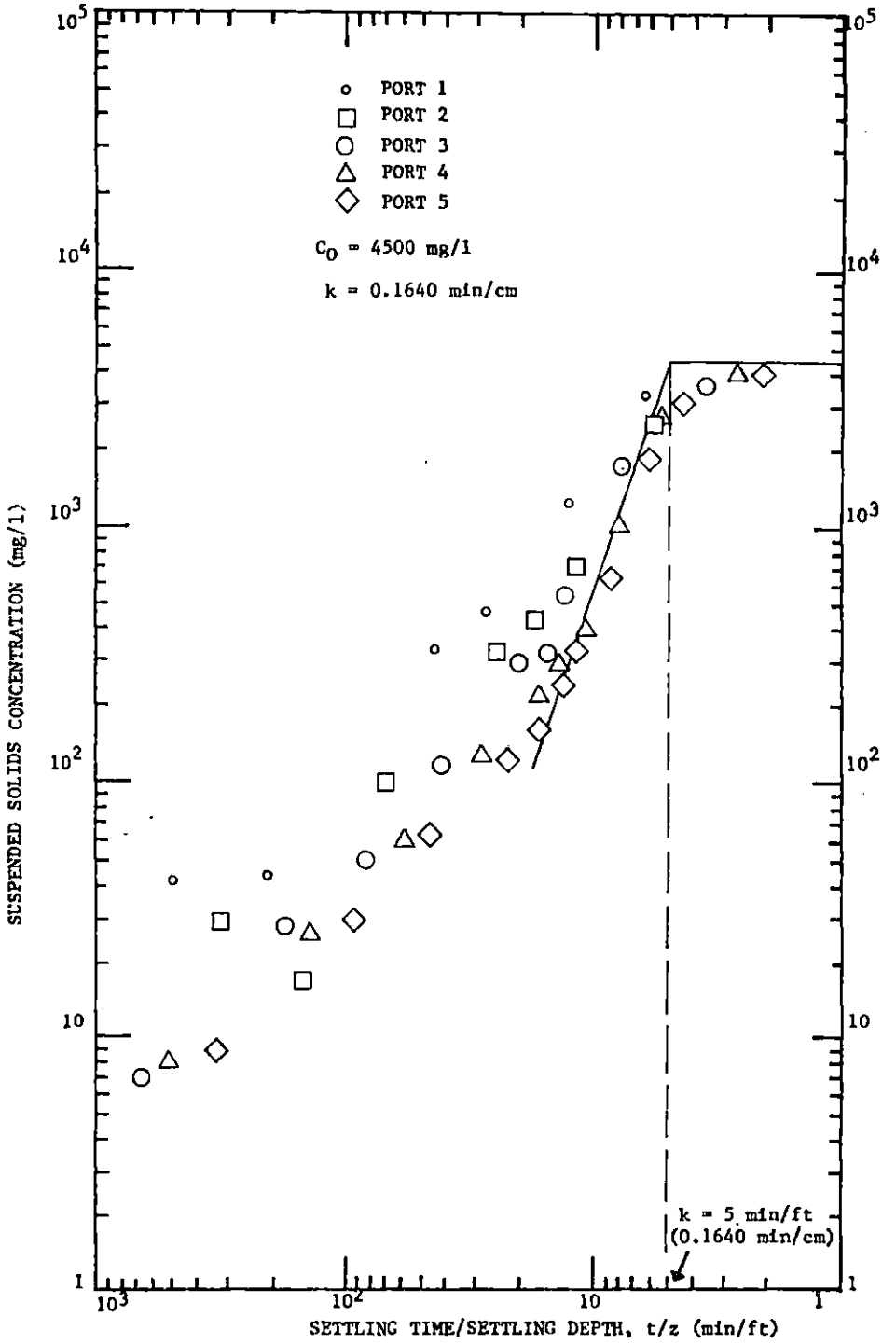

Figure A-17. Suspended solids concentration vs. the reciprocal of settling velocity (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 4500 mg/l).

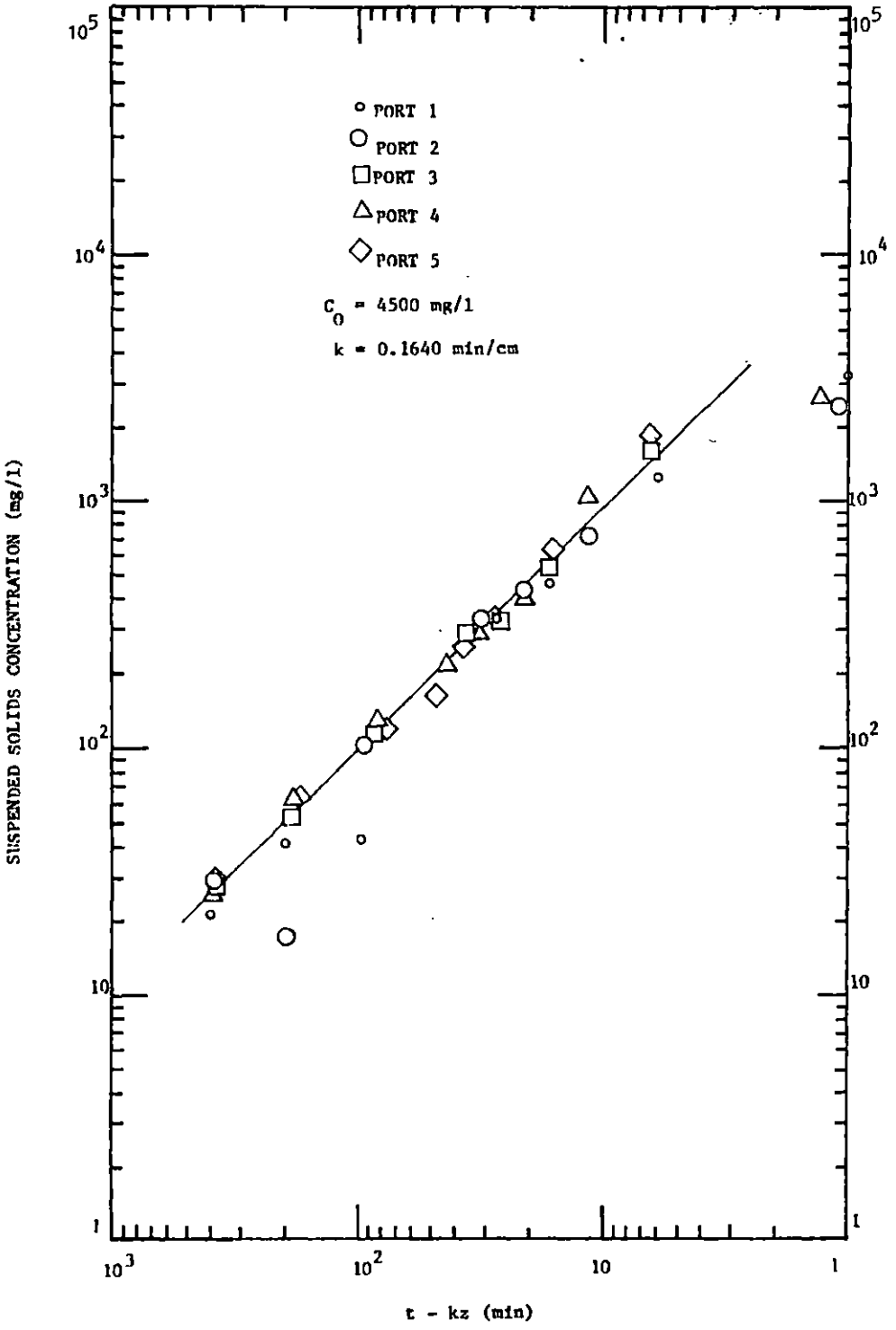

Figure A-18. Suspended solids concentrations vs. t - kz (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 4500 mg/l).

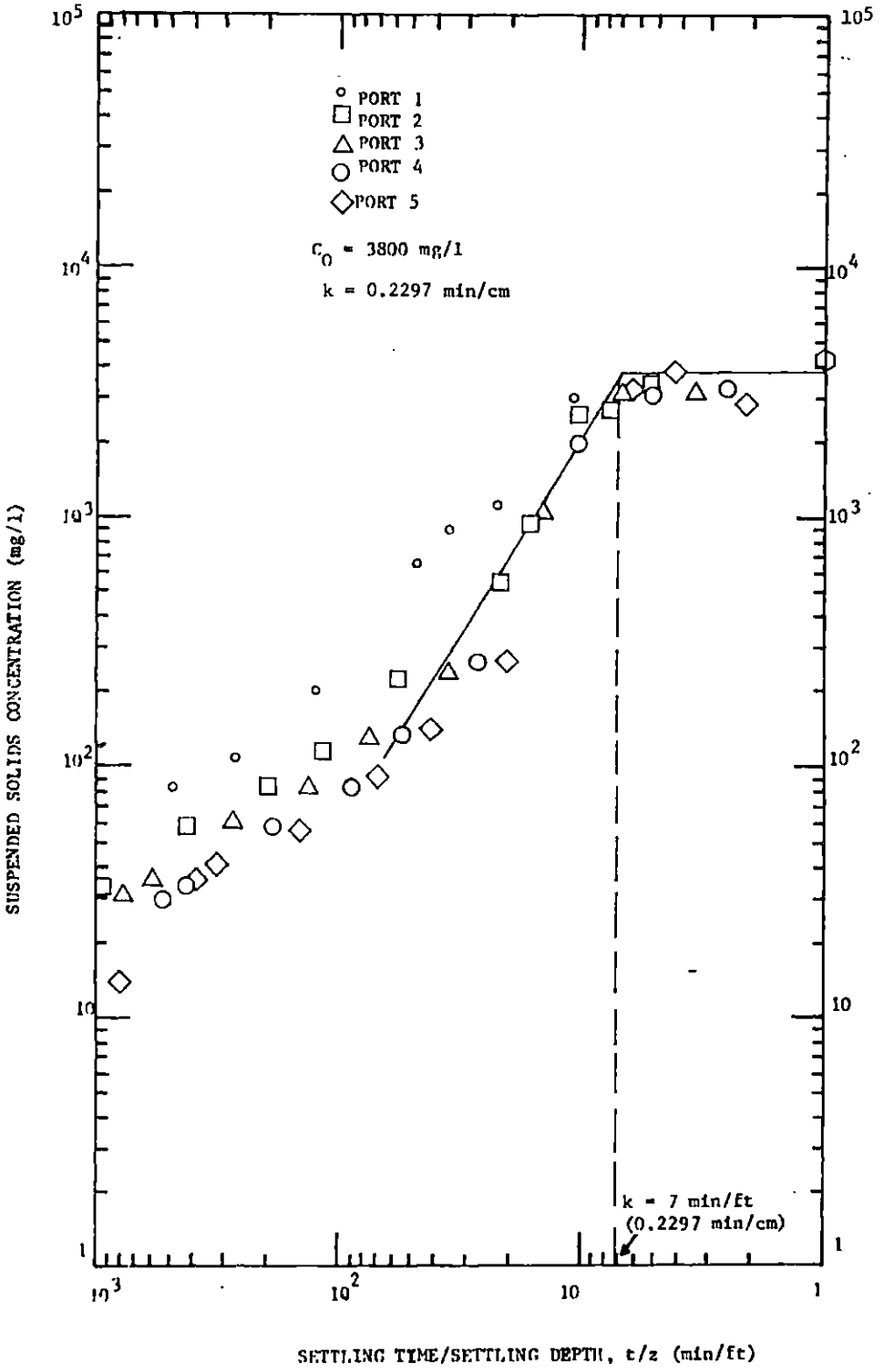

Figure A-19. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 3800 mg/l).

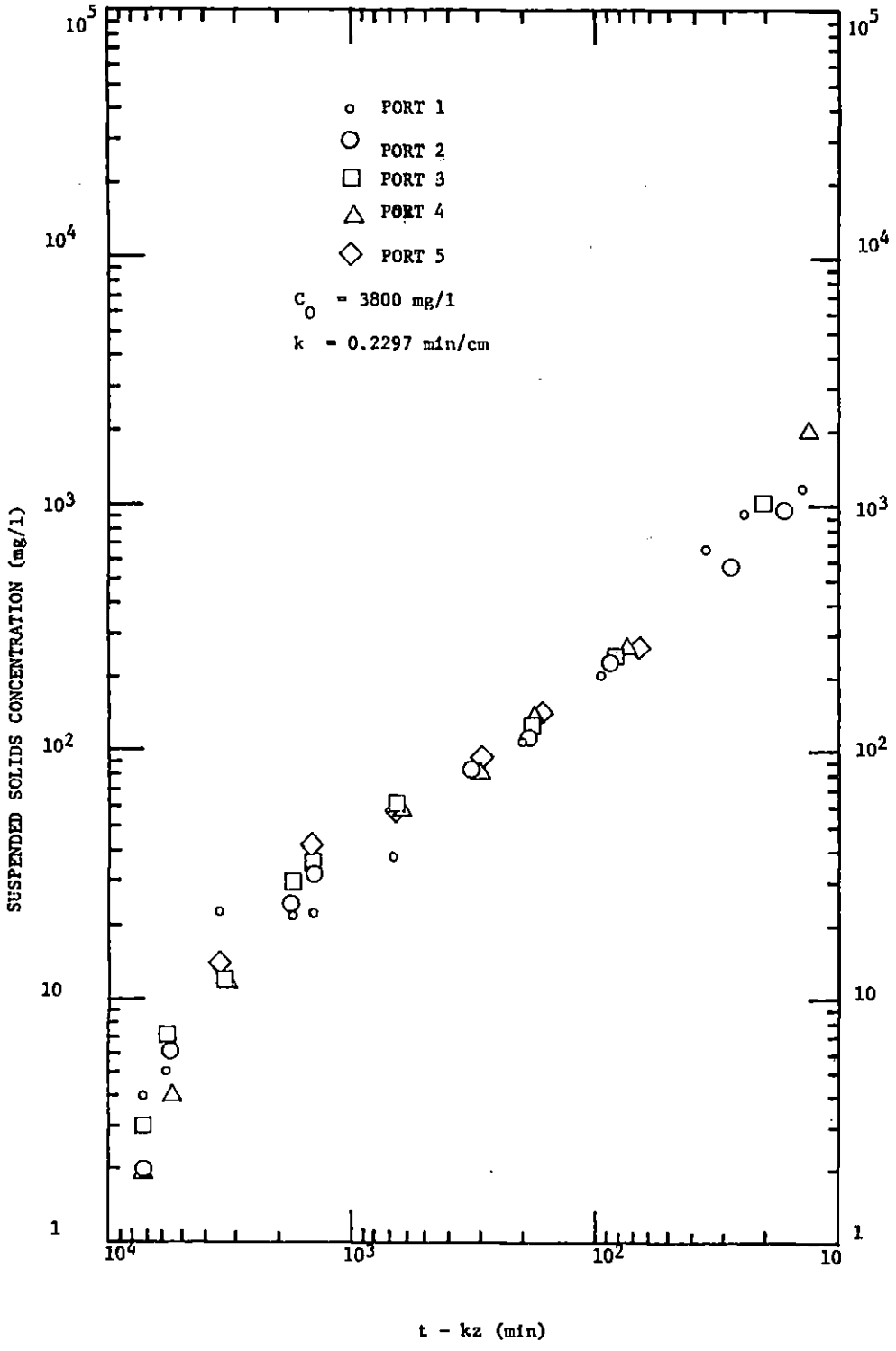

Figure A-20. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant J: initial suspended solids concentration C_0 = 3800 mg/l).

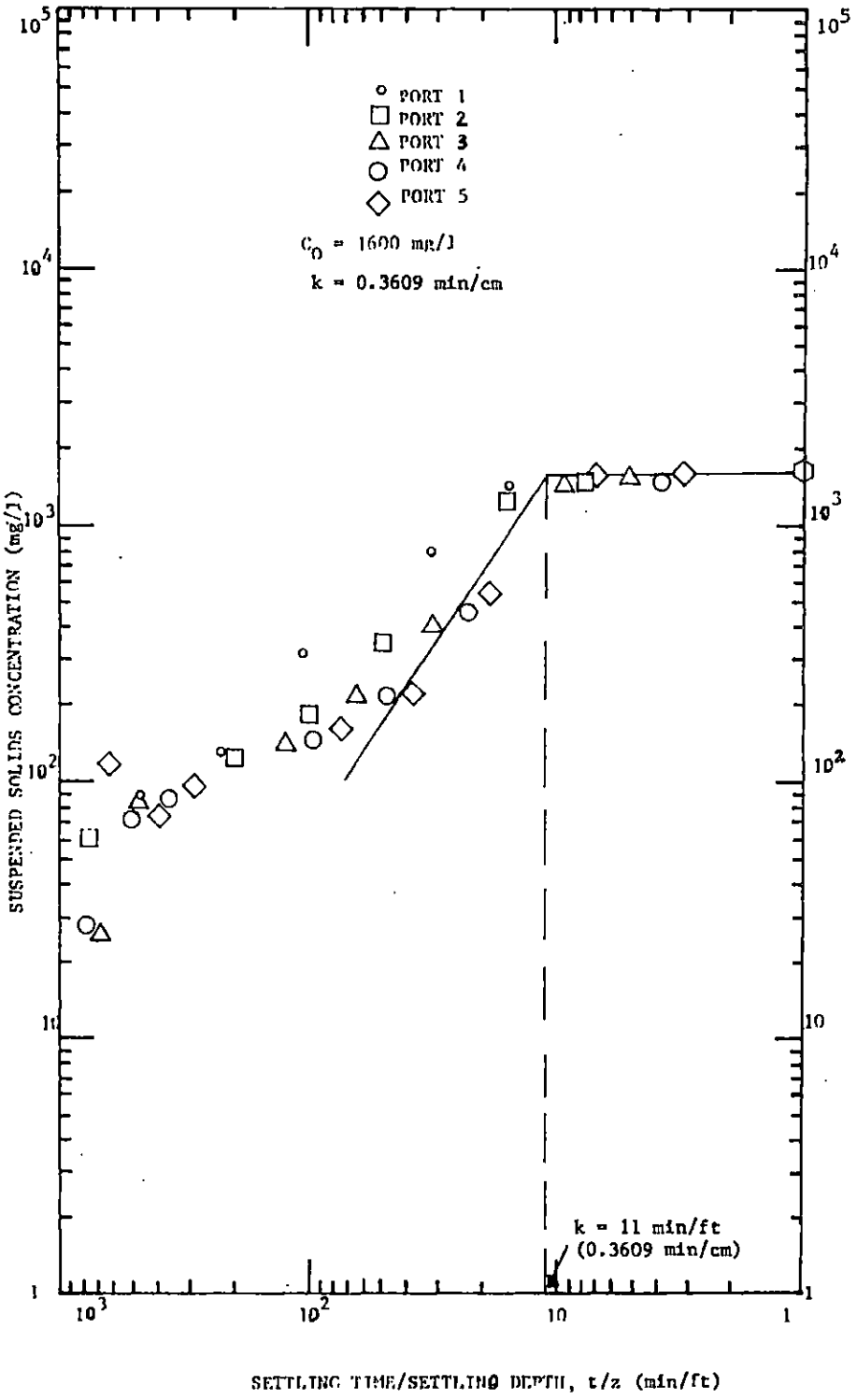

Figure A-21. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant J: initial suspended solids concnetration C_0 = 1600 mg/l).

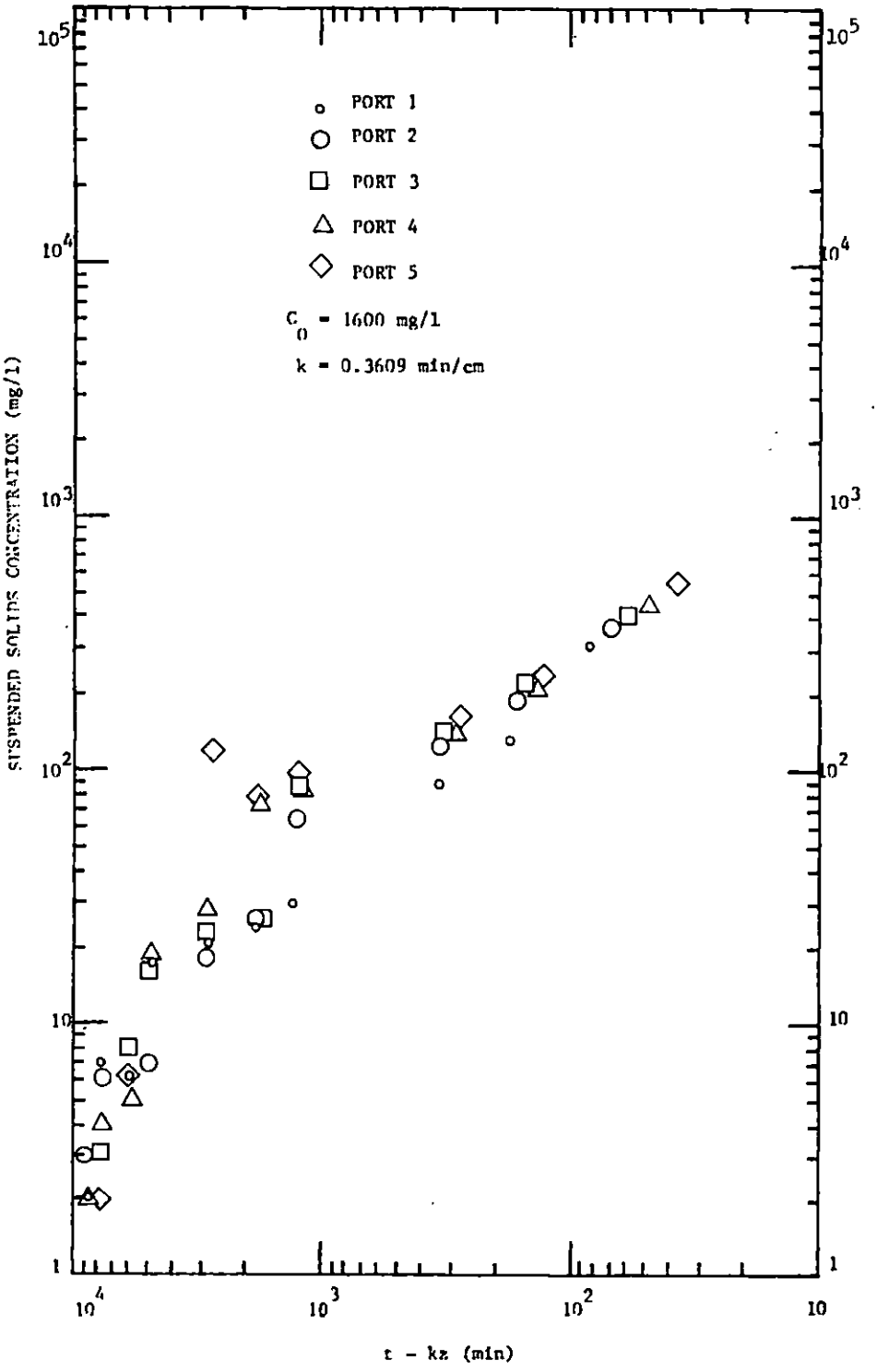

Figure A-22. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 1600 mg/l).

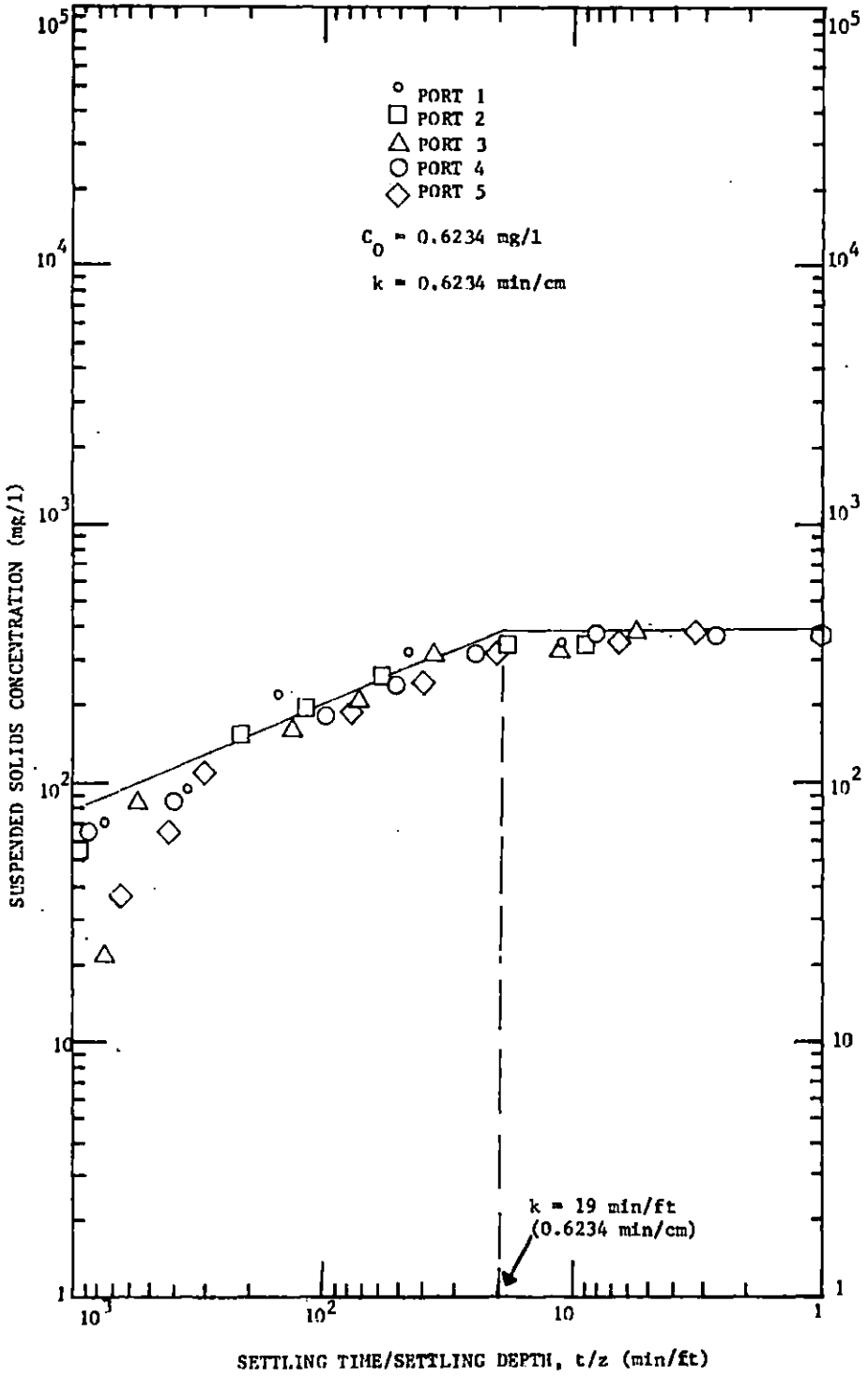

Figure A-23. Suspended solids concentration vs. the reciprocal of settling velocity (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_o = 390 mg/l).

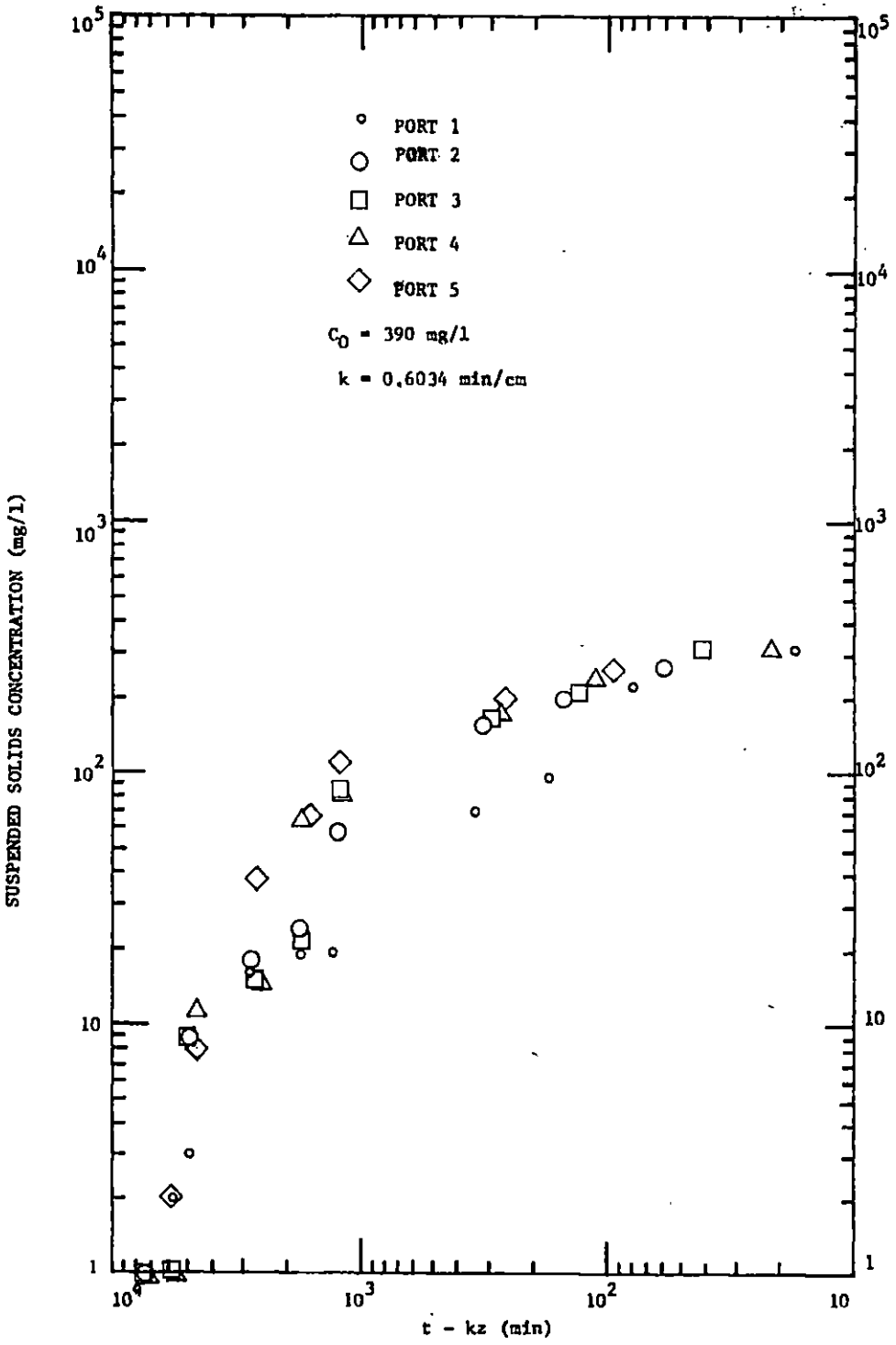

Figure A-24. Suspended solids concentration vs. t - kz (electrostatic precipitator fly ash from plant J; initial suspended solids concentration C_0 = 390 mg/l).

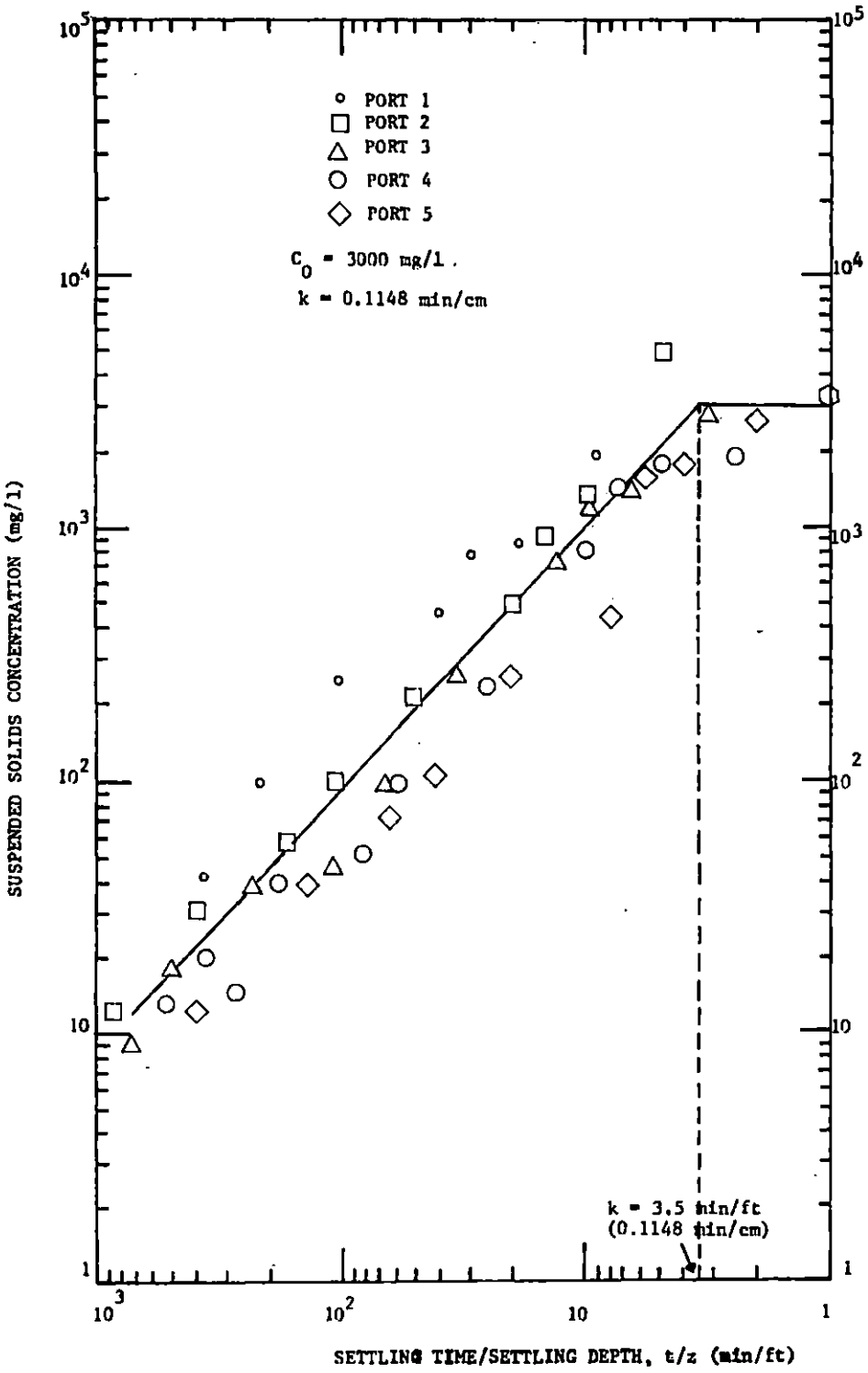

Figure A-25. Suspended solids concentration vs. the reciprocal of settling velocity (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 3000 mg/l).

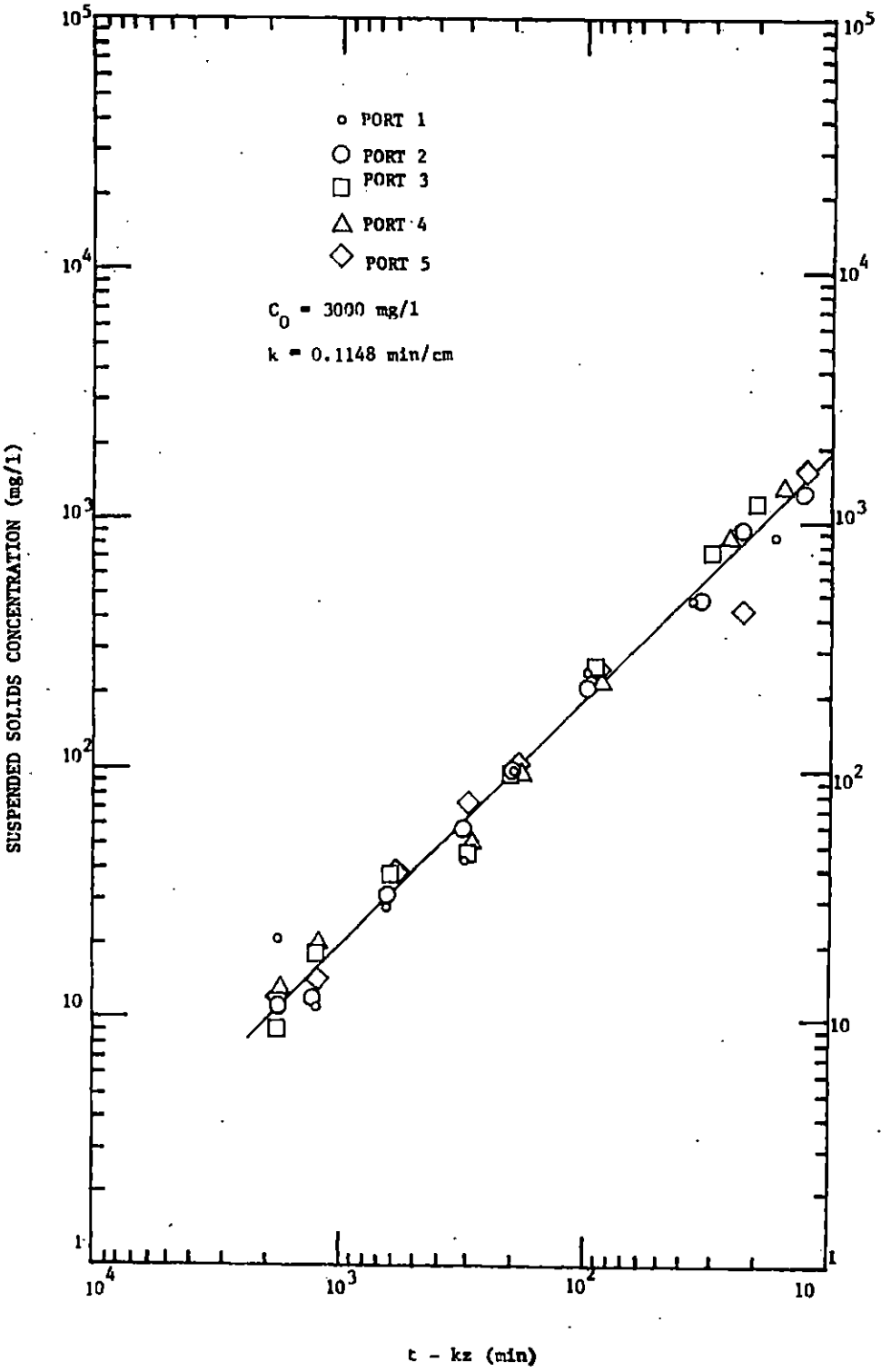

Figure A-26. Suspended solids concentration vs. t - kz (mechanical collector fly ash from plant J; initial suspended solids concentration C_0 = 3000 mg/1).

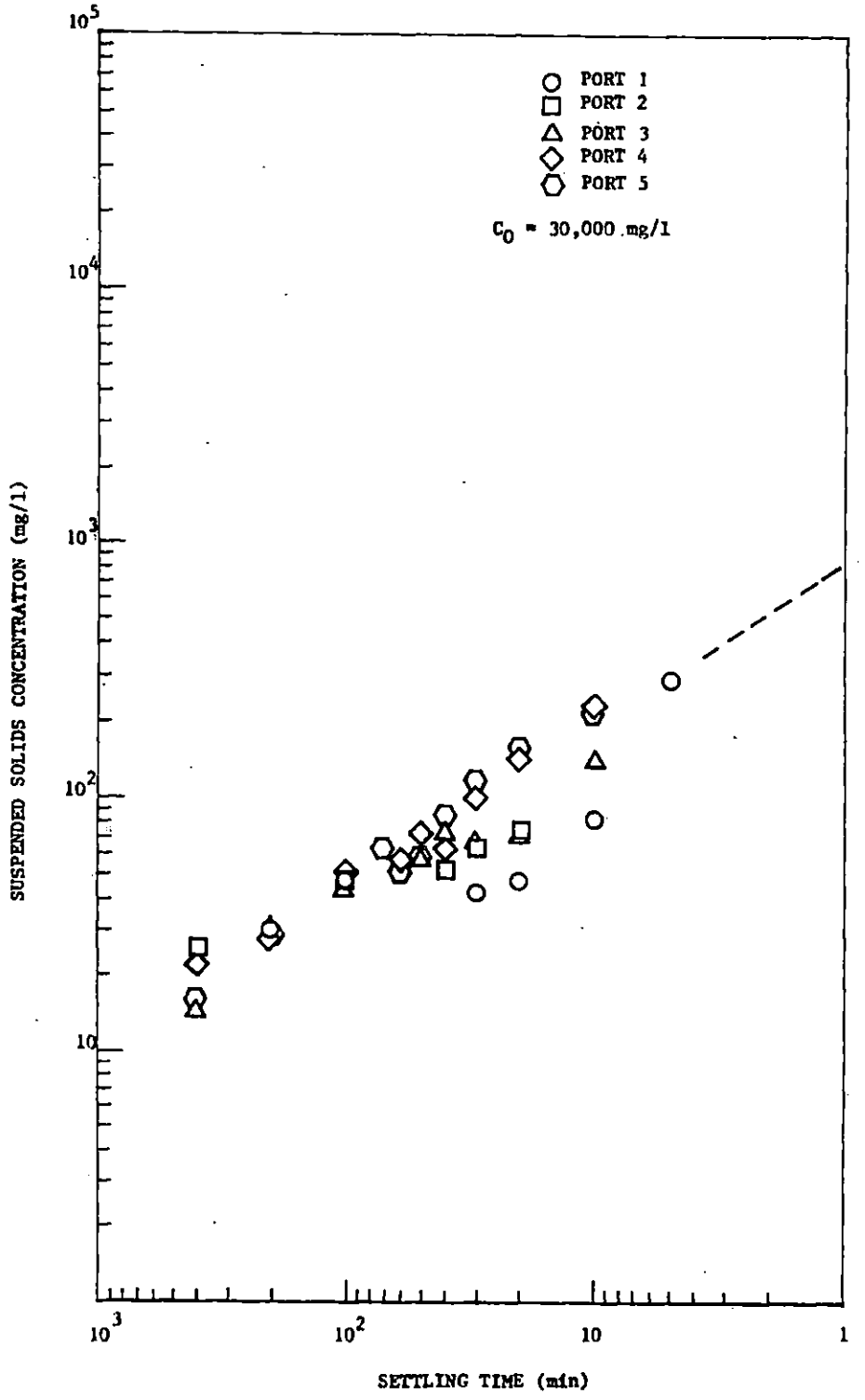

Figure A-27. Suspended solids concentration vs. settling time (bottom ash from plant L; initial suspended solids concentration C_0 = 30,000 mg/l).

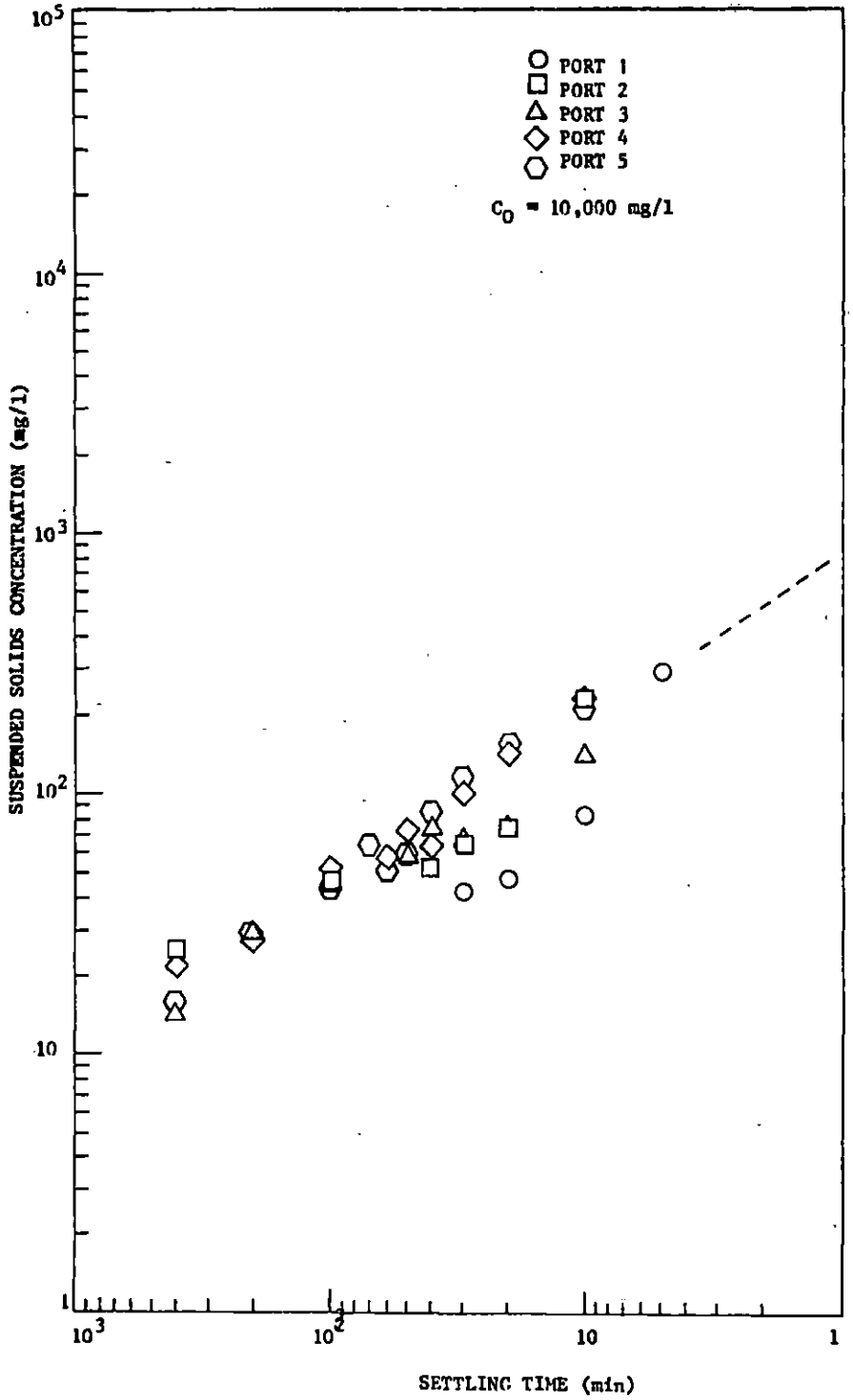

Figure A-28. Suspended solids concentration vs. settling time (bottom ash from plant L; initial suspended solids concentration C_0 = 10,000 mg/l).

APPENDIX B

RESULTS OF INVESTIGATION OF MINERAL LEACHING RATE OF FLY ASHES

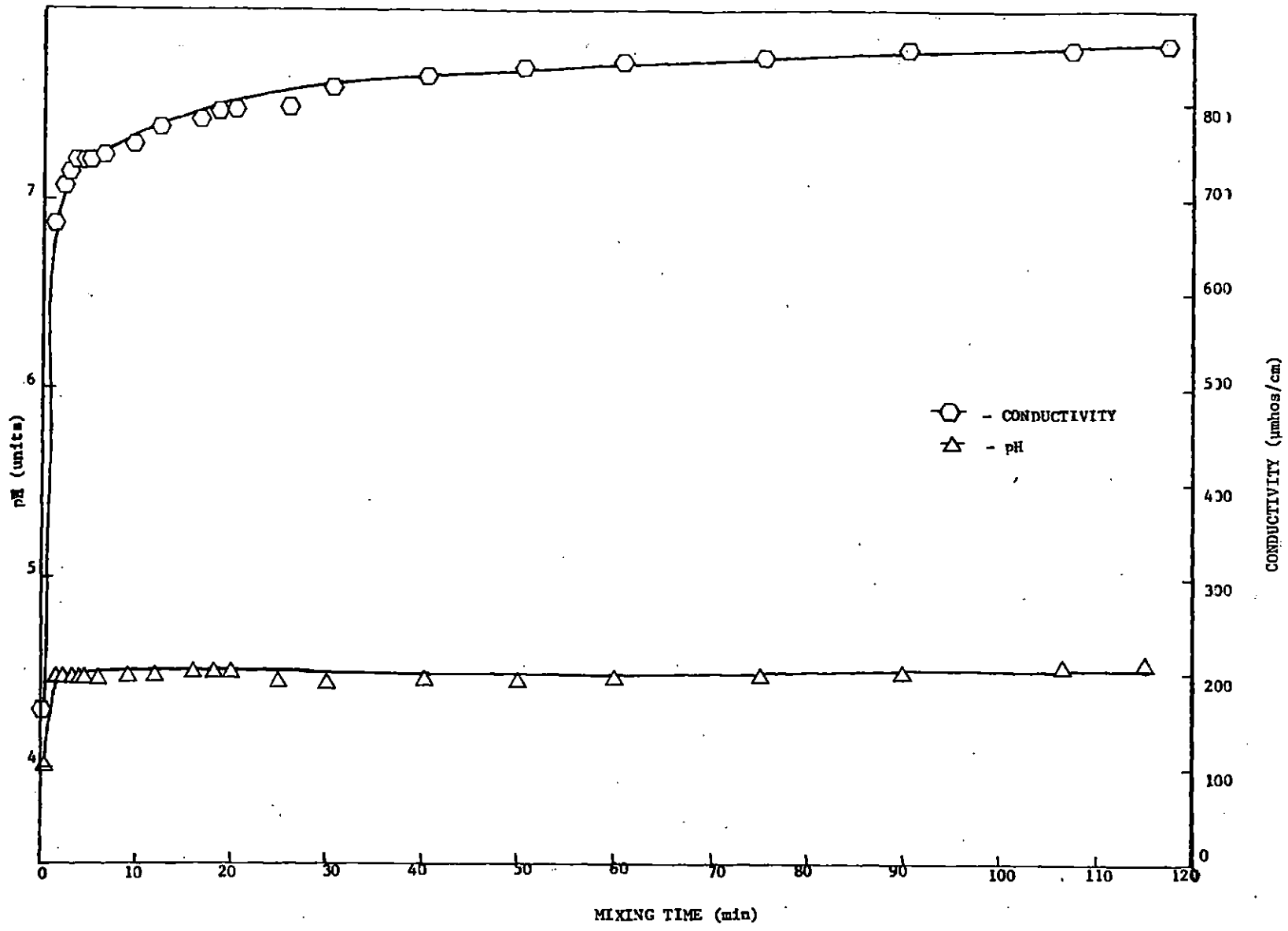

Figure B-1. pH and mineral leaching rate of 3 percent electrostatic precipiter fly ash from plant H.

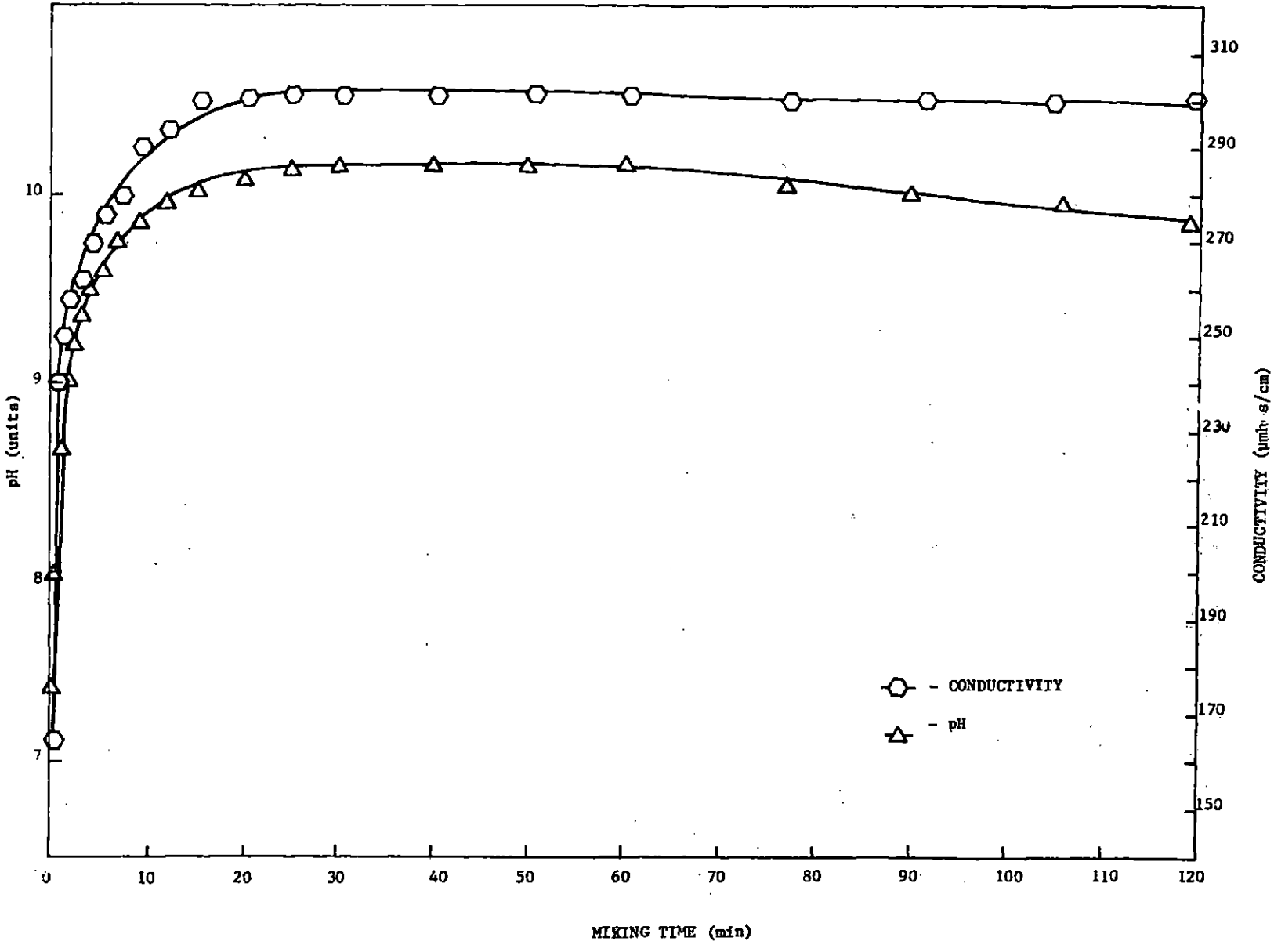

Figure B-2. pH and mineral leaching rate of 3 percent mechanical collector fly ash from plant H.

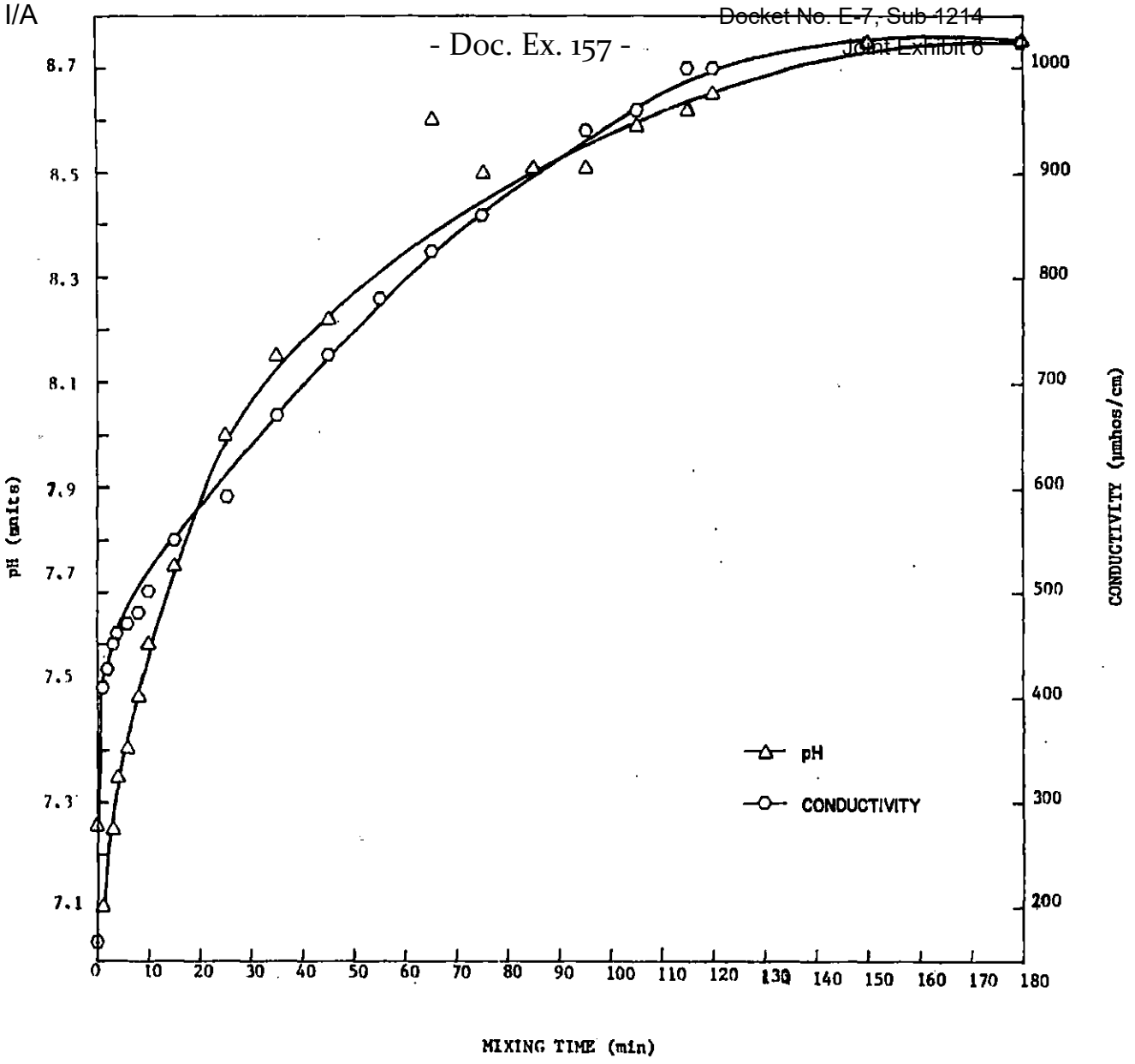

Figure B-3. pH and mineral leaching rate of 3 percent electrostatic precipitator fly ash from plant J.

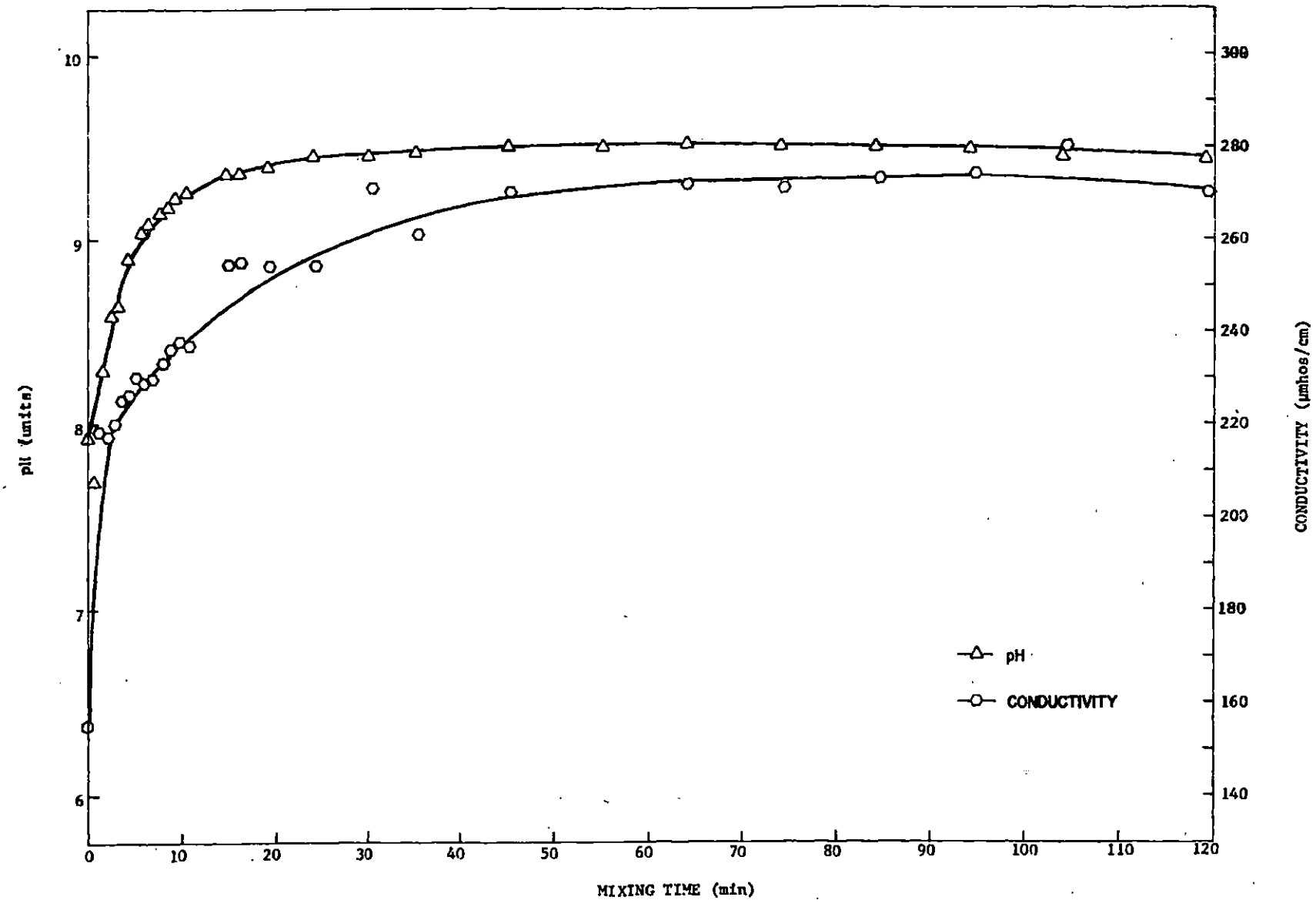

Figure B-4. pH and mineral leaching rate of 3 percent mechanical collector fly ash from plant J.

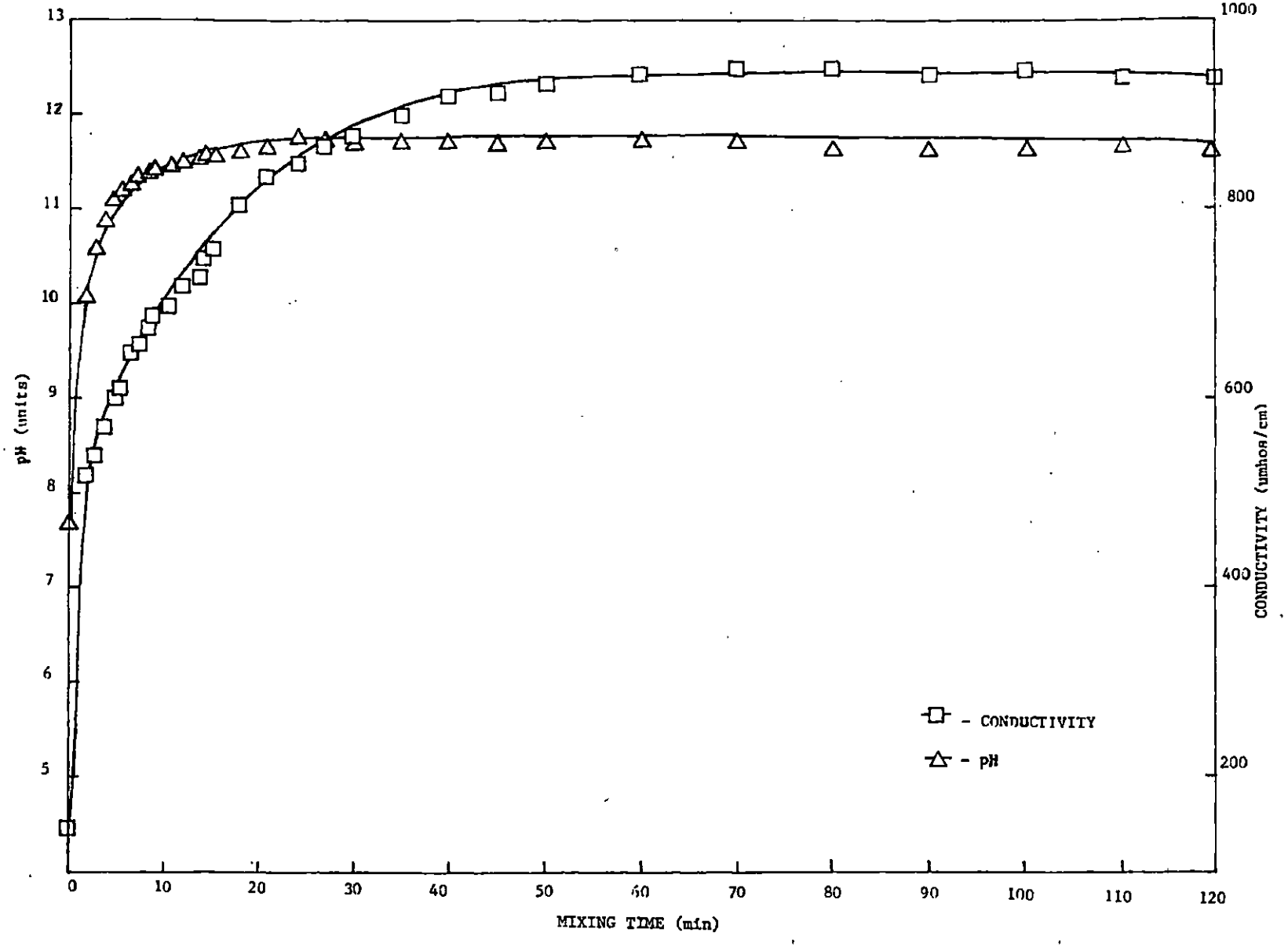

Figure B-5. pH and mineral leaching rate of 3 percent electrostatic precipitator fly ash from plant K.

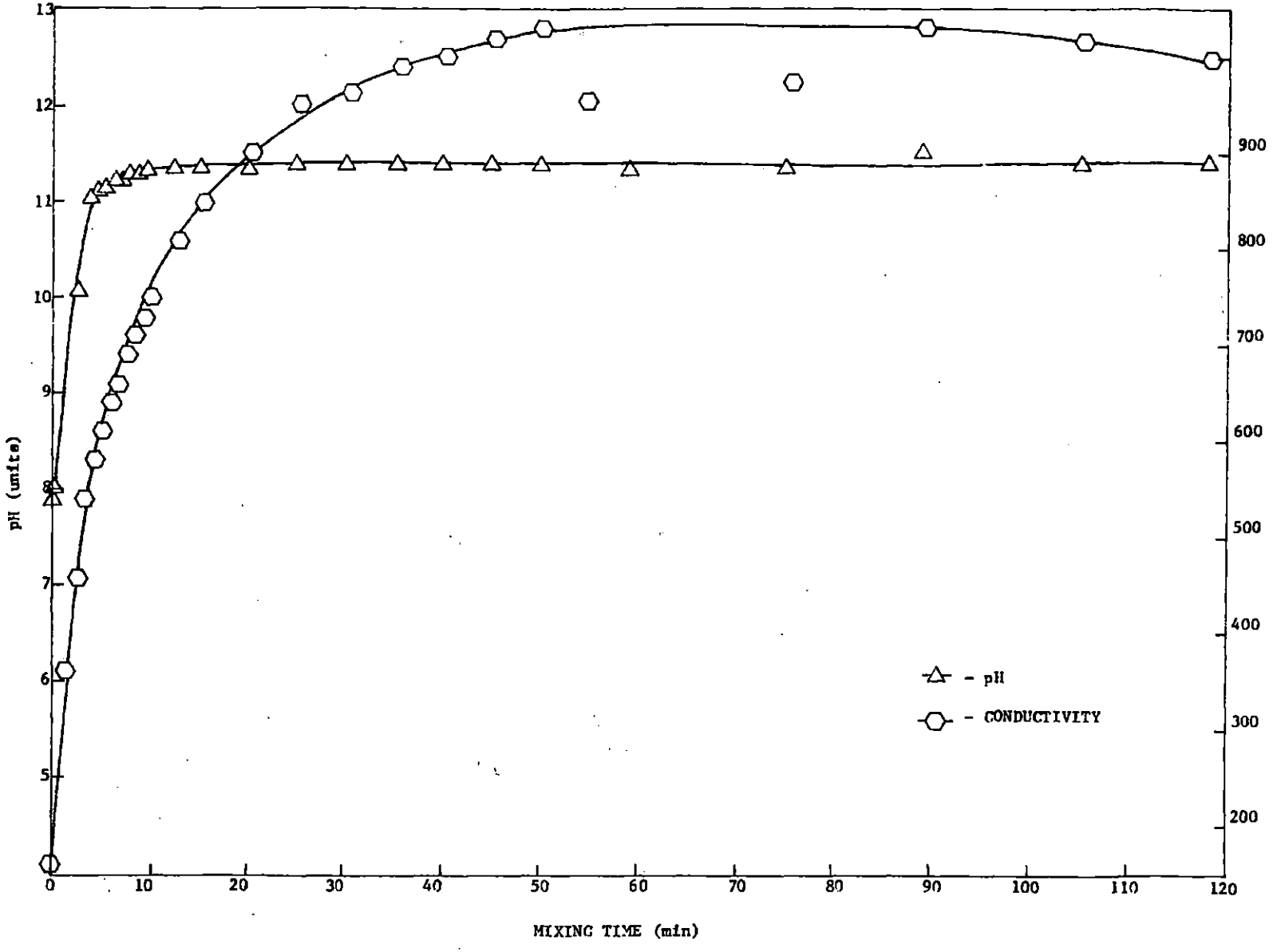

Figure B-6. pH and mineral leaching rate of 3 percent mechanical collector fly ash from plant K.

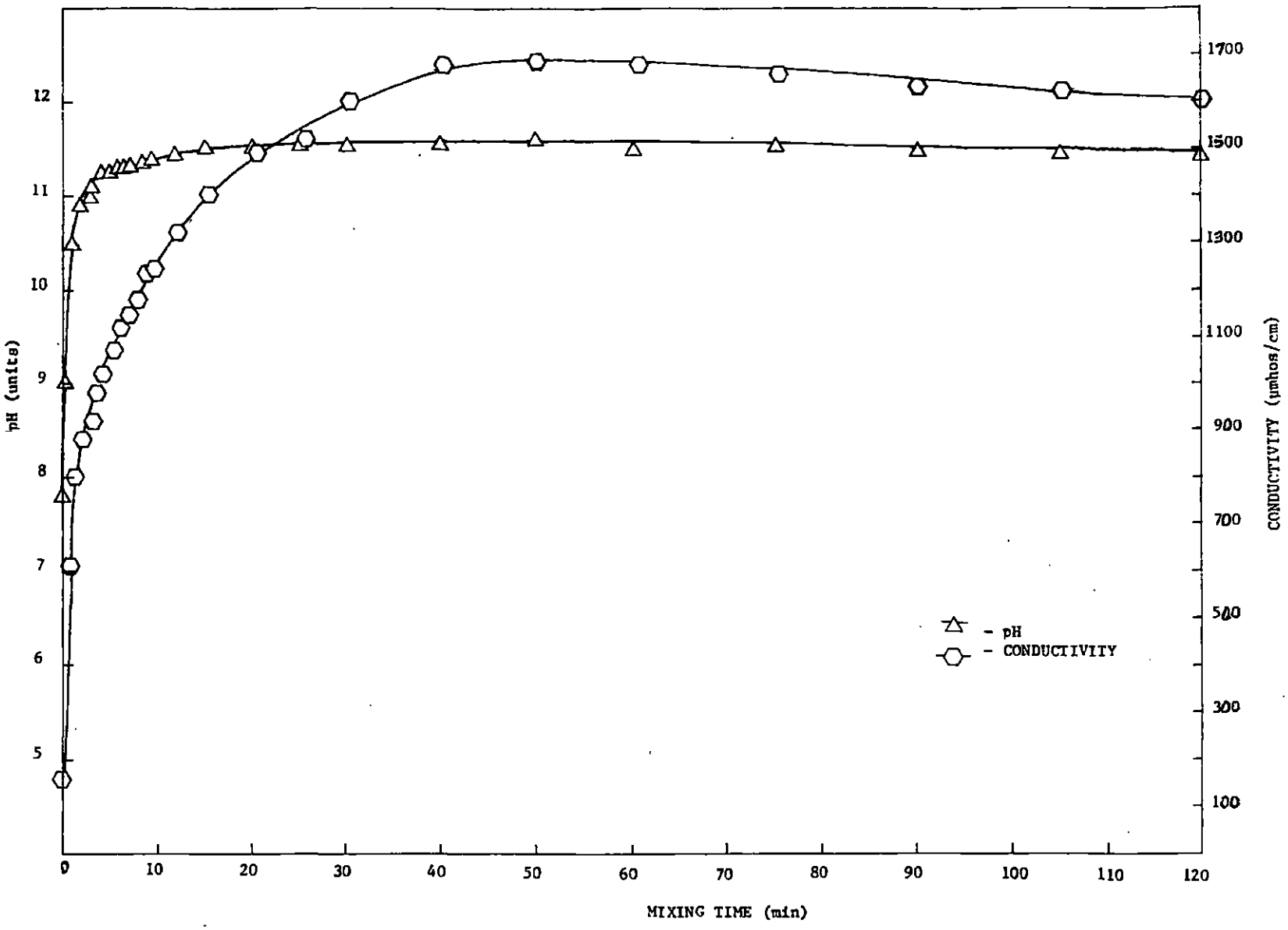

Figure B-7. pH and mineral leaching rate of 3 percent electrostatic precipitator fly ash from plant L.

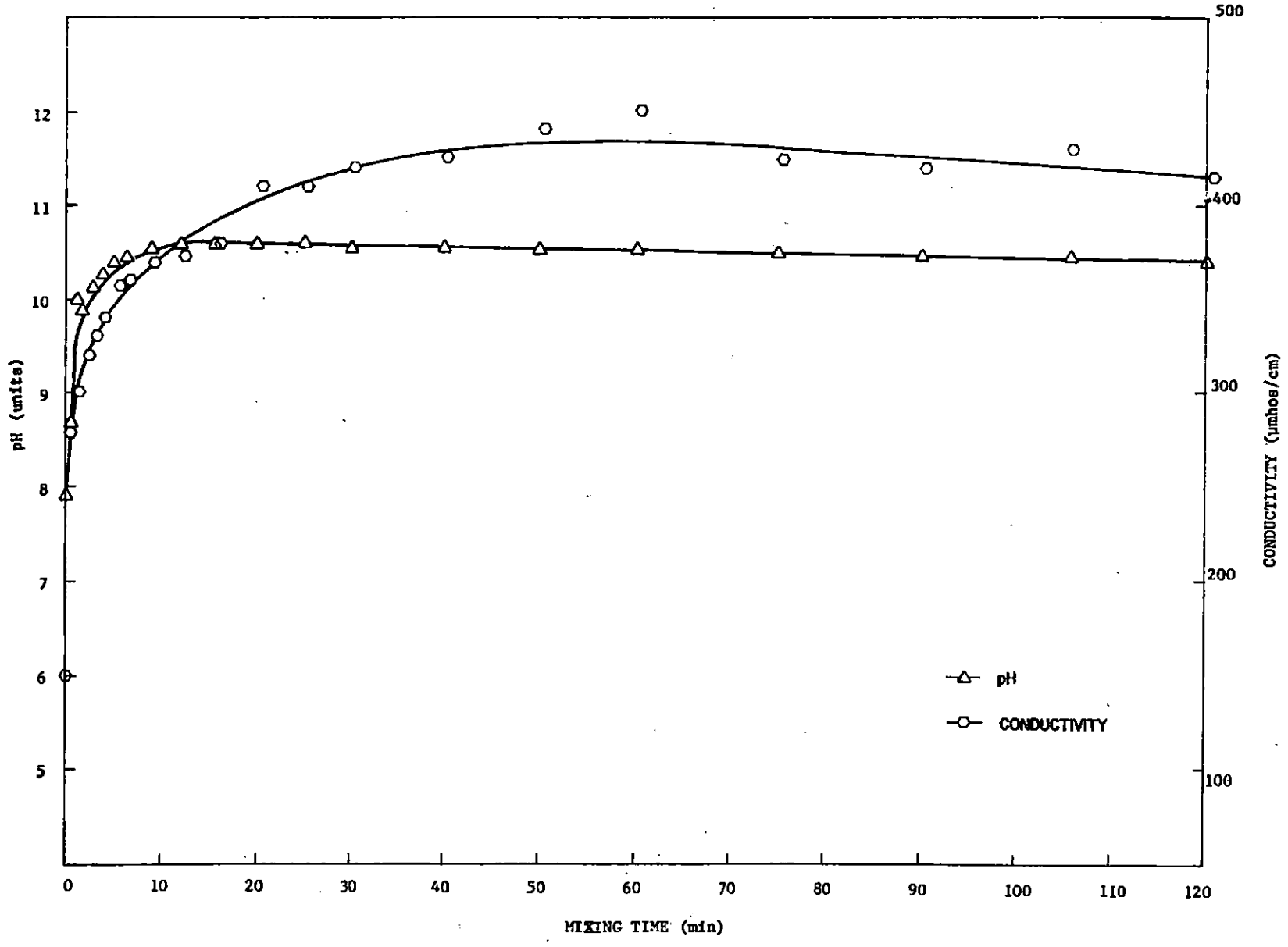

Figure B-8. pH and mineral leaching rate of 3 percent mechanical collector fly ash from plant L.

APPENDIX C

pH AND CONDUCTIVITY OF ASH TRANSPORT WATER VS. MIXING TIME FOR VARIOUS ASH CONCENTRATIONS

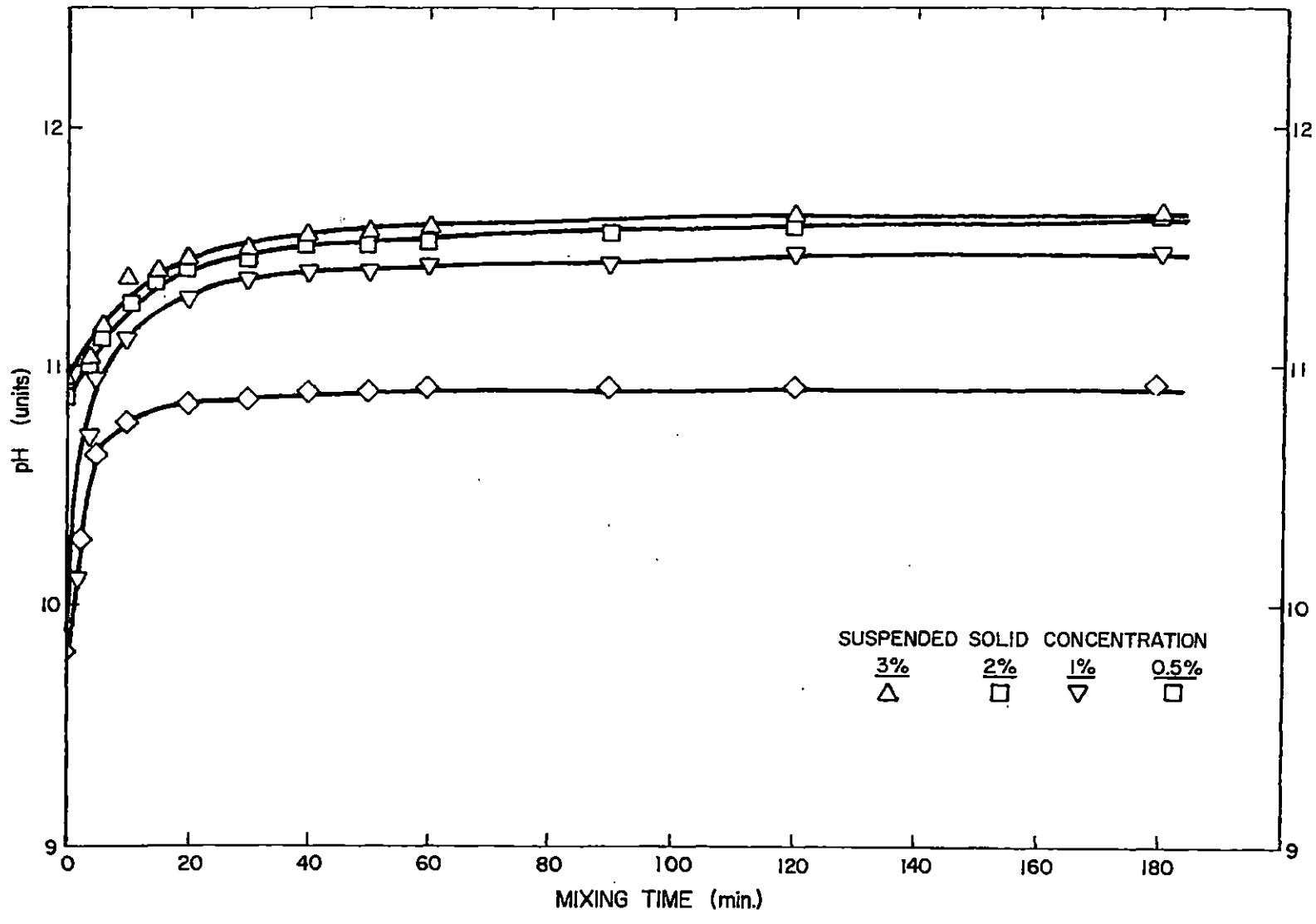

Figure C-1. pH of ash transport water vs. mixing time for various ash concentrations (electorstatic precipitator fly ash from plant E).

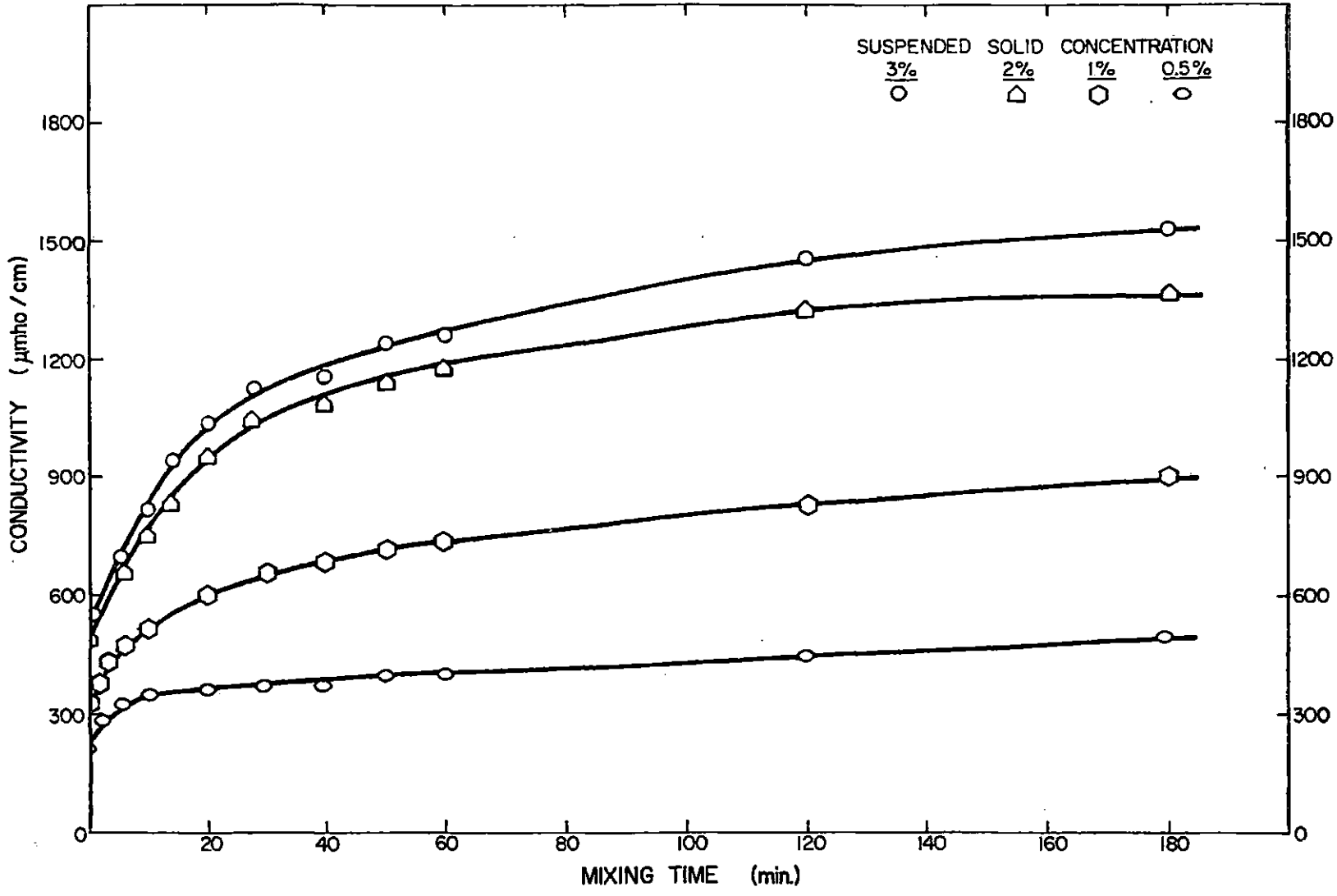

Figure C-2. Conductivity of ash transport water vs. mixing time for various ash concentrations (electrostatic precipitator fly ash from plant E).

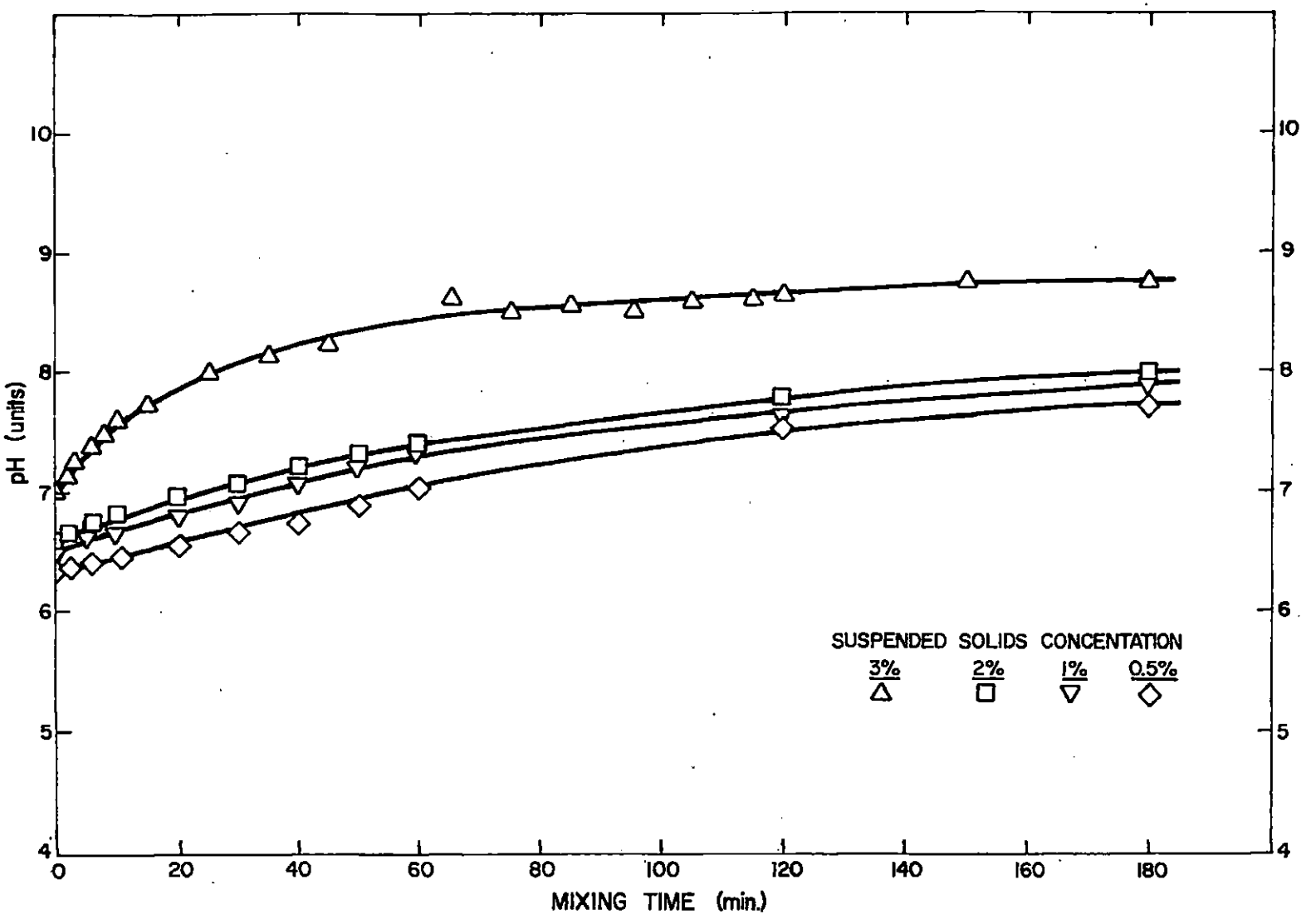

Figure C-3. pH of ash transport water vs. mixing time for various ash concentrations (electrostatic precipitator fly ash from plant J).

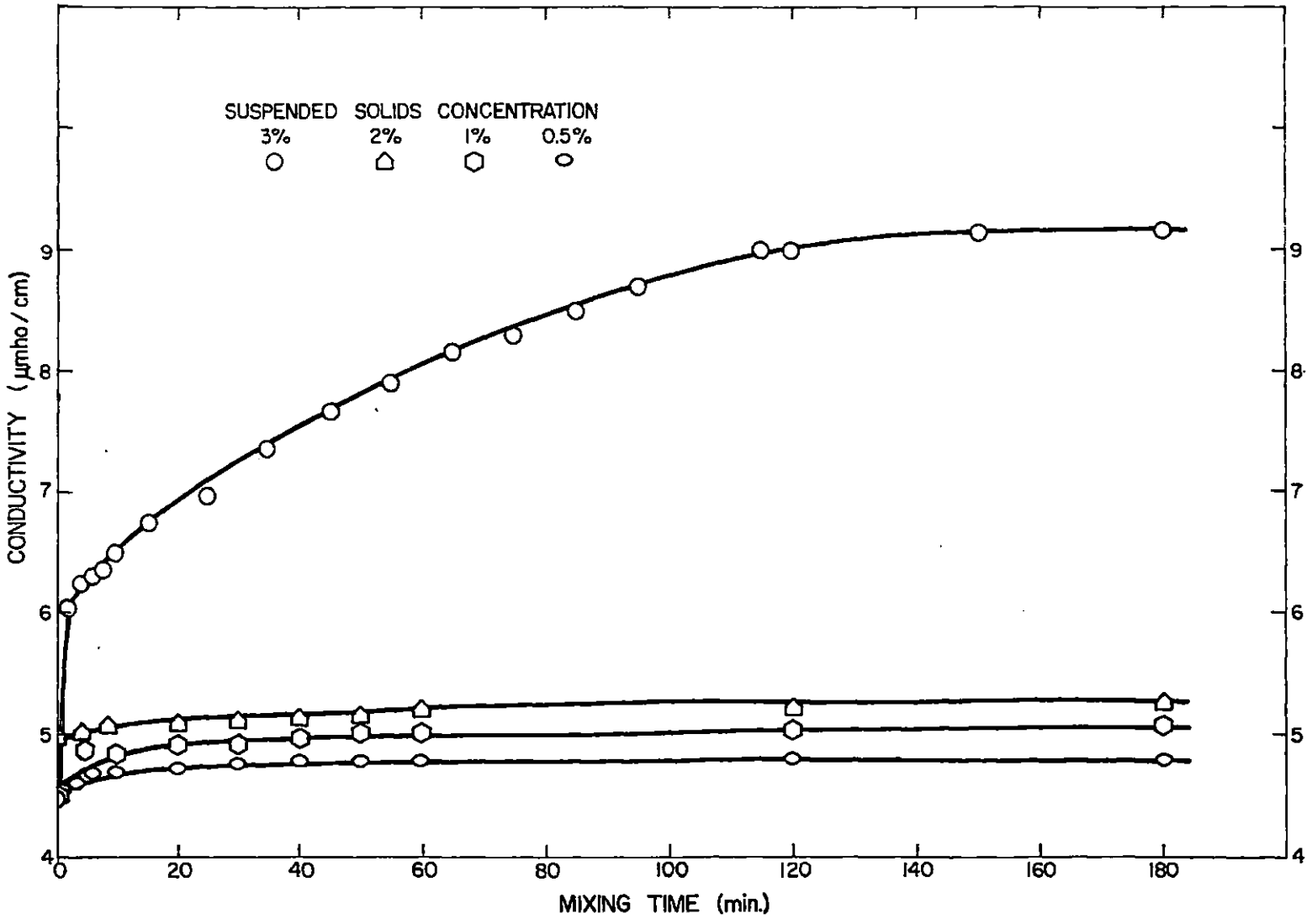

Figure C-4. Conductivity of ash transport water vs. mixing time for various ash concentrations (electrostatic precipitator fly ash from plant J).

APPENDIX D

PERCENTAGE OF TRACE ELEMENT CONCENTRATIONS IN ASH POND EFFLUENTS EQUAL TO OR GREATER THAN VARIOUS GIVEN CONCENTRATIONS

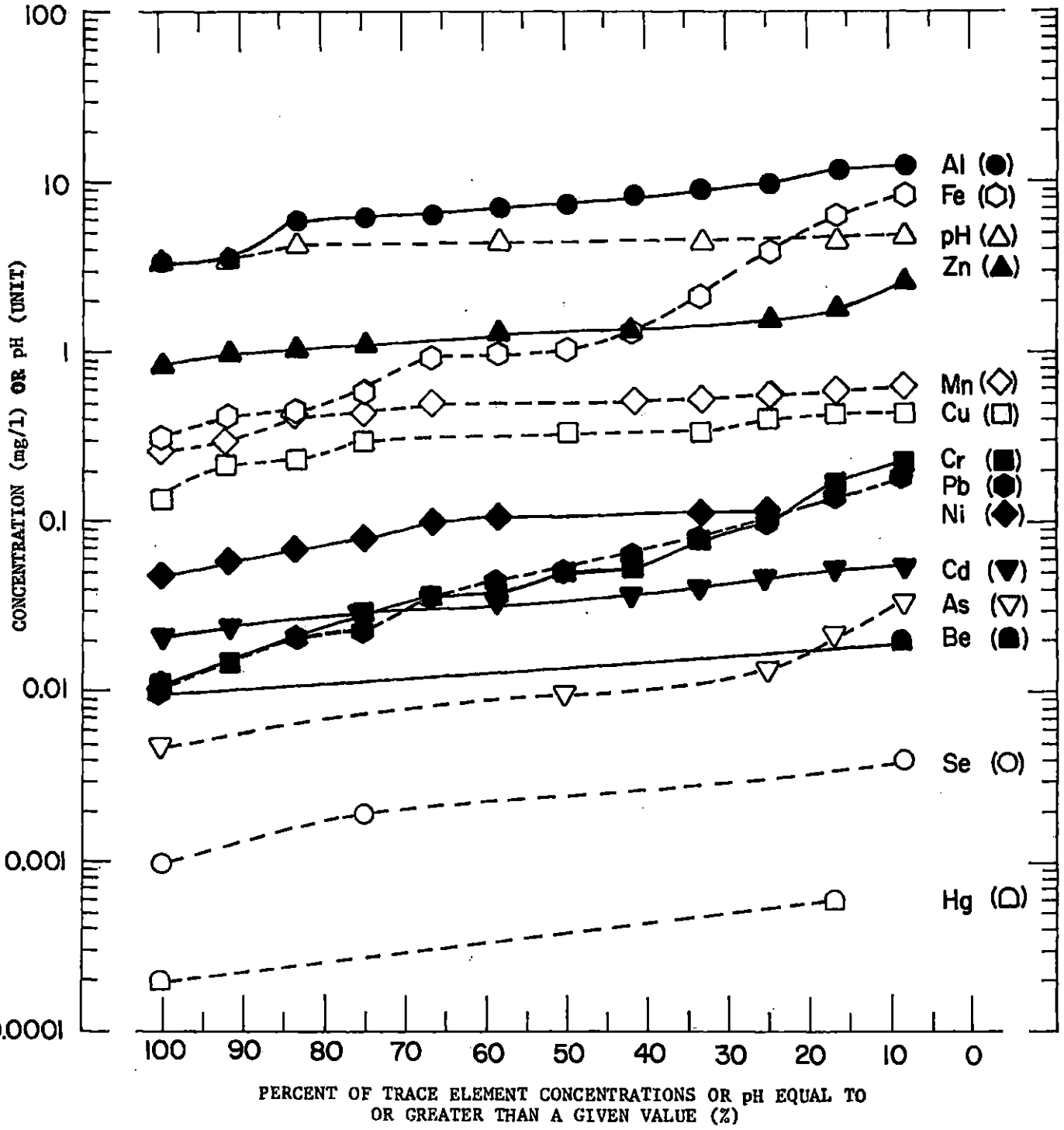

Figure D-1. Percent of trace elements concentrations in fly ash pond effluent at plant A equal to or greater than various given concentrations.

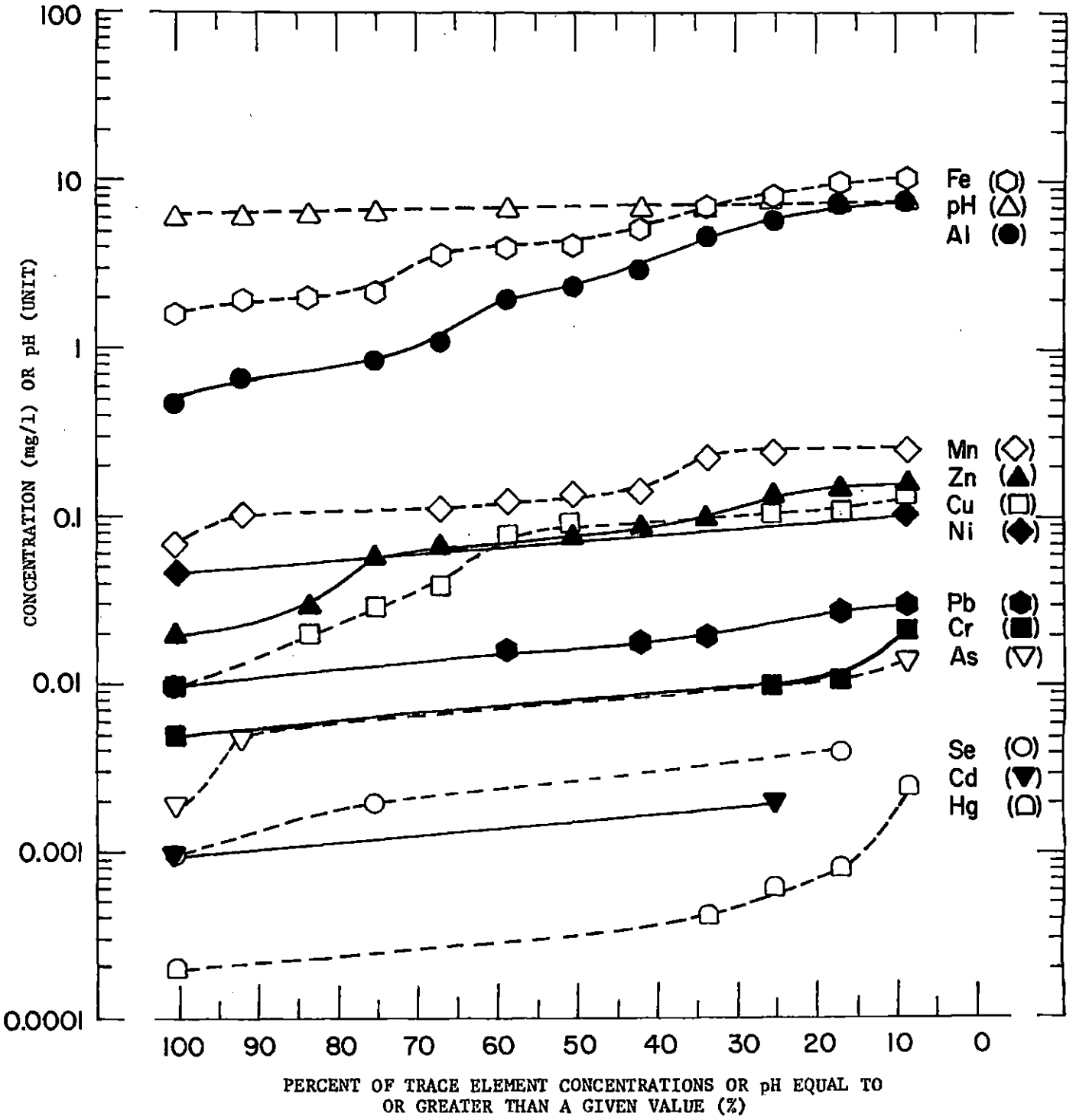

Figure D-2. Percent of trace elements concentrations in bottom ash pond effluent at plant A equal to or greater than various given concentrations.

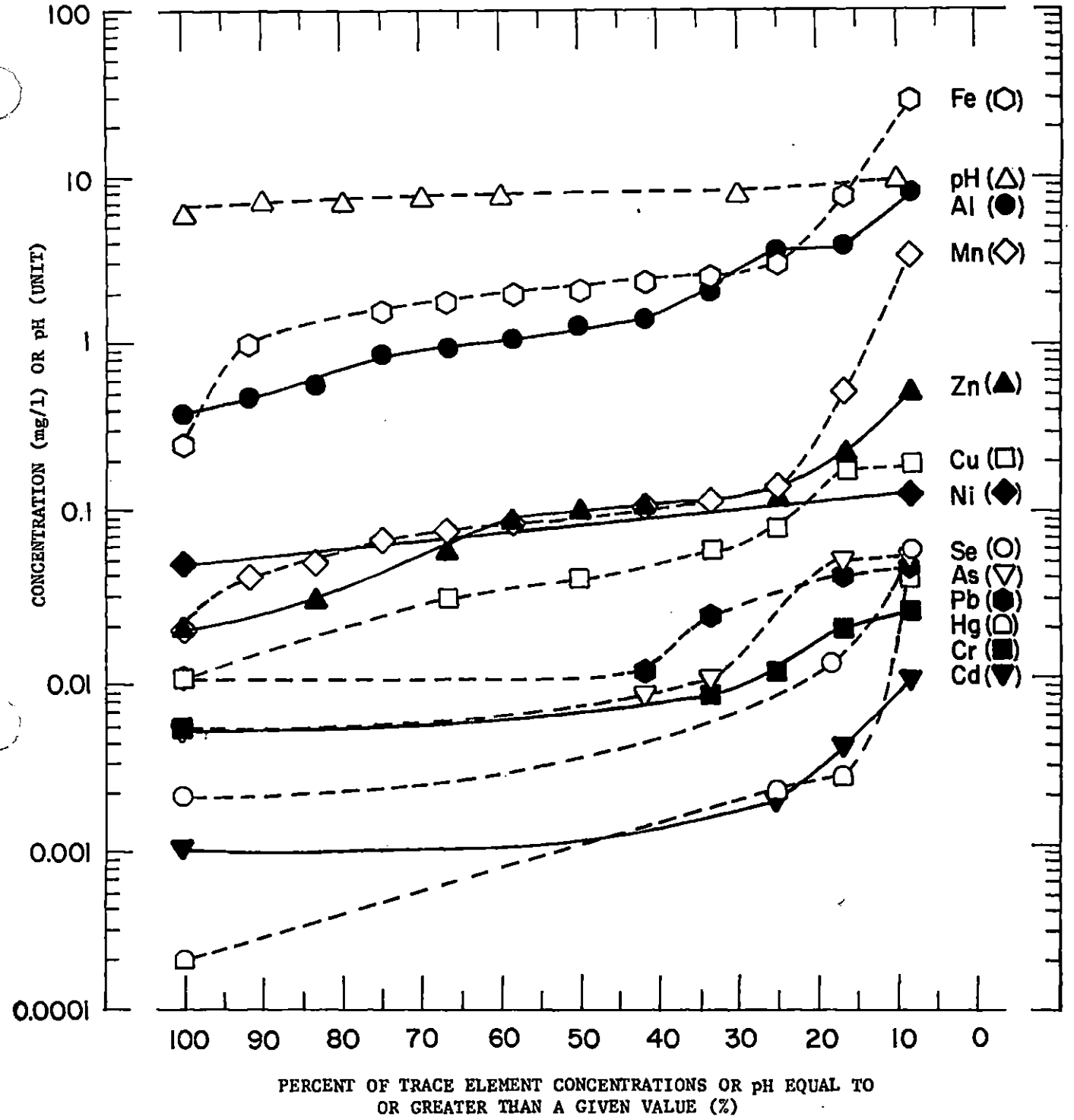

Figure D-3. Percent of trace elements concentrations in bottom ash pond effluent at plant B equal to or greater than various given concentrations.

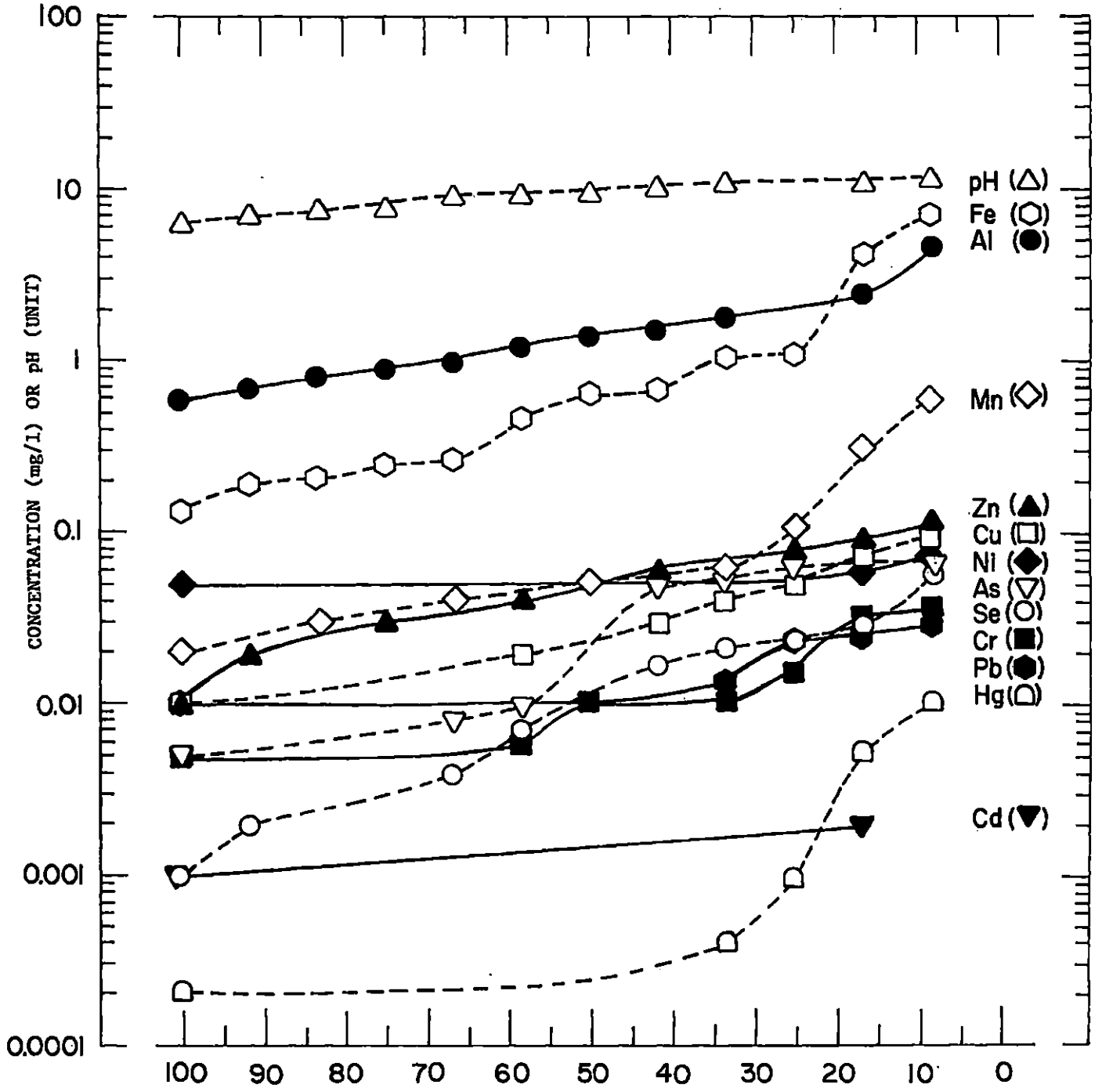

Figure D-4. Percent of trace elements concentrations in fly ash pond effluent at plant B equal to or greater than various given concentrations.

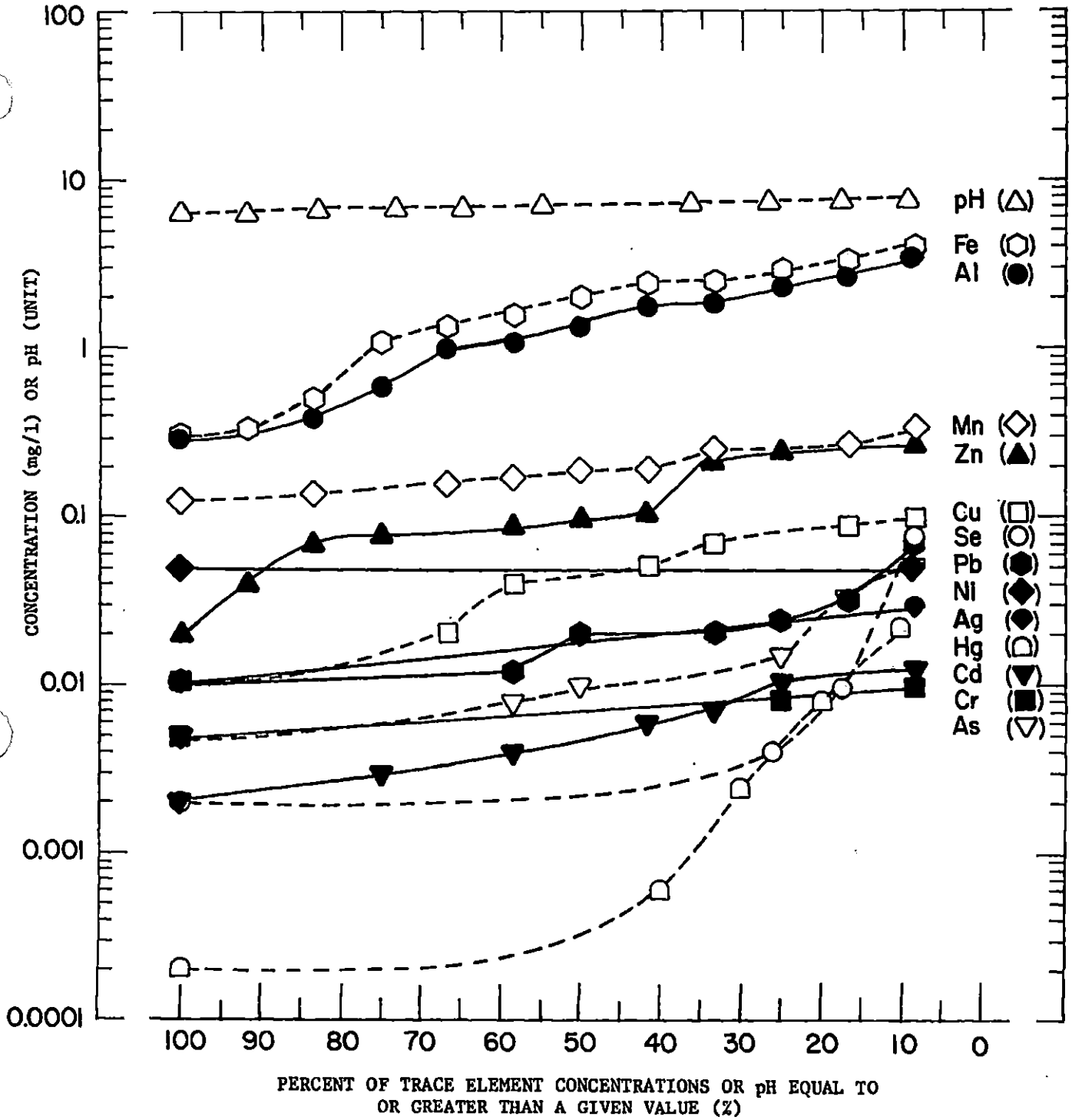

Figure D-5. Percent of trace elements concentrations in combined ash pond (East) effluent at Plant C equal to or greater than various given concentrations.

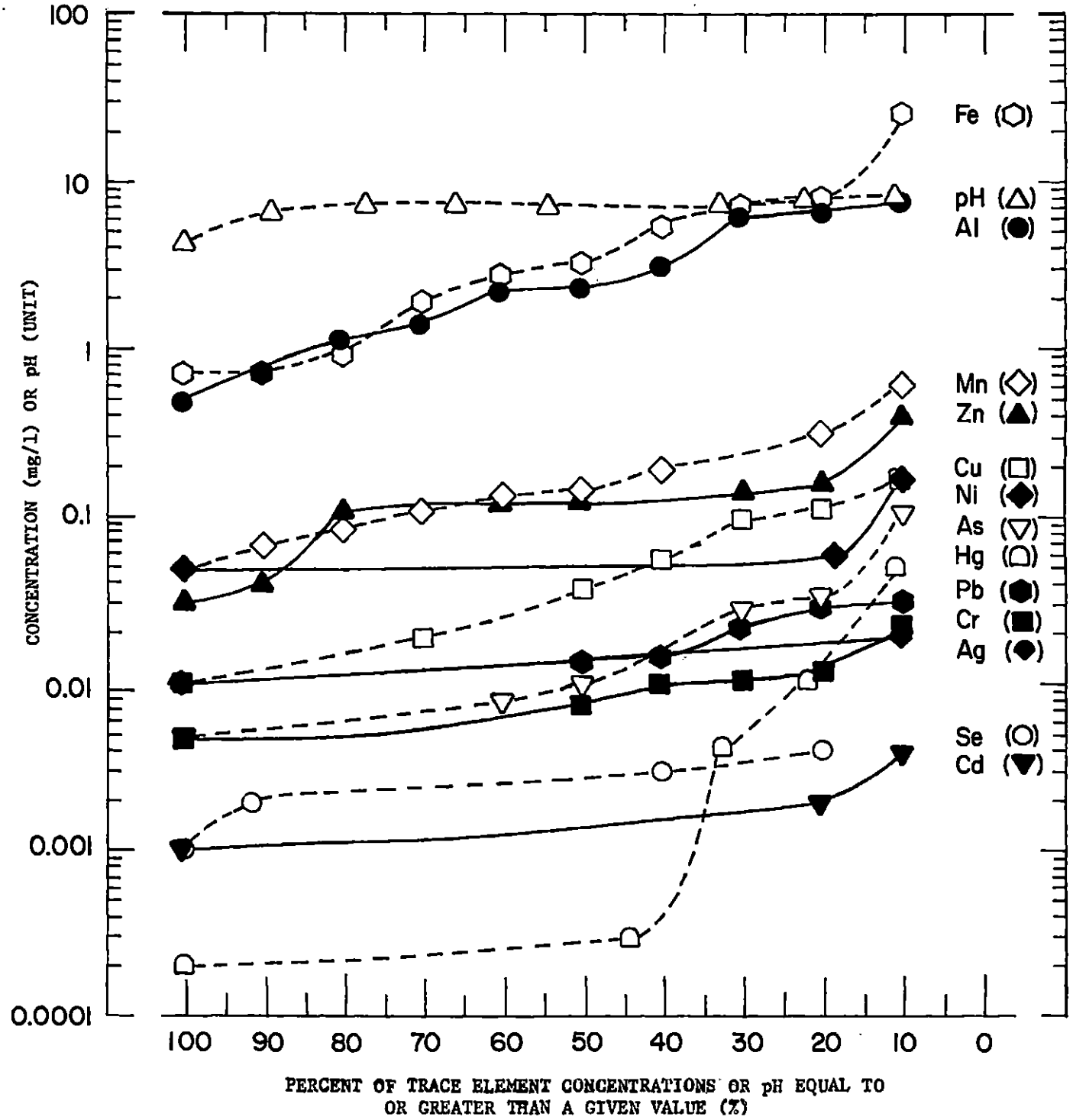

Figure D-6. Percent of trace element concentrations in combined ash pond (West) effluent at plant C equal to or greater than various given concentrations.

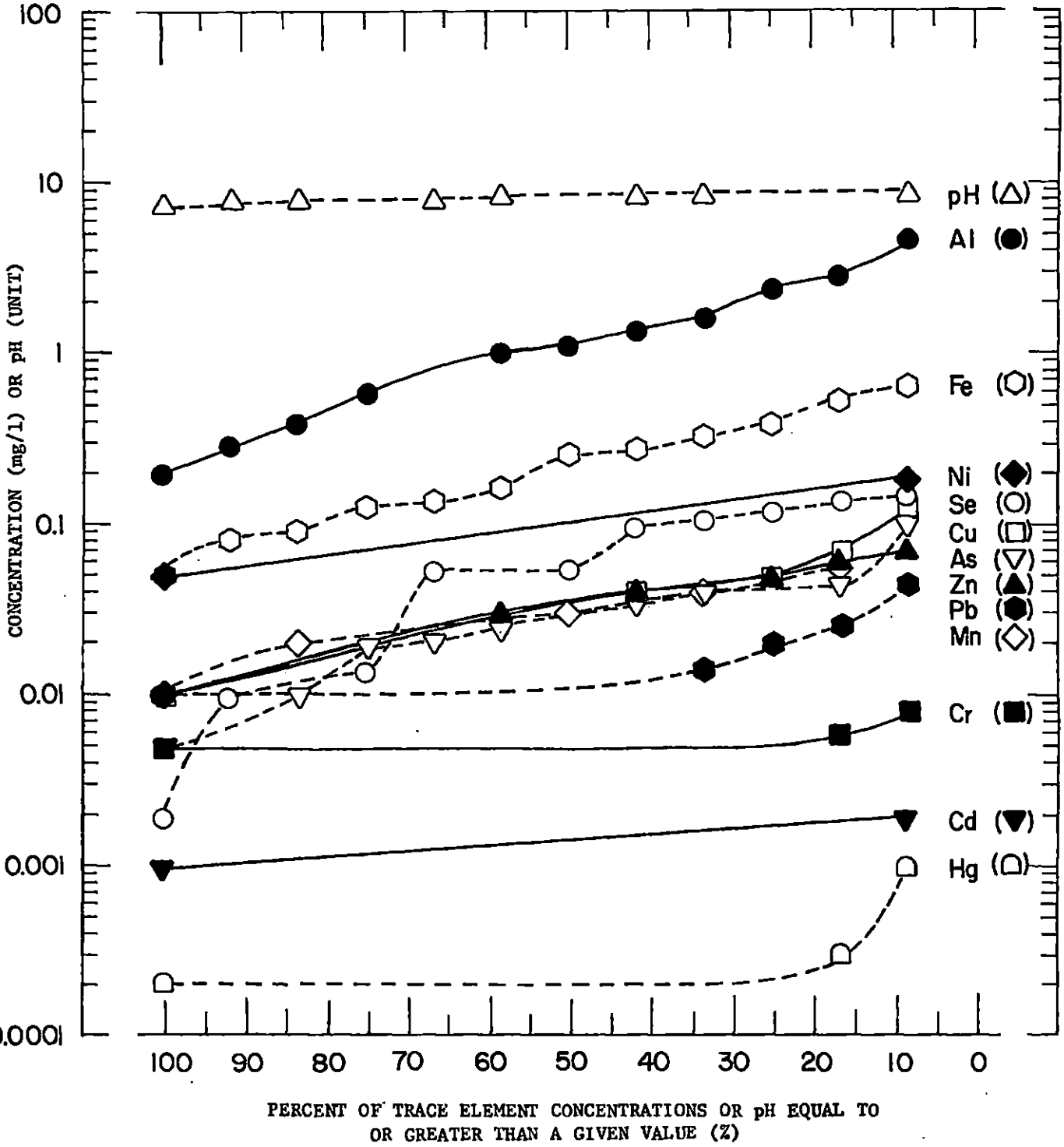

Figure D-7. Percent of trace element concentrations in combined ash pond effluent at plant D equal to or greater than various given concentrations.

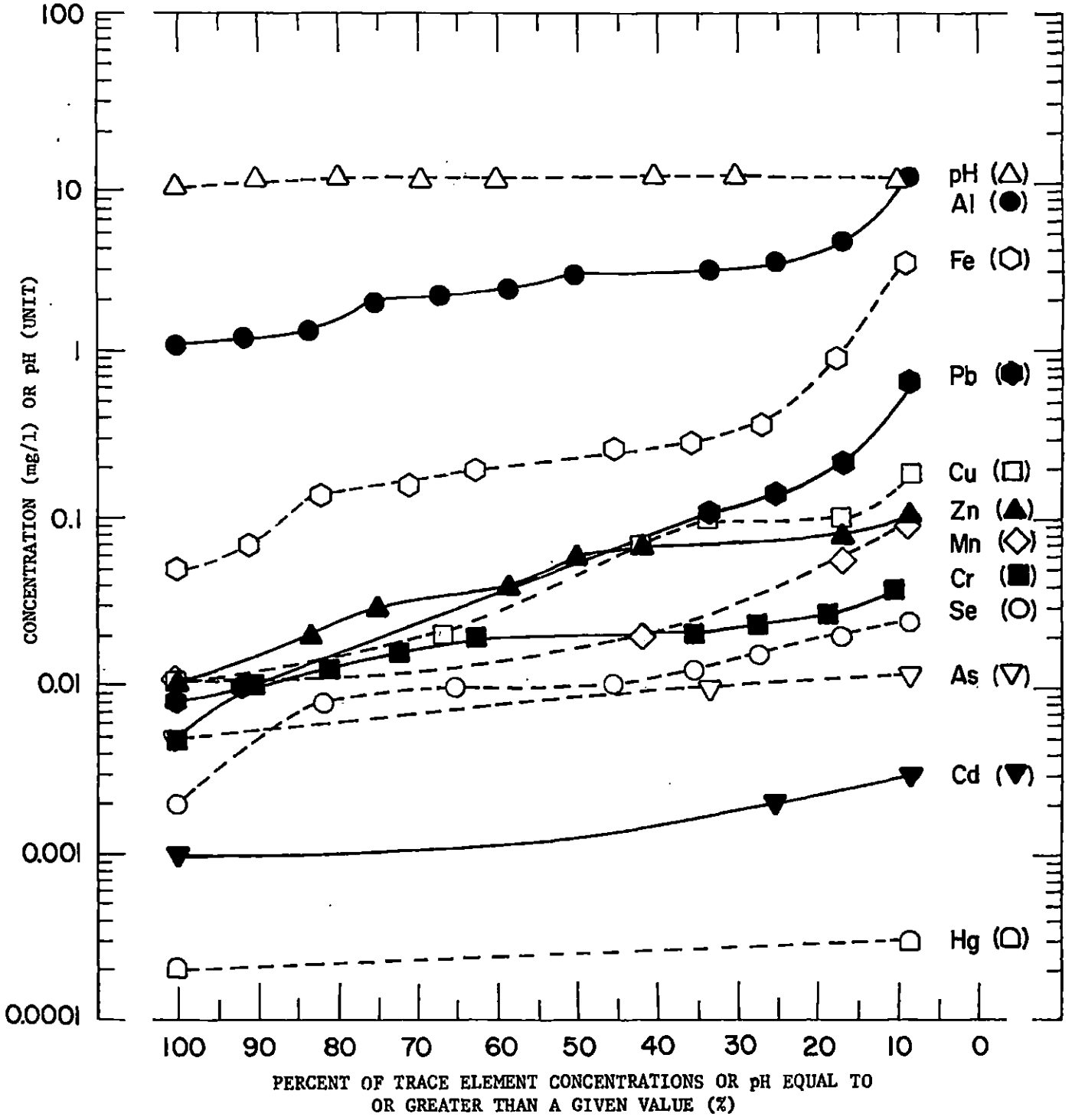

Figure D-8. Percent of trace element concentrations in combined ash pond effluent at plant E equal to or greater than various given concentrations.

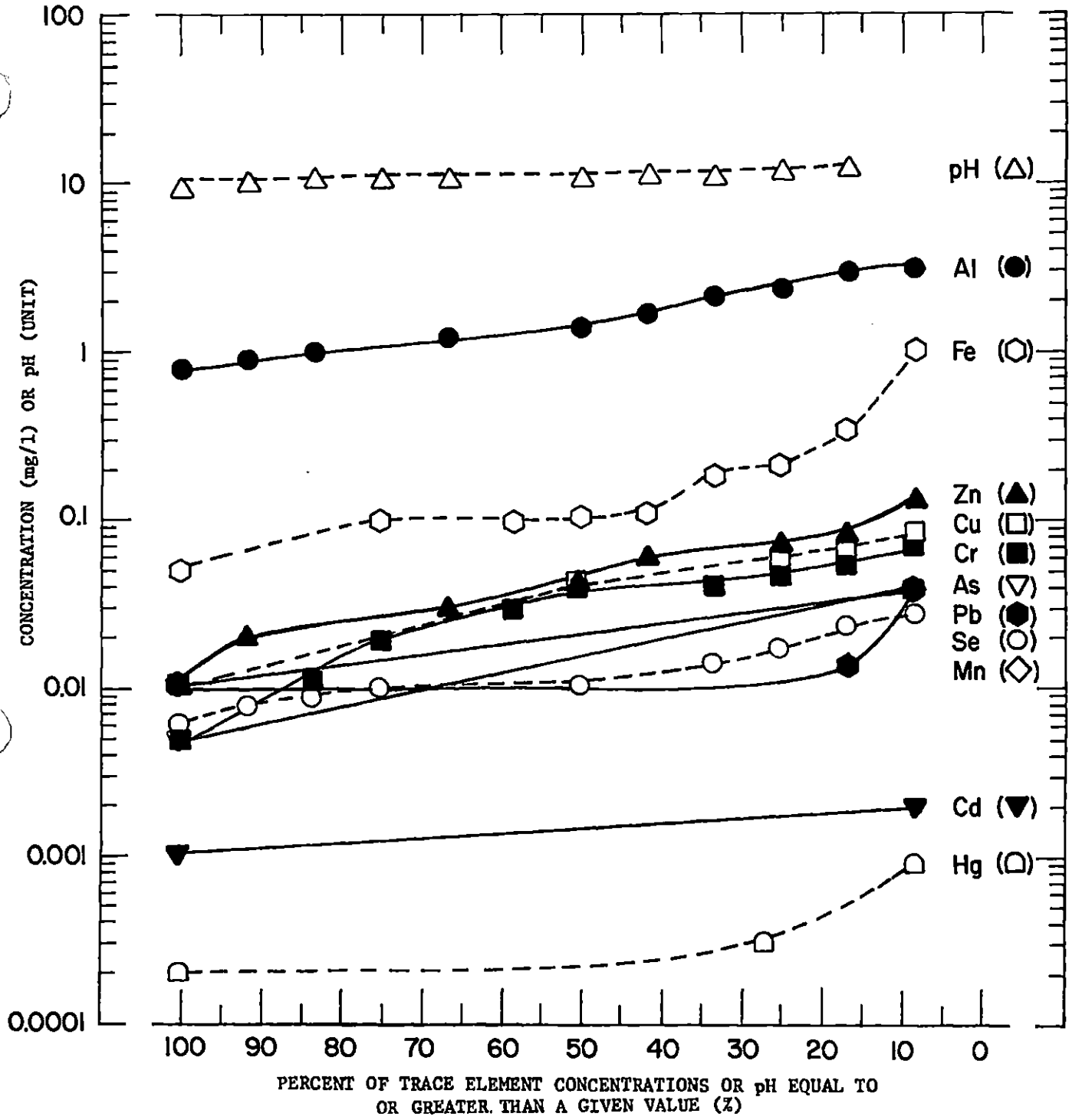

Figure D-9. Percent of trace element concentrations in combined ash pond effluent at plant F equal to or greater than various given concentrations.

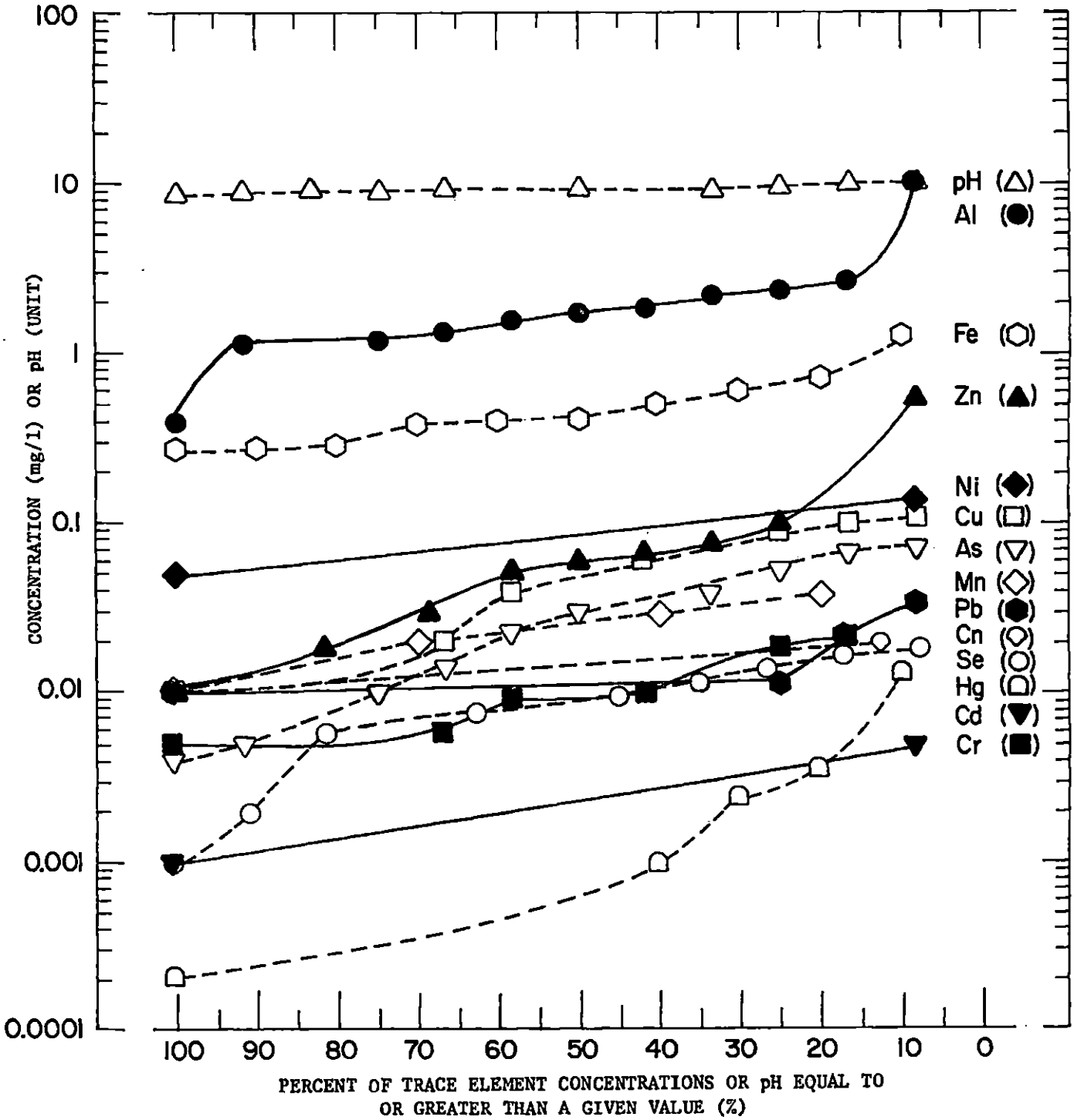

Figure D-10. Percent of trace element concentrations in combined ash pond effluent at plant G equal to or greater than various given concentrations.

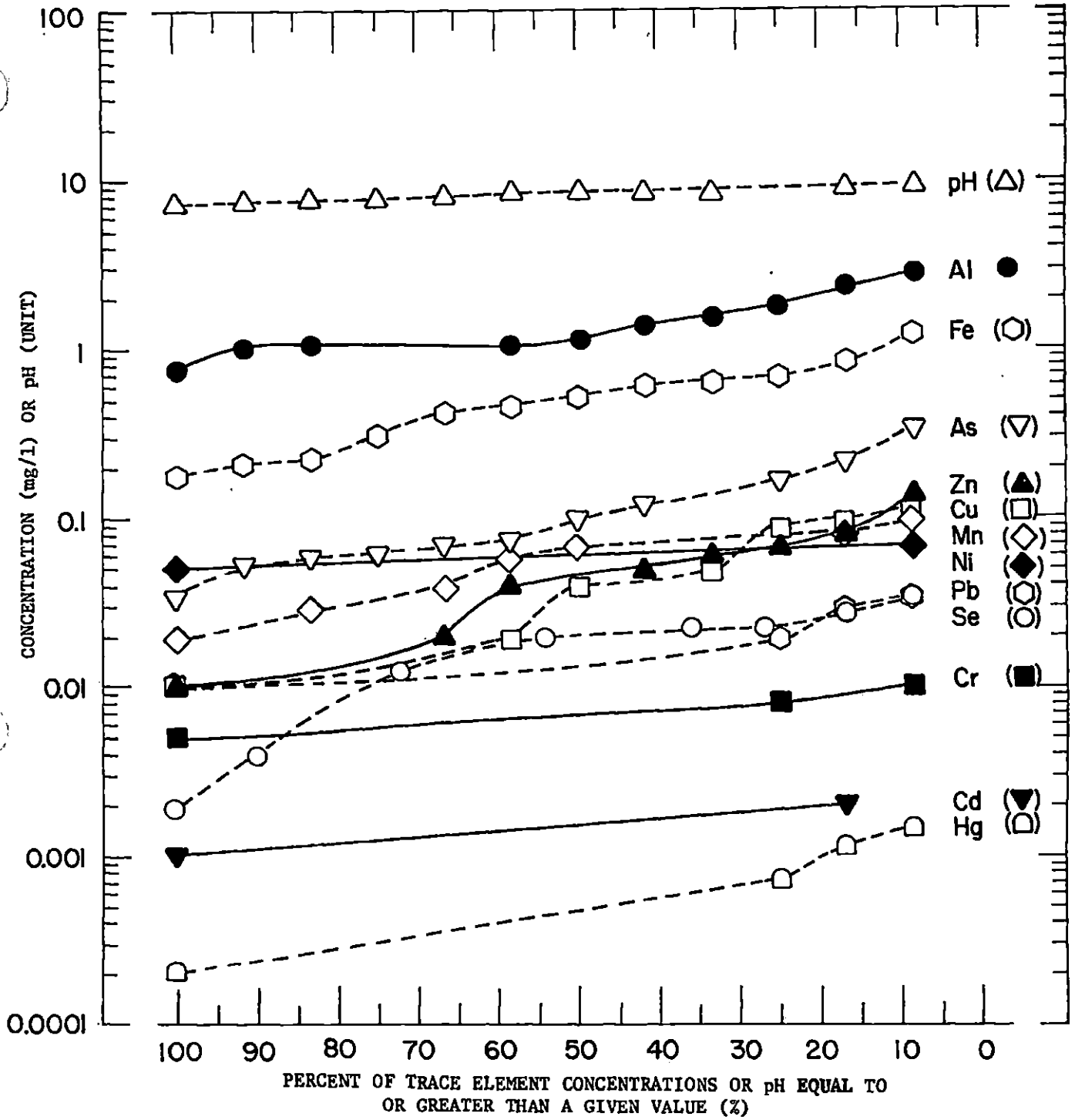

Figure D-11. Percent of trace element concentrations in combined ash pond effluent at plant H equal to or greater than various given concentrations.

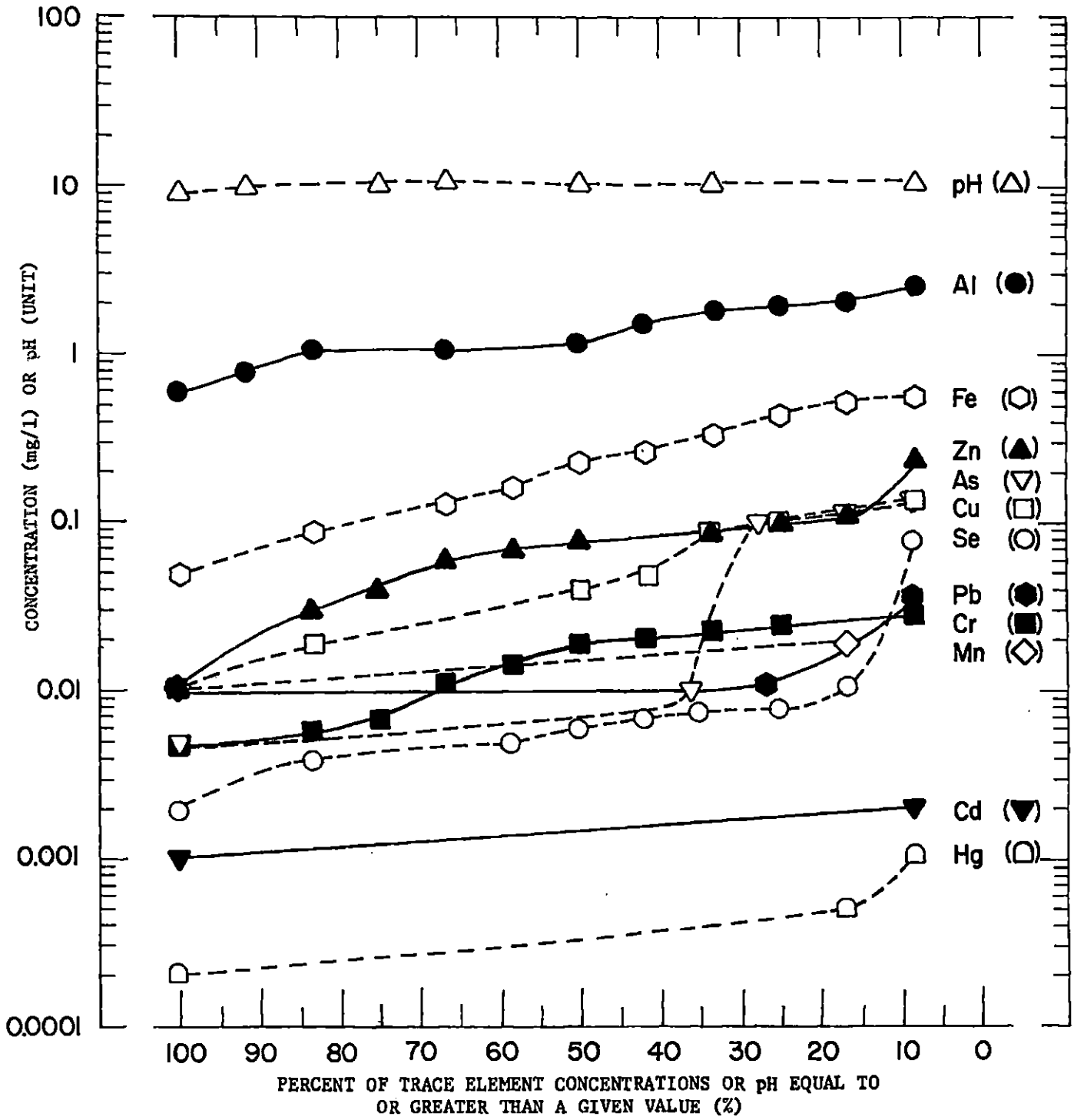

Figure D-12. Percent of trace element concentrations in combined ash pond effluent at plant I equal to or greater than various given concentrations.

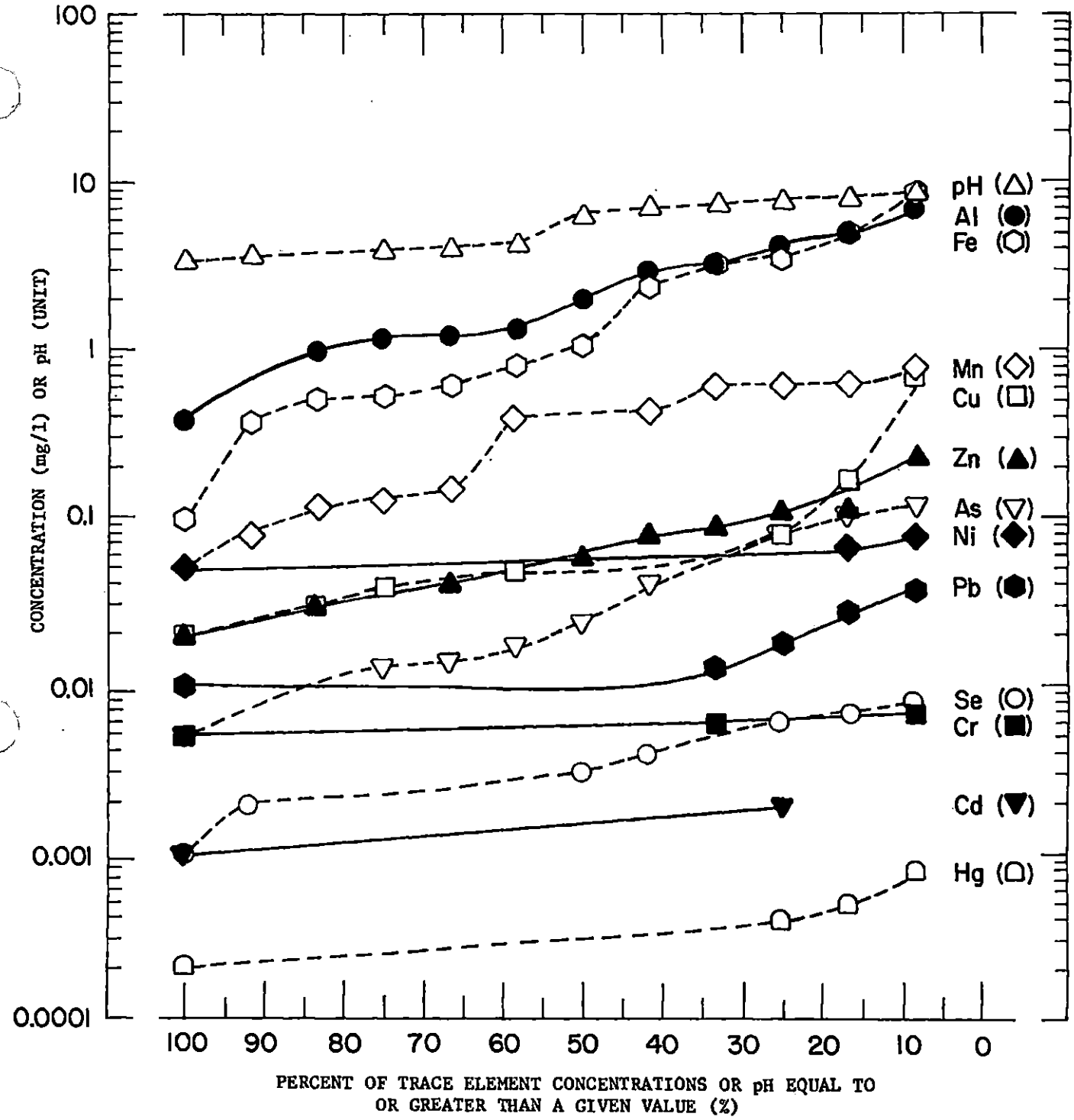

Figure D-13. Percent of trace element concentrations in combined ash pond effluent at plant J equal to or greater than various given concentrations.

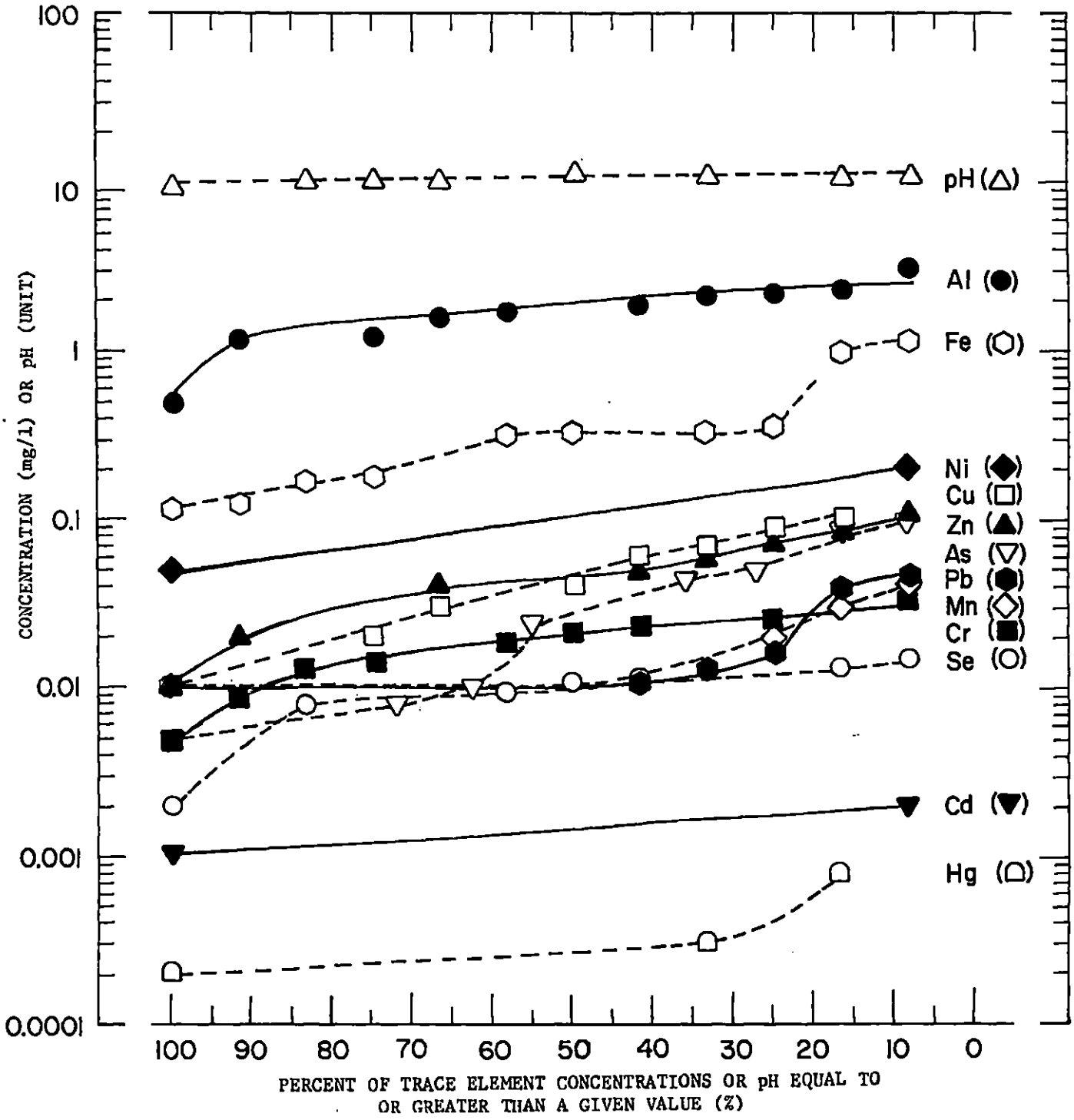

Figure D-14. Percent of trace element concentrations in combined ash pond effluent at plant K equal to or greater than various given concentrations.

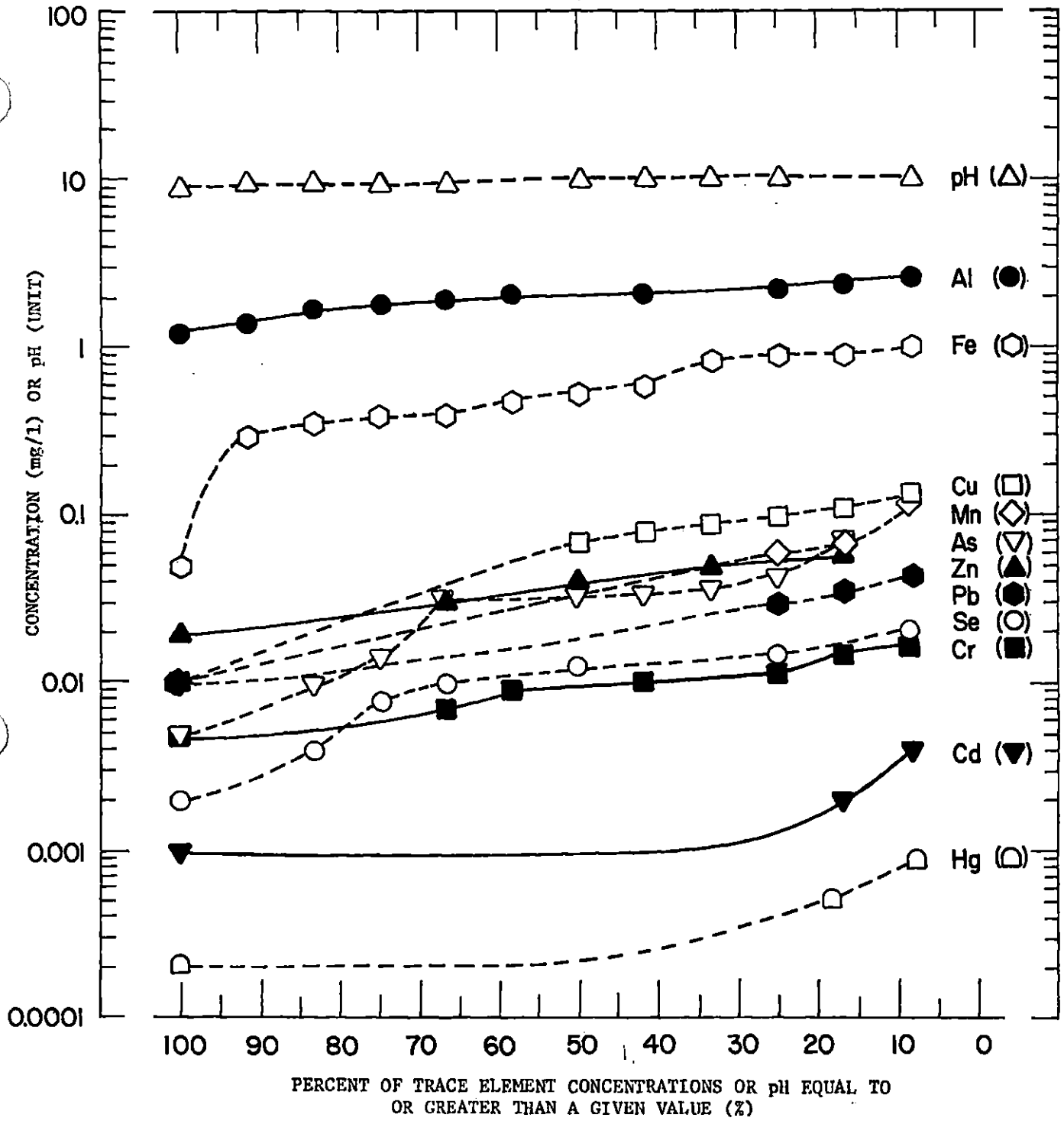

Figure D-15. Percent of trace element concentrations in combined ash pond effluent at plant L equal to or greater than various given concentrations.

APPENDIX E

WATER QUALITY CRITERIA FOR DOMESTIC WATER SUPPLIES

TABLE E-1. WATER QUALITY CRITERIA FOR DOMESTIC WATER SUPPLIES[a]

Parameter	(mg/l, unless otherwise noted) Concentration
Aluminum	b
Arsenic	0.05
Boron	b
Beryllium	b
Calcium	b
Cadmium	0.01
Chromium	0.05
Copper	1.0
Iron	0.3
Lead	0.05
Magnesium	b
Manganese	0.05
Mercury	0.002
Nickel	b
pH, standard units	5-9
Selenium	0.01
Sulfate	250
Sulfide	b
Total dissolved solids	250
Zinc	5.0

[a]U.S. Environmental Protection Agency. Quality Criteria for Water. EPA-440/9-76-023, Washington, DC, 1976. 501 p.

[b]Not applicable.

APPENDIX F

ANALYTICAL PROCEDURES

APPENDIX F

ANALYTICAL PROCEDURES

Parameter	Procedure	Reference	Minimum detectable amount
Alkalinity, total (pH 4.5) mg/l as $CaCO_3$	Titrimetric - electrometric (Orion Model 701)	SM, p. 278	1
Alkalinity, phenolphthalein mg/l as $CaCO_3$	Titrimetric - electrometric (Orion Model 701)	SM, p. 278	1
Aluminum µg/l Al	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 92	200
Antimony µg/l Sb	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 94	100
Arsenic µg/l As	Digestion and colorimetric SDDC (Beckman Model B)	SM, pp. 62, 65	5
	Atomic absorption - gaseous hydride (Techtron Model AA-5 or 1200)	EPA, pp. 81, 95	-

Parameter	Procedure	Reference	Minimum detectable amount
Barium µg/l Ba	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 95, 97	100
Beryllium µg/l Be	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 99	10
Boron µg/l B	Colorimetric - curcumin (Beckman Model DB-Gt)	SM, p. 287 and EPA, pp. 13, 81	100
Bromide µg/l Br	Titrimetric	EPA, p. 14	2
Cadmium µg/l Cd	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 101	10
	Atomic absorption - extracted (Techtron Model AA-5 or 1200)	EPA, pp. 81, 89, 101	1
Calcium mg/l Ca	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 103	1

Parameter	Procedure	Reference	Minimum detectable amount
Chemical oxygen demand mg/l COD	Titrimetric - dichromate reflux	EPA, p. 20	1
Chloride mg/l Cl	Colorimetric-automated ferricyanide	SM, p. 613	1
Chromium µg/l Cr	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 105	50
	Atomic absorption - extracted (Techtron Model AA-5 or 1200)	EPA, pp. 81, 89, 105	5
Cobalt µg/l Co	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 107	100
	Atomic absorption - extracted (Techtron Model AA-5 or 1200)	EPA, pp. 81, 89, 107	5
Conductance, specific µmhos/cm at 25°C	Kohlrausch bridge with carbon conductance cell (Lab-Line Mark IV)	EPA, p. 275	0.5

Parameter	Procedure	Reference	Minimum detectable amount
Copper µg/l Cu	Atomic absorption - Direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 108	10
Cyanide, total mg/l Cn	Distillation and colorimetric (Beckman model B)	EPA, p. 40	0.01
Fluoride mg/l F	Specific ion electrode (Orion Model 101)	EPA, p. 65	0.1
	Distillation and specific ion electrode (Corning Model 101)	SM, pp. 388, 391	0.1
Hardness, total mg/l as $CaCO_3$	Calculation from Ca and Mg values	SM, p. 201	3
Iron, total µg/l Fe	Atomic abosrption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 110	50
Iron, ferrous µg/l Fe	Colorimetric - phenanthroline (Beckman Model B)	SM, p. 208	10

Parameter	Procedure	Reference	Minimum detectable amount
Lead µg/l Pb	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 112	100
	Atomic absorption - extracted (Techtron Model AA-5 or 1200)	EPA, pp. 81, 89, 112	10
Magnesium mg/l Mg	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 114	0.1
Manganese µg/l Mn	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 116	10
Manganese, filterable µg/l Mn	Atomic absorption - membrane filter filtration (Techtron Model AA-5 or 1200)	EPA, pp. 81, 116	10
Mercury µg/l Hg	Digestion and flameless atomic absorption (Coleman Model MAS-50)	EPA, p. 118	0.2
Nickel µg/l Ni	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 141	50
	Atomic absorption - extracted (Techtron Model AA-5 or 1200)	EPA, pp. 81, 89, 141	5

Parameter	Procedure	Reference	Minimum detectable amount
Nitrogen, ammonia mg/l N	Colorimetric - automated phenate (Technicon Auto-Analyzer II)	EPA, p. 168	0.01
Nitrogen, nitrate plus nitrite mg/l N	Colorimetric - automated cadmium reduction (Technicon AutoAnalyzer II)	EPA, p. 207	0.01
Oil and grease mg/l	Separatory funnel extraction and gravimetric (Mettler Model H51)	EPA, p. 232	5
pH standard units	Potentiometric (Orion Model 701)	EPA, p. 239	Not Applicable
Phenols µg/l phenols	Distillation and colorimetric - 4-AAP (Beckman Model B)	SM, p. 577 and EPA, p. 241	1
Phosphate, total mg/l P	Colorimetric - automated digestion and single reagent (Technicon Auto-Analyzer II)	EPA, p. 249 with TVA modifications	0.01
	Colorimetric - manual digestion and automated ascorbic acid reduction (Technicon AutoAnalyzer I)	EPA, p. 256	0.01

Parameter	Procedure	Reference	Minimum detectable amount
Potassium mg/l K	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 143	0.1
Residue, total filterable mg/l	Cravimetric - glass fiber filtration (Mettler Model H51)	EPA, p. 266	10
Residue, total nonfilterable mg/l	Gravimetric - glass fiber filtration (Mettler Model H51)	EPA, p. 268	1
Selenium µg/l Se	Atomic absorption - gaseous hydride (Techtron Model AA-5 or 1200)	EPA, p. 145	2
Silica mg/l SiO_2	Colorimetric - automated molybdosilicate (Technicon Auto-Analyzer I)	EPA, p. 274 automated by TVA	0.1
Silver µg/l Ag	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 146	10
	Atomic absorption - extracted (Techtron Model AA-5 or 1200)	EPA, pp. 81, 89, 146	1

Parameter	Procedure	Reference	Minimum detectable amount
Sodium mg/l Na	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 147	0.1
Sulfate mg/l SO_4	Turbidimetric (Hach Model 2100)	EPA, p. 277	1
Sulfide, total mg/l S	Colorimetric - methylene blue (Beckman Model B)	SM, p. 503.	0.02
	Titrimetric - iodine	EPA, p. 284	1.0
Sulfite mg/l SO_3	Titrimetric - iodide-iodate	EPA, p. 285	2
Tin µg/l Sn	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 150	<1000
Titanium µg/l Ti	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 151	1000
Turbidity Jackson units	Nephelometric - formazin (Hach Model 2100)	EPA, p. 295	1

Parameter	Procedure	Reference	Minimum detectable amount
Vanadium µg/l V	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 153	500
Zinc µg/l Zn	Atomic absorption - direct (Techtron Model AA-5 or 1200)	EPA, pp. 81, 155	10

Abbreviations of references:

EPA - U.S. Environmental Protection Agency. Methods for chemical analysis of water and wastes. EPA, Water Quality Office, Cincinnati, Ohio. 1974. 298 p.

SM - American Public Health Association. Standard methods for the examination of water and wastewater. 14 ed., American Public Health Association, New York, N.Y. 1975. 1193 p.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing) Joint Exhibit 6

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EPA-600/7-80-067		

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	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
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15. SUPPLEMENTARY NOTES IERL-RTP project officer is Michael C. Osborne, Mail Drop 62, 919/541-2547. TVA project director is H.B. Flora II.

16. ABSTRACT The report gives results of a study of the behavior of coal ash particles in water, a study of importance to coal-fired power plants: at a 1000-MW plant, approximately 700 tons of ash residues (fly and bottom ashes) from coal burning must be disposed of daily. Dry or wet handling and disposal are used, depending on water availability, disposal site proximity, environmental regulations, and cost. Ash pond effluent limitations for suspended solids can be met by properly designing ash ponds or by modifying existing ponds. Because of high ash concentration during sluicing, 90% of fly ashes follow the hindered-zone settling behavior, and settle faster than those following discrete settling behavior. Chemical characteristics of ash pond effluents are affected by the ash material and the quantity and quality of sluicing water. TVA ash pond effluent pH varies from 3 to 12, depending on the content of SOx and alkaline metal oxides in the ash and on the buffering capacity of the sluicing water. Alkaline pond water has a ratio of concentration (in terms of ng/l) of dissolved Ca to SO4 greater than 0.4. Trace metal leaching from the ashes depends on the concentration of each trace metal in the ash matrix, its chemical bonding in the ash, and the water pH. Trace metals in the ash pond effluents monitored quarterly under NPDES permits include As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Se, and Zn.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Settling	Pollution Control	13B
Water	Waste Disposal	Stationary Sources	07B
Coal	Ponds	Coal Ash	21D 08H
Ashes	Suspended Sediments	Trace Metals	21B
Particles	Sluices		14B
Leaching			07D,07A

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Mar 15 2018

March 15, 2018

M. Lynn Jarvis, Chief Clerk
North Carolina Utilities Commission
4325 Mail Service Center
Raleigh, North Carolina 27699-4300

Re: Docket No. E-7, Sub 1146

Dear Ms. Jarvis:

Per the request in the rate hearing on March 5, 2018 in Docket No. E-7, Sub 1146, made by Commissioner Daniel G. Clodfelter for complete copies of documents excerpted as cross-examination testimony, Sierra Club hereby submits a complete copy of the 1981 EPRI Coal Ash Disposal Manual, excerpts of which were marked as Sierra Club — Kerin — Cross Ex 4.

By copy of this letter, I am forwarding a copy to all parties of record by electronic delivery. Please let me know if you have any questions or concerns.

Yours very truly,

/s/ Matthew D. Quinn

Matthew D. Quinn

Attachment

I/A

- Doc. Ex. 2 -

Docket No. E-7, Sub 1214
Joint Exhibit 7

Coal Ash Disposal Manual
Second Edition

Keywords:
Coal Ash Properties
Disposal Site Selection
Ash Disposal Design
Site Monitoring
Cost Estimating
Site Reclamation

Prepared by
GAI Consultants, Inc.
Monroeville, Pennsylvania

EPRI

EPRI CS-2049
Project 1685-3
Final Report
October 1981

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SUMMARY

PURPOSE

The purpose of this manual is to present detailed procedures for the evaluation of the technical, environmental, and economic factors involved with the disposal of coal ashes which include fly ash and bottom ash. The manual has been prepared to aid utility design personnel in the selection and location of optimal disposal systems and as such is not a state-of-the-art report. Therefore, only that information needed for the development and implementation of fly ash and bottom ash disposal plans has been included. The background information for many of the detailed procedures presented in the manual can be found in the references listed at the end of each section.

The manual is to be a companion text to three other EPRI publications, FGD Sludge Disposal Manual CS-1515, Manual for Upgrading Existing Disposal Facilities RP1685-2, and Fly Ash Structural Fill Handbook EA-1281, and is to be used in conjunction with these documents. Therefore, detailed coverage of subjects such as site design procedures and transportation systems are not included in this manual. These subjects are covered in considerable detail in the FGD Sludge Disposal Manual and the information presented therein is largely applicable to ash disposal as well. Similarly, design and construction procedures for ash fills are not dealt with in detail, since they are the subject of the Fly Ash Structural Fill Handbook. The reader is encouraged to review these two EPRI publications since they contain supplemental information that is applicable to fly ash disposal.

Subjects covered in this manual are encompassed in three categories. The first is information specific to fly ash and bottom ash, such as their chemical and physical properties, examples of actual ash disposal systems, and cost estimating methods for ash disposal. A second category includes items that are increasingly becoming subjects of interest to utility personnel involved in ash disposal. This category includes site selection methods, environmental monitoring, and site reclamation procedures. Finally, a recent development of particular interest is

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the promulgation of solid waste disposal regulations under authority of the Resource Conservation and Recovery Act (RCRA). The details of this law and its associated regulations and their impact on ash disposal are included in this manual.

DISPOSAL SYSTEMS

There are two basic ash disposal schemes, generally referred to as wet and dry, which are currently being practiced in the utility industry. Section 1, Site Selection Methodology; Section 3, Current Disposal Philosophies; Section 4, Impact of Solid Waste Disposal Regulations on New Disposal Sites; and Section 5, Conceptual Design of Ash Disposal Systems examine these disposal schemes and their variations along with the factors which influence the selection of a particular scheme (i.e., ash characteristics, site characteristics, disposal regulations, etc.).

Figure S-1 illustrates the variations in ash disposal systems which are presented in the manual. The majority of disposal system component variations are in the areas of:

- in-plant ash handling,
- out-of-plant ash transport, and
- disposal site.

Fly ash is commonly collected dry from particulate removal systems and temporarily stored in hoppers. Upon filling these hoppers to a predetermined level, the fly ash is pneumatically conveyed to either a storage silo prior to dry transport, or to a mixing area where it is slurried for wet transport. Pneumatic fly ash handling systems can be vacuum, pressure, or a combination of vacuum and pressure. From storage or sluicing areas, ash is transported to either a wet or dry disposal area. Dry fly ash transport methods include truck, conveyor, rail, and barge.

Bottom ash is commonly fed by gravity from the boiler bottom into a hydraulic handling system, although dry bottom ash handling systems are available. Bottom ash is sluiced from storage hoppers to a dewatering area for subsequent transport to a dry disposal site, or directly to a wet disposal site. Dry bottom ash transport methods are the same as those for dry fly ash (i.e. truck, conveyor, etc.)

CONTENTS

Section 1, Site Selection Methodology, presents detailed information concerning the selection of an optimal disposal site and includes a discussion of the physical,

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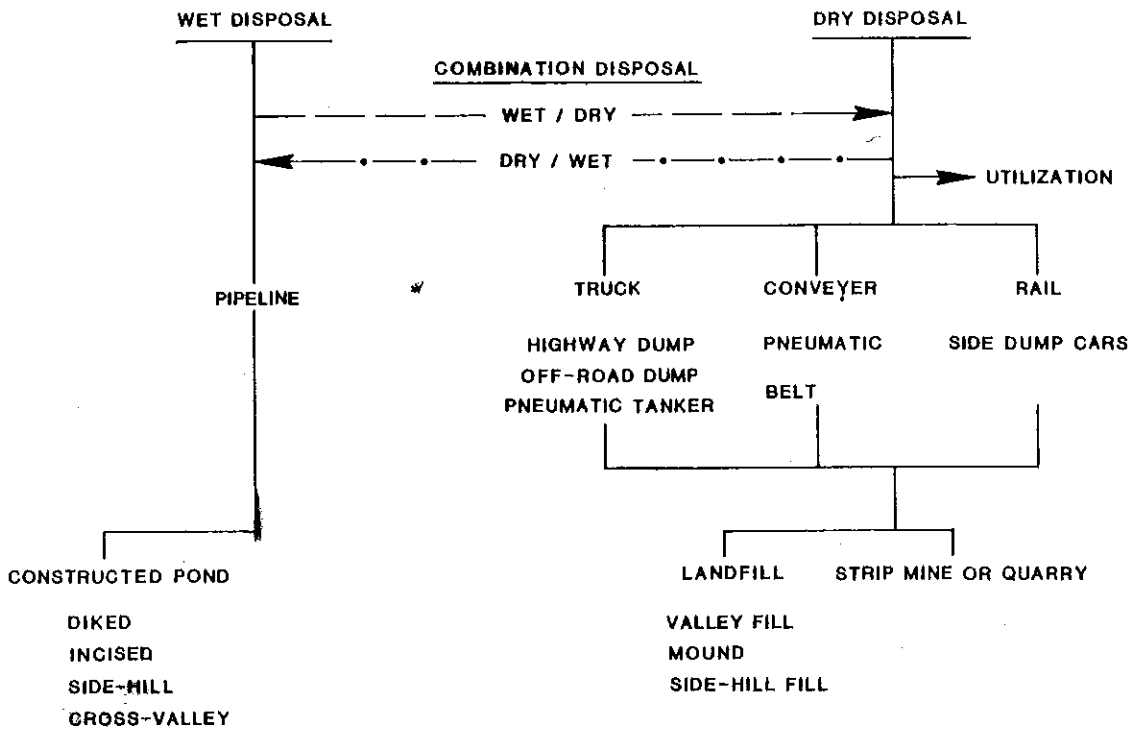

Figure S-1. Variations in Ash Disposal Schemes

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engineering, regulatory, environmental, and economic factors influencing site selection. The characteristics of wet and dry systems are reviewed early in the site selection process. Next, candidate sites are inventoried. This process starts with review of the overall physical constraints such as site size, proximity to the power plant, suitable topography, etc. These constraints are relatively inflexible. For example, if a site does not have enough capacity, there is little that can be done to significantly improve the situation, and the site will likely be rejected. Sites which are acceptable physically are more closely scrutinized to determine what engineering development is required to create a suitable disposal area. These engineering criteria are typically somewhat flexible in that most site constraints can be overcome, but at some development cost. Factors such as access road construction, surface water control, and embankment design and construction are identified and the estimated costs developed in increasing detail as the site selection process proceeds. Construction and operating costs for each potential site are used as one method of evaluating the alternatives.

Another factor to be considered in the site selection process are political or regulatory constraints on site development. Zoning restrictions, permits, and local public acceptance are relatively inflexible constraints. While problems of this nature can often be overcome through cooperation with the appropriate agencies or governmental bodies, significant expense and time may be involved if substantial conflicts exist. Ranking of candidate sites in terms of regulatory and political restrictions is sometimes possible on an economic basis.

Environmental restrictions on site selection are typically flexible and will not eliminate a site from consideration unless the impact is severe, such as the displacement of endangered species. In most situations, the environmental impacts are not this severe. However, they are also not cost relatable, and ranking candidate sites is difficult. To resolve this problem and allow environmental concerns to be included in the site selection process, Section 1 presents a decision matrix method for ranking sites on the basis of environmental impacts. This decision matrix provides a methodology which can minimize both cost and environmental impacts. A case study of a typical site selection process using this method is included.

Section 2, Properties of Power Plant Ash, discusses the chemical and physical characteristics of coal ash relative to the coal source and the effects of methods of combustion, ash collection, and handling. Specifically, this section presents information on the physical, chemical, and engineering properties of coal ash and its leachate, and includes ranges of typical values for specific characteristics of

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interest. In the past, most ash disposal was in wet systems where the ash was sluiced to a pond with only minor handling. Little characterization as to its physical or chemical properties was necessary. However, as environmental regulations and concerns have become increasingly important, more attention is being given to the chemical makeup of the ash. In recent years, many utilities have been switching from wet to dry disposal systems. The use of dry disposal systems has also required more attention to the engineering properties of the ash as a fill material than was required with wet systems. Thus, there is a general increase in interest in the physical and chemical characteristics of ash and ash leachate.

Section 3, Current Disposal Philosophies, includes a review of current disposal practices. The design philosophies relative to these alternative disposal methods are also discussed to provide an overview. Finally, ash production, utilization, and disposal practices are detailed on a regional and statewide basis.

Section 4, Impact of Solid Waste Disposal Regulations on New Disposal Sites, includes a discussion of the requirements of RCRA for both hazardous and non-hazardous wastes. Although coal ashes are currently defined as non-hazardous, these regulations should be of particular interest to many in the utility industry, since they will have a major impact on coal ash disposal practices in the future. Therefore, the details of the legislative history of RCRA, its current status, and anticipated future events are included. As currently promulgated by the May 19, 1980 regulations, coal ashes are defined as being non-hazardous and as such are currently regulated under Sub-title D, Section 4000. Regulation under this section is by the individual states. To illustrate this regulatory approach, the ten states with the greatest coal-fired capacity were reviewed as to their current and proposed solid waste disposal regulations.

The purpose of Section 5, Conceptual Design of Ash Disposal Systems, is to present the information required for the prediction of the waste quantities to be generated, describe the individual components of ash disposal systems, and delineate specific requirements for liners used with coal ashes. Coal ash waste quantities can be predicted in terms of factors such as ash content of the coal, heat rate, plant capacity, etc. A series of formulas that allow computation of expected ash quantities is presented. Detailed liner installation procedures are given in Appendix A.

Section 6, Case Studies, includes illustrations of current disposal philosophies practiced at various sites around the U.S. Case histories of four regional sites that are representative of the disposal practices in their area have been presented

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in detail. Example topics include revegetation procedures, groundwater monitoring systems, ash transportation, and ash placement. Other sites which illustrate certain key features of interest to site design are presented in Appendix B.

Section 7, Monitoring, provides an overview of surface water monitoring and groundwater monitoring well systems. Topics include the design and operation of monitoring systems, the importance of modeling the groundwater conditions in developing a monitoring system as well as the limitations of such models, the number of recommended locations of monitoring points, the schedule for monitoring, and the selection of a collection method to assure representative samples. The general design of monitoring wells is also included along with typical details illustrating this design.

Equally important in the operation of monitoring systems are the testing procedures to be conducted once representative samples are obtained. Rather than present detailed testing procedures, the text refers the reader to appropriate sources of information. Also presented in this section is a discussion of which parameters to test for, and why. Finally, a discussion of the cost of monitoring systems, sampling, and testing is included.

The purpose of Section 8, Site Reclamation, is to present information on site reclamation procedures for ash disposal areas. Because of increased environmental awareness, increased concern for site aesthetics and resulting public opinion, and more stringent environmental regulations, efforts to reclaim and revegetate disposal sites have recently accelerated; however, there is considerable confusion regarding which methods are appropriate. There are a number of reasons for this confusion. Because of differences in soil and climate, what works in one place may fail in another; because of differences in ash properties, one investigator may report on the toxicity of coal ash to plants, while another cites its benefits as a soil supplement. State regulatory agencies may require a minimum of two feet of soil cover as part of the site closure procedure, while in other states utilities may report successful growth of vegetation directly on the coal ash. To assist utility personnel in dealing with site retirement procedures in their area, this section gives specific guidance to effective and economical site retirement and revegetation procedures, as well as sources of additional information and assistance.

Section 9, Cost Estimating, presents a methodology for preparing cost estimates for various coal ash disposal systems. Cost estimates for five different ash disposal systems are developed for varying transport distances and site topographies. Economic comparisons are key factors in the decision process when selecting an ash

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disposal system. The cost of disposal at alternate sites is also of primary importance in the site selection process. Cost estimates prepared in accordance with Section 9 are useful in conjunction with the site selection process presented in Section 1.

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Section 1

SITE SELECTION METHODOLOGY

INTRODUCTION

The selection of coal ash disposal sites is a complex problem, entailing the development of engineering and environmental design criteria, and the evaluation of environmental impact, economics, and regulations governing ash disposal.

This section describes a site selection methodology which provides for the orderly collection, development, and evaluation of the data and information required to select coal ash disposal sites which will provide the optimumal balance of low cost and high environmental acceptability. The approach provides a means for documenting the decision making process and helps ensure an equitable evaluation of all sites. To summarize and illustrate the disposal site selection methodology, a case study is included. This section will address only the siting of the disposal facility. Specific details pertaining to the design and cost of a disposal facility can be found elsewhere in this manual.

SITE SELECTION METHODOLOGY

The site selection method described below provides a systematic approach for determining the best ash disposal site(s) from an inventory of potential sites. As shown in Figure 1-1, the method involves the following phases:

- Criteria development,
- Initial screening of prospective sites,
- Design, evaluation, and selection,
- Final design.

Criteria Development

As shown in Figure 1-1, the development of siting and design criteria for an ash disposal area requires the following activities:

- Collection of power plant ash data,
- Review of applicable regulations.

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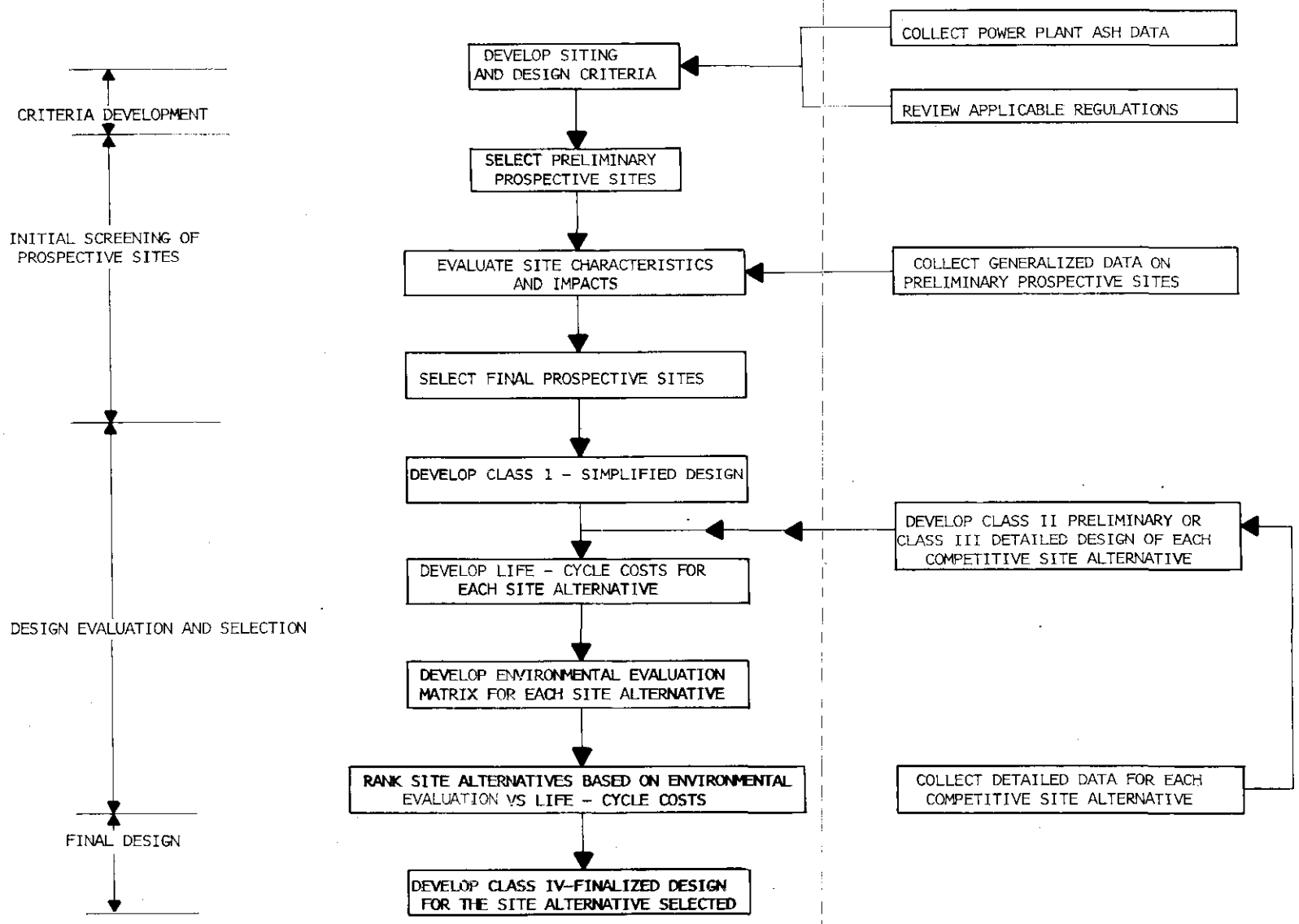

Figure 1-1. Disposal Site Selection Methodology

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Collection of Power Plant Ash Data. The collection of power plant ash data involves gathering the following types of information:

- Physical, chemical, and engineering properties of the ash,
- Expected quantities of ash,
- Production processes at the plant,
- Operating procedures at the plant.

The data indicated above should be collected for both the existing plant situation as well as for a time period into the future for which the evaluation is being made. The quantity of ash requiring disposal is dependent upon several factors, including the degree of coal pulverization, the type of boiler, ash content of the coal, collection efficiency of emission control equipment, plant capacity factor, operating life of the plant generating units, and quantity of ash marketed. Chemical properties of the ash are required for proper environmental design of the site, while physical and engineering properties, such as in-place dry density, are needed to determine required disposal volumes. Production processes and operating procedures at the plant are discussed in Section 5.

Review of Applicable Regulations. The following regulatory information concerning the siting and design of ash disposal sites should be collected and reviewed:

- Zoning ordinances,
- Regional master plans,
- Waste disposal regulations - local, county, state, and federal.

As indicated, zoning ordinances and regional master plans may exist and the development of a site may require a variance. It should be kept in mind that the ultimate site use after closure may determine the extent of variance from planned land use.

The geographic area involved in the collection of zoning ordinances, regional master plans, and local and county waste disposal regulations cannot be generalized since it is highly power plant specific. However, it is generally a good idea to evaluate a zone around the power plant in circular areas having specific radii. For example, an area having a radius of 10 miles could be initially evaluated. If this area does not provide a fruitful ash disposal site, the radius of the zone could be enlarged to possibly 20 miles.

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While regulatory requirements vary from location to location, it is possible to identify permits that may be required for each site under consideration. Table 1-1 provides a checklist for possible local, state, and federal permits. As indicated, local permits can involve health, zoning, water rights, land use, soil and water conservation, and dumping/burning considerations. At the state level, permits can involve dam construction, highway trucking, soil and water conservation, stream encroachment, water rights, and water quality considerations. At the federal level, National Pollutant Discharge Elimination System (NPDES), waterway obstruction, water rights, and solid waste permits would be required. A detailed description of Resource Conservation and Recovery Act (RCRA) requirements is provided in Section 4 of this manual.

Table 1-1

FREQUENTLY ENCOUNTERED PERMIT REQUIREMENTS

Local:	County Health Department Zoning Variance Soil and Water Conservation Dumping/Burning Flood Plain Development
State:	Solid Waste Disposal Highway Occupancy Erosion and Sedimentation Control Stream Encroachment Dikes and Dams Water Withdrawal Water Quality
Federal:	Industrial Waste Discharge/National Pollutant Discharge Elimination System (may be enforced by state) Wetlands Construction under Section 404 of Clean Water Act Possible Resource Conservation and Recovery Act Permit (may be enforced by state) Waterway Obstruction in Navigable Waterways (water withdrawal and intake structures) Water Withdrawal or Usage in Navigable Waterways

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A detailed review of specific permit requirements will aid in the development of detailed siting and design criteria. For example, permissible slopes for dry fly ash embankments may be specified or requirements regarding the monitoring of groundwater quality would be indicated.

Develop Siting and Design Criteria. Based on a review of power plant ash data and applicable zoning, planning and solid waste regulations, detailed siting and design criteria can be developed for the potential disposal sites located within the zone under study around the power plant. Siting criteria includes items such as:

- floodplain limitations,
- earthquake considerations,
- water supply implications,
- critical habitat areas.

Design criteria includes items such as:

- volume requirements,
- allowable ash embankment slopes,
- allowable cut slopes,
- maximum lift thickness,
- groundwater quality monitoring requirements,
- surface water quality effluent criteria.

Initial Screening of Prospective Sites

As shown on Figure 1-1, this phase involves the following activities:

- selection of preliminary prospective sites,
- collection of generalized data on preliminary prospective sites,
- evaluation of each site's characteristics and impacts,
- selection of final prospective sites.

Selection of Preliminary Prospective Sites. The procedure for selecting preliminary prospective sites varies from utility to utility. In some cases, the real estate department of a utility or the department directly responsible for disposal activities will have an inventory of potential disposal sites in the

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vicinity of each power plant. In other cases, there may be no inventory at all. In that case, a review of United States Geological Survey (USGS) topographic maps, property maps, etc., for the zone under consideration can lead to an inventory of sites. The selection of preliminary prospective sites will be based on a review of the site inventory relative to the specific siting and design criteria developed previously. For example, only sites which can be developed to satisfy the design disposal volume requirement should be placed on the preliminary site list.

Collection of Generalized Data on Preliminary Prospective Sites. The collection of generalized data involves the following activities for each preliminary prospective site:

- perform a literature search,
- inspect each site,
- inspect the areas adjacent to each site,
- assess community acceptability.

A literature review generally includes the collection of the following types of information for each site:

- ownership,
- USGS or other topographic maps,
- USGS geologic reports,
- aerial photographs,
- property tax maps,
- well and mine maps,
- floodplain information (Corps of Engineers, others),
- power plant environmental impact statement,
- groundwater data,
- Soil Conservation Service data.

The determination of ownership is a very important activity. This search should include a study of mineral rights, water rights, rights-of-way and easements. The assessment of these characteristics is important because they may place serious restrictions on usable areas within a site or may be indicative of future subsidence problems.

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The inspection of each potential site should include items such as:

- present land use,
- site access,
- natural screening opportunities,
- ground and surface water,
- soil types,
- vegetation,
- wildlife,
- wells and mine openings,
- construction limitations,
- potential for future development after closure.

While inspecting each site, the area adjacent to the site should also be evaluated with respect to items such as:

- present land use,
- potential future land use (if not specified),
- Ttransportation routes - modes and restrictions,
- downstream population and development,
- visibility of the site,
- susceptibility to disposal site generated air and noise pollution,
- identification of other potential sites (if required).

The assessment of community acceptability is a very important parameter in this phase. Public opinion of ash disposal may be difficult to assess; however, there is a tendency for community acceptability to follow previous utility performance. Poor planning and operation of past disposal sites adversely affects public relations, making the acquisition and permitting of new sites difficult. On the other hand, good past performance can go a long way to gain community acceptability of a new site.

Evaluation of Each Site's Characteristics and Impacts. Based on the generalized site data collected above, an evaluation of developing dry and/or wet disposal alternatives for each prospective site should be made by an experienced designer of

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ash disposal sites. Some sites may be suitable for both wet and dry disposal alternatives and can be carried through the remainder of the selection process as supporting both alternatives. This study generally includes an evaluation of engineering and environmental siting and design criteria such as:

- storage volume requirements,
- dam/embankment height,
- adequacy of existing soils,
- slope stability,
- need for special structures,
- need for special construction procedures,
- alternate transportation modes, routes, and distance,
- segregated ash storage/ash recovery,
- potential surface and groundwater quality problems,
- potential air/noise pollution,
- need for well or mine sealing,
- impact on vegetation and wildlife,
- impact of failure on life and property,
- suitability based on land use considerations,
- impact of disposal method on existing plant facilities,
- potential land acquisition/rezoning difficulties.

Selection of Final Prospective Sites. The evaluation of site characteristics and impacts relative to the suitability of each preliminary prospective site will result in a generalized ranking of the alternatives. This listing can then be screened to select final prospective sites for further study and evaluation.

Design, Evaluation and Selection

As outlined on Figure 1-1, this phase involves the following activities:

- develop a Class I - Simplified Design for each site alternative,
- develop life-cycle costs for each site alternative,
- develop an environmental evaluation matrix for each site alternative,

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- rank site alternatives based on environmental evaluation versus life-cycle costs.

Develop Class I - Simplified Design. A simplified design of the disposal area should be prepared for each of the final prospective site alternatives (wet and/or dry). The layouts should be based on generalized site data previously developed and should satisfy the engineering and environmental design criteria previously established for the sites. At this point in the selection procedure, the design criteria which has the greatest influence on the layout of each site alternative is required storage volume. The considerations involved in the various classes of site design are delineated in Table 1-2.

Table 1-2

SITE DESIGN CLASSIFICATIONS

Item	Design Description	Design Information Required	Required Map Scale
Class I	Simplified	General Site Conditions Geographic Location Plant Layout Waste Quantities	1" = 2000" (USGS 7-1/2' Quad)
Class II	Preliminary	Class I Information Plus Specific Site Conditions	1" = 500'
Class III	Detailed	Class II Information Plus Detailed Site Information	1" = 200'
Class IV	Finalized	Same as Class III	1" = 200'

Develop Life-Cycle Costs. Section 9 of this manual provides an outline of the method and specific examples of doing life-cycle cost estimates. The method involves the determination of total capital costs, levelized annual revenue requirements and a cost per ton of ash for the design period under consideration. Once the Class I designs are completed, using the technique of Section 9, life-cycle cost estimates can be made for the disposal alternatives feasible at each prospective site.

Develop Environmental Evaluation Matrix. Ash disposal necessitates the handling and placement of great quantities of material over an extended period of time.

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During the operation of the disposal system, areas around the disposal site and along transportation routes are altered. These alterations reflect the disposal method practiced and the efficiency of the disposal operation. While impact on the environment is inherent in ash disposal, it can be minimized through proper planning, site selection, and design. Concern about environmental effects should be based on a broad view of the disposal system as a whole.

In order to rank the final prospective site alternatives, it is necessary to evaluate the impact of site development, operation, and closure activities on man and his environment. Organization of the pertinent environmental factors and impacts into matrix form greatly aids this process. The matrix presented in this section is based upon a technique developed by Leopold, et. al. (2), and is intended to provide a basis of environmental comparison between sites.

Methodology. The environmental evaluation matrix provides a means of gauging relative impacts through the generation of a numerical value (known as the environmental evaluation factor - EEF) for each site. Large EEF values correspond to high adverse impact.

The first step in the determination of an EEF for each site alternative is the development of environmental parameters to be evaluated. The selection of environmental parameters is, to a great extent, site specific. However, parameters such as the following should generally be considered:

- Aesthetics
- Air Quality
- Aquatic/Ecology Water Quality
- Cultural Resources
- Land Use
- Noise
- Public Health and Safety
- Terrestrial Ecology
- Socio-Economics

The list of environmental parameters given above can be reduced or expanded based on the specific situation under study. For example, terrestrial ecology

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could be divided into plant and animal categories, or even selected species, if a more detailed analysis is warranted.

It is well known that construction and operation activities can produce environmental impacts at each site. However, significant environmental impacts can also occur following closure of the site. Thus, the overall environmental evaluation factor, EEF, for each site alternative is computed as the sum of a construction/operation $EEF_{c/o}$ and a post-closure EEF_{pc} as follows:

$$EEF = EEF_{c/o} + EEF_{pc}$$

$$EEF = [WF_{c/o} \sum_{i=1}^{m} (WF_{ic/o} \times IM_{ic/o})] + [WF_{pc} \sum_{i=1}^{m} (WF_{ipc} \times IM_{ipc})]$$

where:

EEF = overall environmental evaluation factor

$WF_{c/o}$ = secondary weighting factor to reflect the importance of impacts during construction and operation relative to post-closure; $0 \leq WF_{c/o} \leq 1$

$WF_{ic/o}$ = primary weighting factor for environmental parameter i during construction and operation

$IM_{ic/o}$ = magnitude of impact of the project on environmental parameter i during construction and operation

WF_{pc} = secondary weighting factor to reflect the importance of impacts post-closure relative to pre-closure; $WF_{pc} = 1-WF_{c/o}$

WF_{ipc} = primary weighting factor for environmental parameter i after closure

IM_{ipc} = magnitude of impact of the project on environmental parameter i after closure

m = number of environmental parameters being considered

The selection of weighting factors (WF's) and impact magnitudes (IM's) is an important step in the development of the matrix.

The selection of values for the secondary weighting factor $WF_{c/o}$ depends on whether the most significant impacts are going to occur during construction and operation or after closure. For example, if impacts during construction and operation are thought to be four times more significant than those which will occur after closure, then $WF_{c/o} = \frac{4}{5} = 0.8$. Accordingly, $WF_{pc} = 1 - WF_{c/o} = 1 - 0.8 = 0.2$

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To assess values for the primary weighting factors associated with each environmental parameter, an arbitrary range from 1 to 10 has been assigned to the WF's with increasing values indicating increasing importance. Water quality, for example, is extremely important at most sites and might have a primary weighting factor value of 9. Land use may be somewhat less important, and as such could be weighted 3 or 4.

Environmental concerns and their primary weighting factors will generally vary from power plant to power plant throughout the United States; however, the primary weighting factor for a particular environmental parameter during construction and operation and after closure can generally be assumed to be identical for a particular power plant; that is $WF_{ic/o} = WF_{ipc}$ for a particular environmental parameter i at a given power plant.

To assess values for impact magnitudes for each environmental parameter, an arbitrary range from -5 to +5 has been assigned to the IM's. Negative values indicate beneficial impacts, such as strip mine reclamation.

Care should be taken to insure uniform application of the matrix to all prospective sites. It should be recognized that matrix evaluation entails a numerical evaluation of qualitative elements, and as such reflects the biases of individuals participating in the procedure. Group consensus techniques can help to minimize biased environmental evaluation, especially if individuals in the group have diverse backgrounds such as engineering, hydrology, geology, agronomy, ecology, construction, and planning.

Suggested Procedure. The procedure for matrix utilization can be separated into several steps.

1. Review areas of environmental concern and develop a list of environmental parameters.

2. Select a primary weighting factor (WF) for each environmental parameter and secondary weighting factors for the construction and operation and post-closure time periods.

3. Determine the magnitude of the impact (IM_i) which ash disposal would have on each environmental parameter during the construction and operation phase of disposal, and during the post-closure phase.

4. Calculate the environmental evaluation factor (EEF) for each parameter ($EEF_i = WF_i \times IM_i$) for both the construction/operation and post-closure phases.

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5. Sum the EEF_i's for both the construction/operation and post-closure phase.

6. Apply secondary weighting factors.

7. Calculate the overall site EEF by adding the weighted construction/operation and post-closure EEF's.

Rank Site Alternatives. After the life-cycle costs and environmental impact due to the development of each site alternative have been developed, site alternatives can be ranked and compared to determine desirability. A graph relating the life-cycle cost and overall EEF for each site alternative will provide a visual method for ranking the sites. Figure 1-2 is a schematic sketch of such a graph in which the computed life-cycle cost, as well as the estimated range in Class I cost estimates (±20 to ±30 percent) are shown. The objective of this ranking is to select the site of least cost and least adverse environmental impact. In this example, the completed life-cycle cost for Site 3 is slightly less than that estimated for Site 4. However, the adverse impact of Site 3 is much greater than Site 4. The site planner must evaluate whether the savings associated with adopting Site 3 are worth the relatively high environmental impact. If not, Site 4 would be selected for final design.

In some cases, due to the degree of accuracy in Class I cost estimates (±20 to ±30 percent) it may be difficult to differentiate between sites. In that situation, the following steps (shown in Figure 1-1) may be necessary to provide additional information to aid in ranking the competitive site alternatives:

- Collect detailed data for each competitive site alternative,
- Develop a Class II or Class III Design for each site alternative,
- Re-evaluate life-cycle costs and environmental evaluation matrix,
- Rerank sites.

The collection of detailed data for each site alternative could involve activities such as a detailed site reconnaissance, the drilling of test borings, etc. With respect to a more detailed design of the ash disposal area, a Class II or Class III Design of each competitive site could be performed depending on the degree of accuracy needed in cost estimates at this stage of the selection process. Based on the more detailed designs, life-cycle costs and environmental impact can be re-evaluated and the sites ranked once again.

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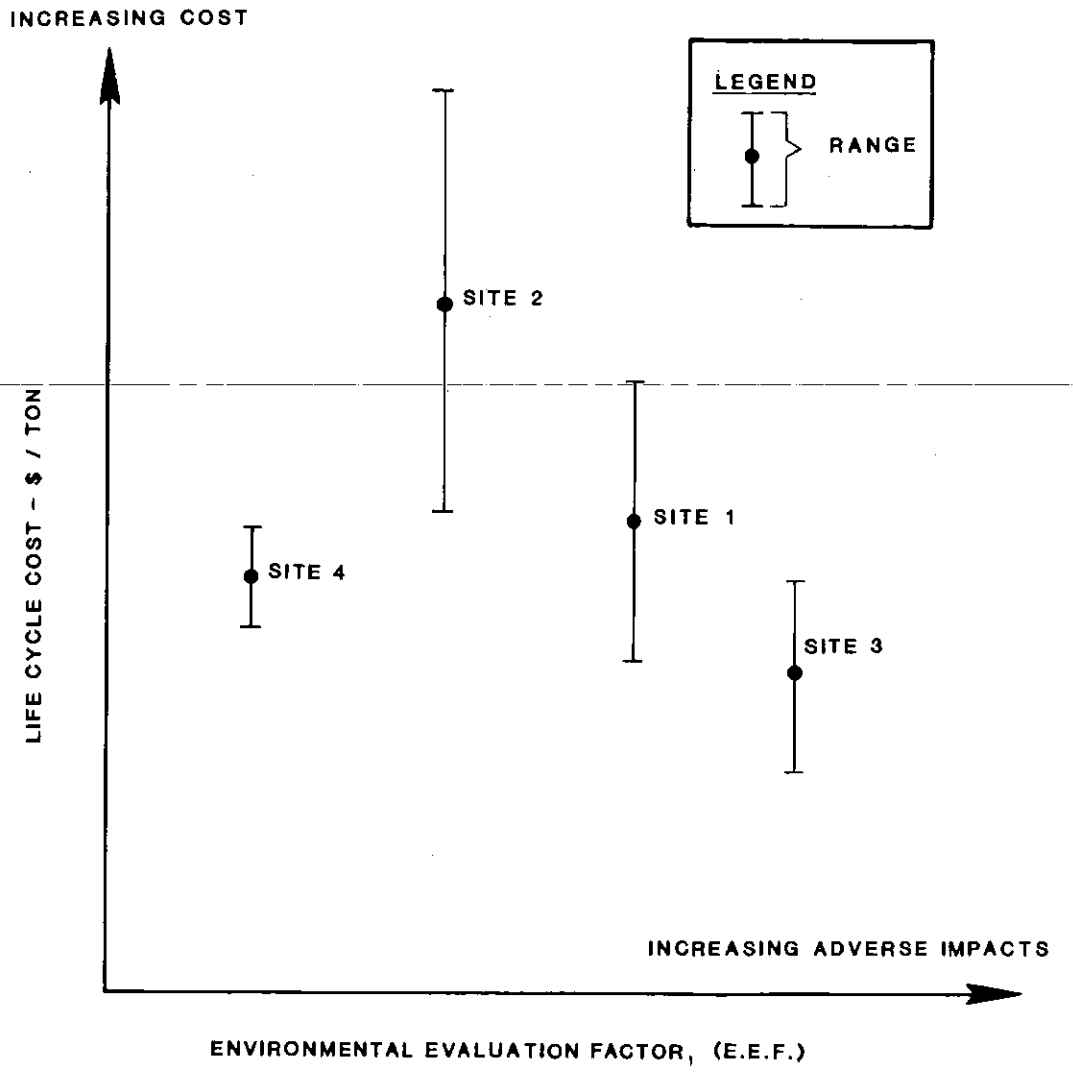

Figure 1-2. Schematic Relationship Between Life-Cycle Costs and Environmental Evaluation Factor (EEF)

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Final Design

The final step in the site selection procedure is to develop a Class IV Design for the site alternative selected.

Develop Class IV - Finalized Design. Based on the site rankings shown by the schematic relationship between life-cycle costs and environmental evaluation factors, an optimum site can be selected and a Class IV Design performed. The final design may require additional site specific information such as test borings, test pits, the installation of a groundwater quality monitoring system, etc.

CASE STUDY

In this section, a case study of a typical ash disposal site selection study is presented to illustrate the methodology previously outlined. Only general information is mentioned. Engineering and environmental criteria presented in this study, while generally applicable to ash disposal as a whole, were developed specifically for the sites considered. Siting and design criteria vary considerably between generating stations. Therefore, site specific information presented in this section should not be used in the selection of other ash disposal areas. It should also be noted that this study was conducted prior to the establishment of current and proposed RCRA regulations. Environmental requirements listed are those which were in effect at the time that the study was done, 1976. Section 4 discusses in detail the applicable RCRA regulations.

Background

As shown on Figure 1-3, the generating station is located along a major river and is bordered on the east by a railroad and highway, on the north by a small town, and on the south by wetlands which are part of a wildlife and fish refuge.

The generating station is comprised of five existing units and a sixth unit currently under construction. The total generating capacity of Units 1 through 5 is 210 megawatts. Unit 6 will have a capacity of 350 megawatts when it goes on-line.

At the time the study was made, bottom and fly ash were being sluiced to a wet disposal area near the plant. This facility was nearing capacity; thus, a new site was required to handle the ash from Units 1 through 5 along with the anticipated ash quantities from Unit 6. Four potential ash disposal sites shown on Figure 1-3, were identified by the utility.

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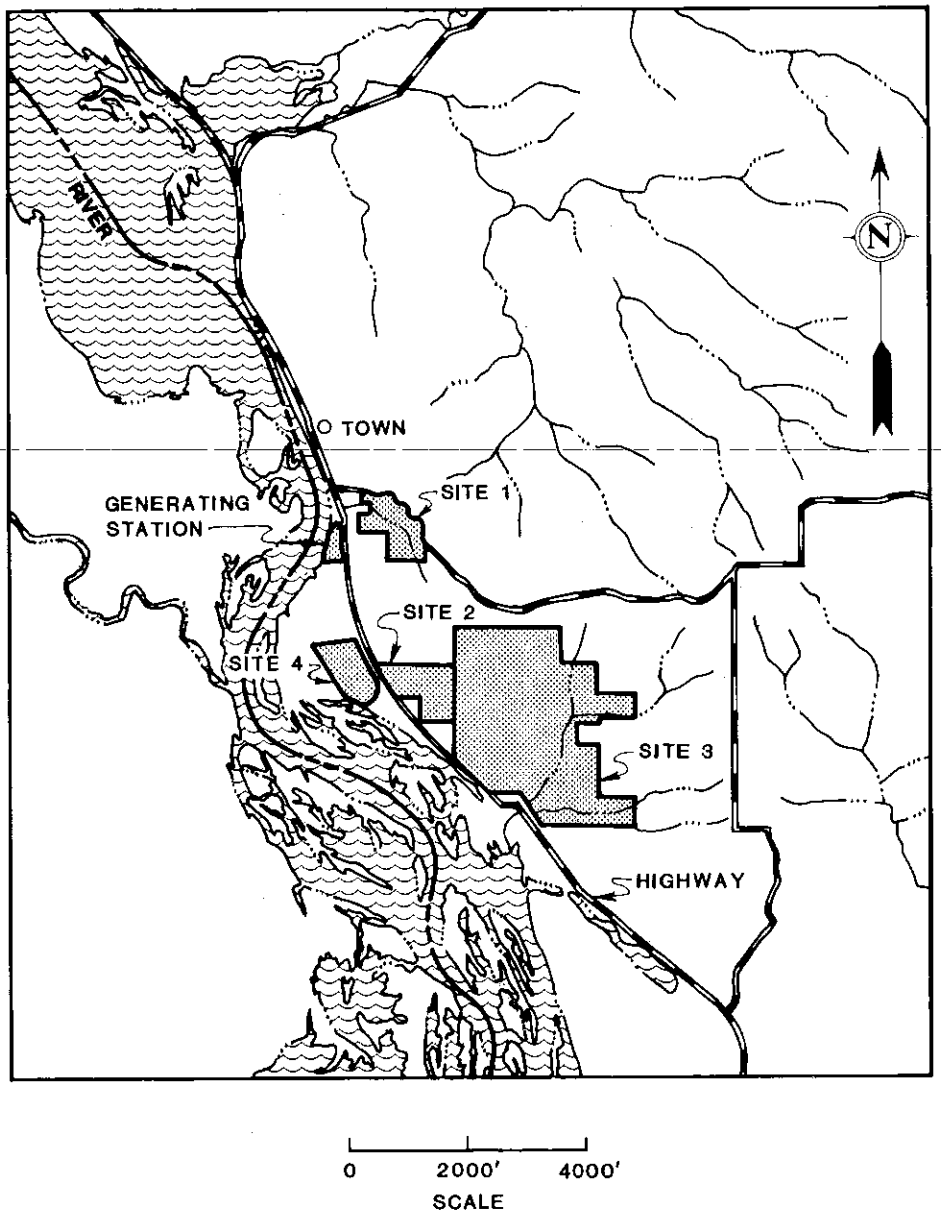

Figure 1-3. Case Study Site Location Map

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Engineering and Environmental Design Criteria

Units 1 through 5 burn bituminous coal from Kentucky and Southern Illinois and subbituminous coal from Montana. Approximately 46,000 tons (42,000 metric tons) of ash are produced by Units 1 through 5 annually. Approximately 80 percent of the total ash is fly ash, and the remainder is composed of bottom ash and pyrites. Unit 6 will burn low sulfur, subbituminous coal from Wyoming. Annual total ash production by Unit 6 is projected to be 90,000 tons (82,000 metric tons). Since the utility plans to market half this volume only, 45,000 tons (41,000 metric tons) per year will require disposal.

Based on anticipated annual ash production, projected retirement dates for older units, and a 4:1 ratio of fly ash to bottom ash, the following volumes of ash requiring disposal over a 35-year period were calculated, beginning with the 1979 on-line date for Unit 6.

- Fly Ash - 2,226,000 tons (2,000,000 metric tons)
- Bottom Ash - 554,000 tons (500,000 metric tons)

The following in-place dry densities were assumed:

- Sluiced fly ash - 45 pcf (pounds per cubic feet) (721 kg/m^3)
- Compacted fly ash - 70 pcf (1122 kg/m^3)
- Sluiced bottom ash - 70 pcf (1122 kg/m^3)

Using the above assumptions, volume requirements were calculated. Sluiced fly ash would require 3,664,000 cubic yards (2,801,700 m^3) of disposal volume, dry compacted fly ash would require 2,356,000 cubic yards (1,801,530 m^3) of disposal volume, and sluiced bottom ash would require 586,000 cubic yards (448,090 m^3) of disposal volume.

The utility intended to sluice bottom ash to a redeveloped ash pond located near the power plant. Bottom ash stored there would serve as a source of drainage blanket material if dry fly ash disposal were chosen. The redeveloped ash pond was large enough to store the anticipated volume of sluiced bottom ash.

At the time the study was done, the ash properties of the subbituminous coal to be burned in Unit 6 were unknown. Due to the retirement schedule of the older units and the comparatively large capacity of the new unit, Unit 6 fly ash would form a substantial portion of the total ash requiring disposal. Since this ash would be

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the end product of subbituminous coal combustion, there was a possibility that it might be self-hardening. This reactive characteristic would severely limit the distance that fly ash could be sluiced, would place restrictions on truck transport methods, and would permit the addition of little or no water at the storage silo. For short haul distances, it may be possible to add a small amount of water to cause "caking" of the fly ash in small agglomerations. The agglomerations are still fairly easy to transport and place in a disposal area using conventional means; however, larger haul distances can require the use of pneumatic tank trucks and special equipment to handle and place dry reactive ash once it reaches the disposal site.

Regulations governing fly ash disposal were centered around protection of surface and groundwaters. Water discharge from the ash disposal site had to comply with the State Administrative Code and Environmental Protection Agency regulations. These restrictions included the following effluent requirements:

- Total suspended solids $\leq$ 15 mg/l
- pH range 6.0 to 9.0
- No release of substances toxic to aquatic life

It was anticipated that the State Department of Natural Resources would require that any fly ash leachate released into the groundwater have no detrimental effects on water quality.

The volume of leachate generated by a dry disposal area is considerably smaller than that associated with a wet disposal area. The volume of leachate associated with a dry disposal area can be minimized by restricting the amount of water entering the coal ash through proper design and operating procedures. This can be accomplished by sloping the surfaces of the disposal area to accelerate runoff, using peripheral diversion ditches, slope benches, drainage blankets, compaction, and soil cover and seeding.

The ability to successfully operate an ash disposal area without detrimental effects on the groundwater should be assessed before site design and permitting. Such an assessment is obtained from the following information:

- On-site soils - depth of overburden, in-situ permeability
- Groundwater - depth, flow patterns, volumes, present quality
- Fly ash - leachate characteristics, anticipated in-place permeabilities

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Sufficient information was available at the time of the site selection study to indicate that all sites were technically feasible without liners. Due to the uncertainty of regulatory requirements, however, it was necessary to also consider liners for the sites. Although the use of liners may have a significant effect on the cost of developing a site, the installation of liners does not affect the relative ranking of the sites. Therefore, only the unlined options are discussed here for purposes of brevity.

It was further assumed that the utility would be required to monitor leachate quality. Any disposal site discharge not in compliance with effluent standards previously mentioned would require treatment.

Evaluation of Site Characteristics and Impacts

Each site was inspected to determine physical features, environmental setting, land use, and access. Table 1-3 summarizes the topography, geology, soils, and hydrology of each site. Table 1-4 summarizes the physiography, vegetation, wildlife, and aquatic life of each site. A search of available information, including well logs, USGS maps, property maps, and soil maps, was made for each site. For each site, both wet and dry disposal schemes were considered and possible operational difficulties were analyzed.

Site 1. Site 1, as shown on Figure 1-4, is located one-quarter mile north of the existing power plant on the east side of the highway. The site is a narrow valley comprising 109 acres (44.1 hectares). County Trunk Road "E" borders the north and east edges of the property. A small cemetery, a commercial establishment, and a number of homes are situated at the valley mouth between the property boundary and the highway. The south and west edges of the site abut an upland wooded area. Upland clearings south of the site are cultivated. A house and a few farm buildings are located on the property near the east boundary.

The principal advantage of Site 1 is its proximity to the generating station. As indicated by Figure 1-4, the major drawback was seen to be the relocation of transmission lines crossing the property.

Dry and wet disposal alternatives were considered for the site. Figure 1-5 shows a plan of Site 1 developed for a dry disposal area. The dry disposal plan utilizes 28 acres (11.3 hectares) of land at the head of the valley and is capable of handling 35 years of ash production. Major features of the plan are:

- Relocation of the 12 kV distribution line,

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Table 1-3

TOPOGRAPHY, GEOLOGY, SOILS, AND HYDROLOGY OF CASE STUDY SITES

Site	Topography	Geology	Soils	Hydrology
1	Narrow valley of 109 acres. Elevations 1222 to 717 feet. Valley slopes 3:1 to 1:1. Valley floor slopes N.W. at 5 to 10%	Prairie du Chien Group Shakopee Dolomite New Richmond Sandstone Oneato Dolomite sandstone, Trempealeau Formation Francoria Sandstone Dresbach Group	Steep stony rock land (SCS St) Upper Valley Sides, Fayette silt loam (SCS Fv) Lower alluvial Soil (SCS Lw) Valley Floor	No springs or seeps. Ephemeral streams. Groundwater elevation; 930-900 upland 660 near river Watershed 270 acres
2	Narrow valley of 118 acres. Elevations 1220 to 680 ft. Valley slopes 2:1. Valley floor slopes S.W. at 7%	Similar to Site 1	Similar to Site 1	No springs or seeps. Ephemeral streams. Groundwater levels same as Site 1. Watershed 350 acres.
3	Varied valleys and upland plain comprising 860 acres. Upland plain elevations 1100 to 1240. Large valley elevations 900 to 780. Slopes south at 3%. Smaller valley elevations 840 to 780. Slopes S.E. at 5%. Valley slopes 2:1.	Similar to Site 1	Upland plain: Fayette silt loam (Fa) Dubuque silt loam (De) Valley Slopes: Steep story rockland(St) Fayette silt loam (Fv) Urne-Norden loam (Un) Norden silt loam (Gf) Valley bottom: Loamy alluvial land (Lw) Bertrand silt loam (Be) Chaseburg silt loam (Ca) Jackson silt loam (Ja)	Similar to Site 2. Watershed 1,300 acres above large valley; 635 acres above smaller valley.
4	Rail loop enclosing 22 acres. Bottom elevation 645. Top of dike elevation 680. Elevation of undisturbed wetlands 660 to 663.	Sand and gravel Mt. Simon sandstone	Silt (excavated)	Located in major river floodplain. Dike protection: 150 year flood. Groundwater elevation 660.

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Table 1-4

PHYSIOGRAPHY, VEGETATION, WILDLIFE AND AQUATIC LIFE OF CASE STUDY SITES

Site	Physiography	Vegetation	Wildlife	Aquatic Life
1,2, & 3	Location in valleys adjacent to the major river floodplain	Second and third growth of oak-hickory forest: birch, aspen, maple, cedar. Fields and pasture: Milkweed, foxtail, yellow dock, white cockle, dandelion, and a variety of grasses.	Animal: deer, raccoon, gray & fox squirrels, cotton-tail rabbit, jack rabbit, gray & red foxes, woodchucks, skunks, ground squirrels, mice, shrews, moles. Bird: sparrows, finches, English sparrows, wood-peckers, flickers, thrushes, martins, swallows, rough-shouldered hawks, blue jays, barred owls, great horned owls, whippoorwills.	None due to ephemeral stream flow.
4	Located south of the power plant on the major river flood-plain in bottomlands intersection by several shallow slow-moving sloughs.	Wooded areas: silver maple, American elm, river birch, swamp white oak. Open marsh: sedges, rushes, grasses, submerged aquatic plants, green-brier, wood nettle, goldenrod.	Animal: muskrat, beaver, raccoon, deer, mink, reptile, amphibian, & insect species. Bird: migratory waterfowl: ducks, coot, geese crows, woodcock, red-winged blackbirds, tanagers, kingfishers, barred owls, grackles, starlings, wrens, red-shouldered hawks, bald eagles.	Bluegill, black & white crappies, northern pike, walleyed pike, sauger, channel catfish, northern redhorse, yellow perch, largemouth bass.

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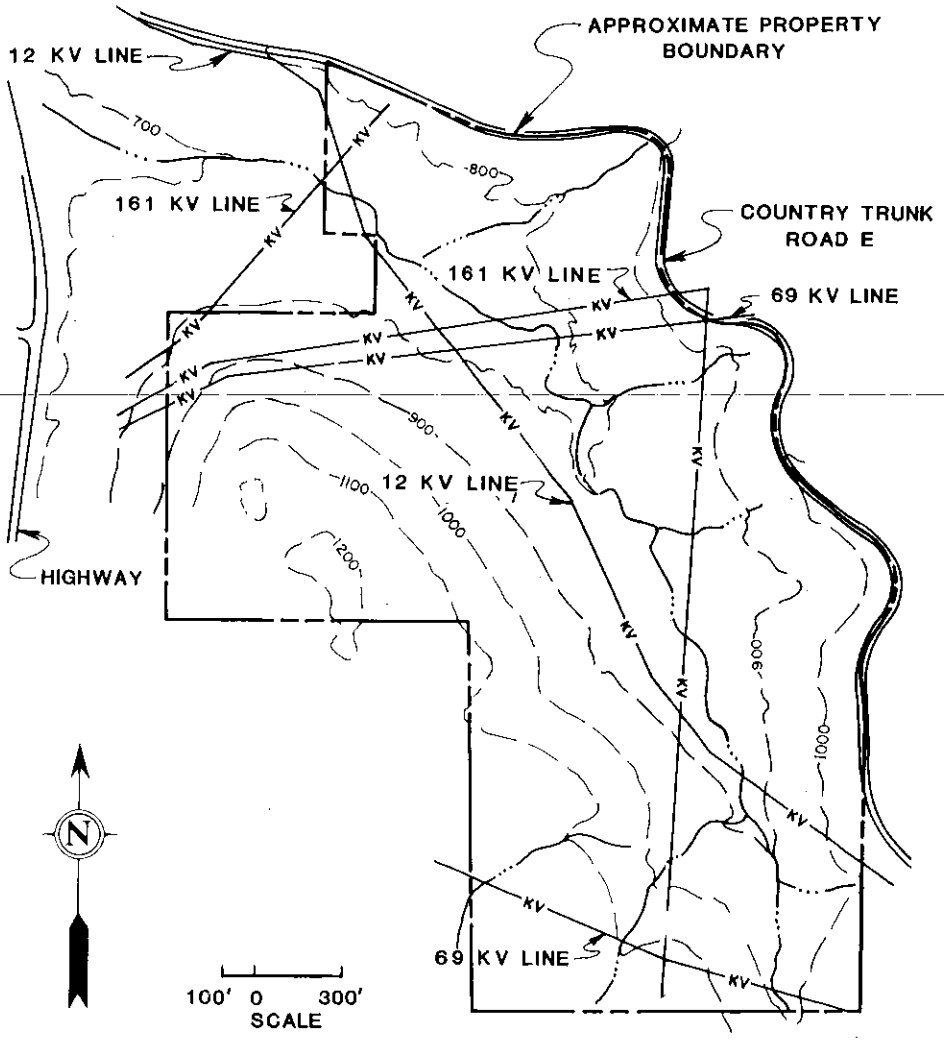

Figure 1-4. Case Study - Site 1 Existing Conditions

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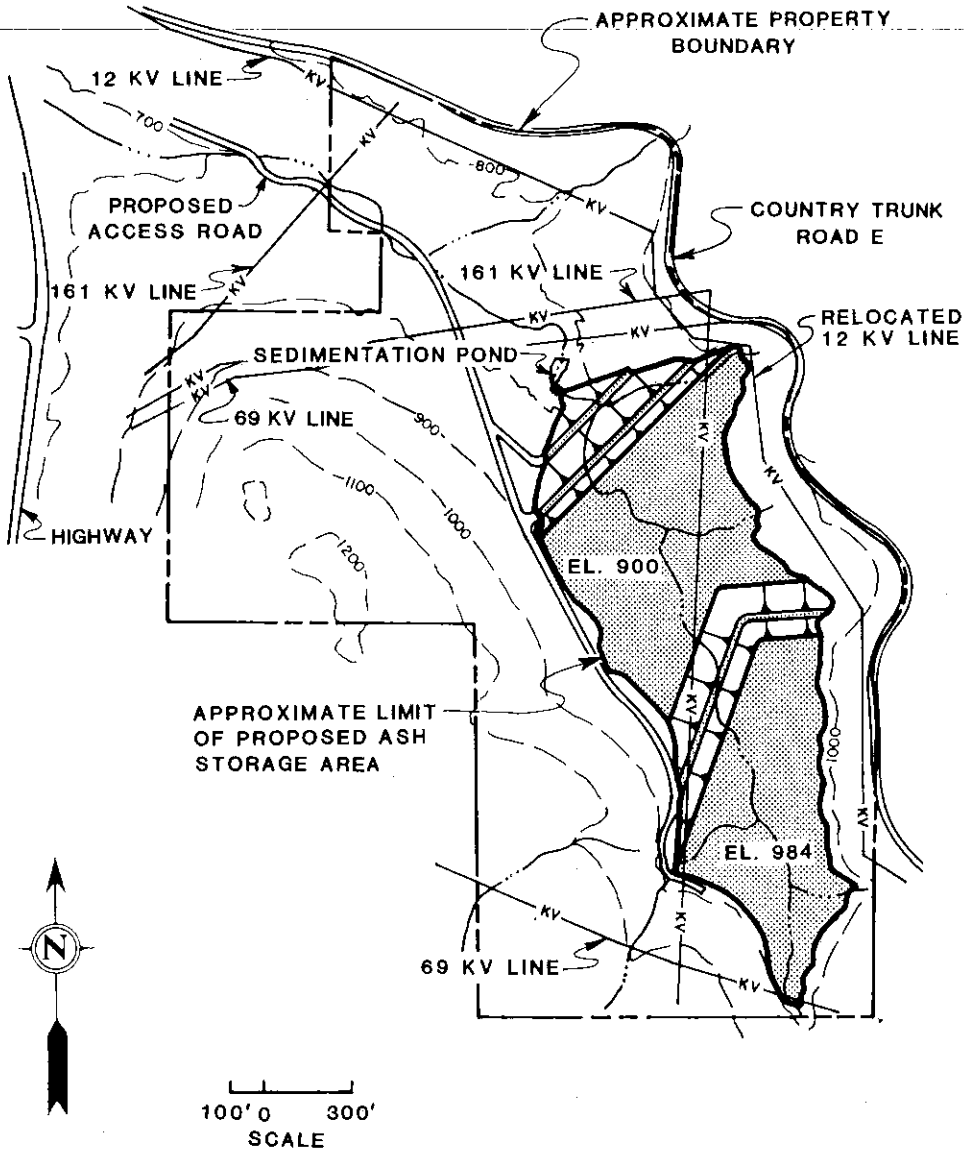

Figure 1-5. Case Study - Site 1 Conceptual Plan for Dry Ash Disposal Area

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- Site preparation - staged development to minimize erosion and sedimentation, construction of a haul road, clearing and grubbing, stripping and stockpiling topsoil for later use, construction of runoff diversion ditches, construction of a drainage blanket and underdrain system,
- Operation - fly ash transport by highway dump truck, spreading and compaction of ash as soon as possible after arrival, dust control through watering, special handling, and placement of reactive ash if necessary,
- Restoration - staged restoration following completion of section of fill, topsoil cover and seeding, possible future use as residential or commercial agricultural site.

In order to maximize wet storage volume, it was deemed necessary to place a dam as far toward the west end of the property as possible. The elevation of the top of the dam was established by clearance requirements for an existing transmission line.

The conceptual scheme developed for wet storage on the site entailed a dam with a crest elevation of 870 feet. However, even with the utilization of fly ash in construction of the embankment, storage volume would accommodate only 11 years of fly ash production, and relocation of the 69 kV and 161 kV lines would be required to achieve sufficient volume. Furthermore, it was thought that sluicing ash 3,000 feet (914 meters) would be difficult if the fly ash from Unit 6 proved to be reactive. Based on the above constraints, it was concluded that an adequate wet disposal area could not be developed on Site 1.

Site 2. This site, as shown in Figure 1-6, is a narrow heavily wooded valley located one and one-half miles south of the power plant and east of the highway, and is comprised of approximately 118 acres (47.8 hectares). A few homes are located at the mouth of the valley along the east side of the highway. The only development at the site was the cultivation of a small uplands plain.

While this site was thought to be suitable for development as an ash disposal area, it had several drawbacks. The dry disposal plan for Site 2, as shown in Figure 1-7, entails the use of 26 acres (10.5 hectares) at the south end of the site. The landfill configuration shown would provide adequate disposal volume for 35 years of fly ash production. Additional storage could be created by increasing the height of the terrace and both embankments.

While operation and abandonment of Site 2 would be similar to those of Site 1, more work would be required in the preparation of Site 2. Clearing and grubbing would

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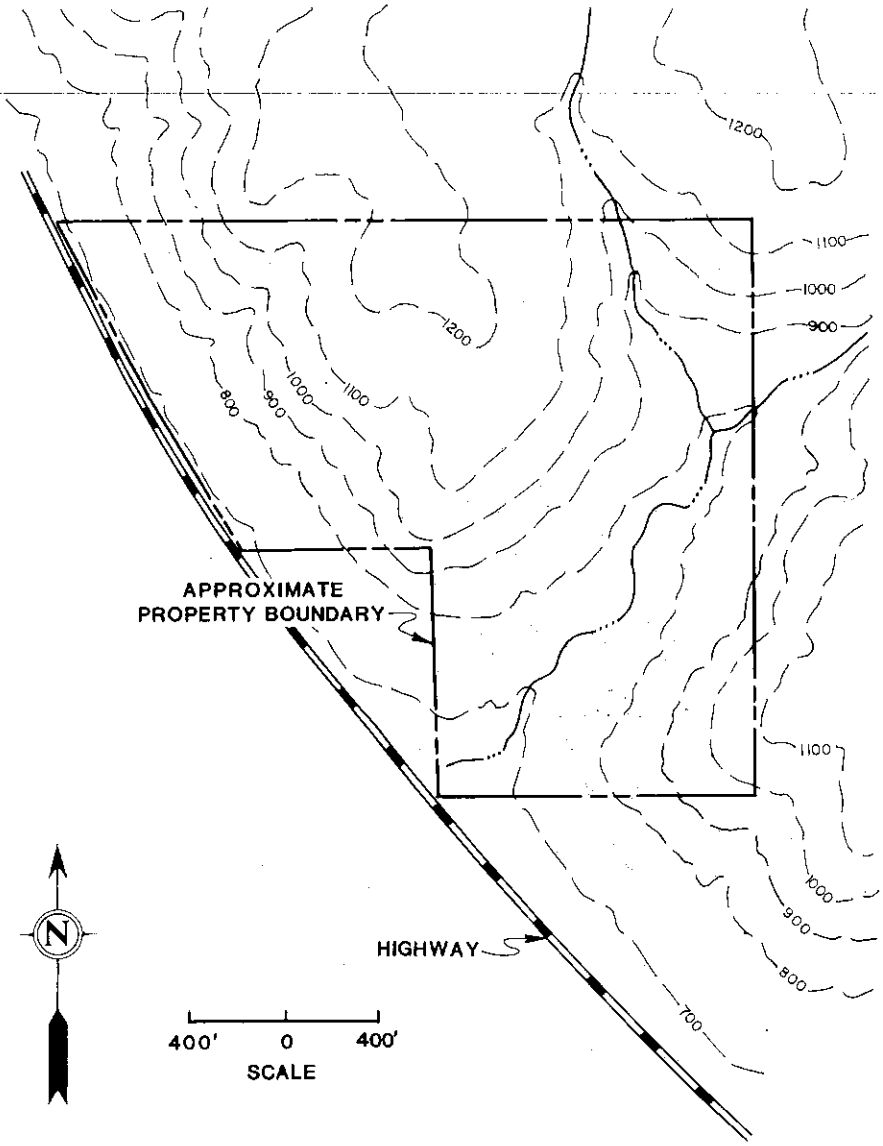

Figure 1-6. Case Study - Site 2 Existing Conditions

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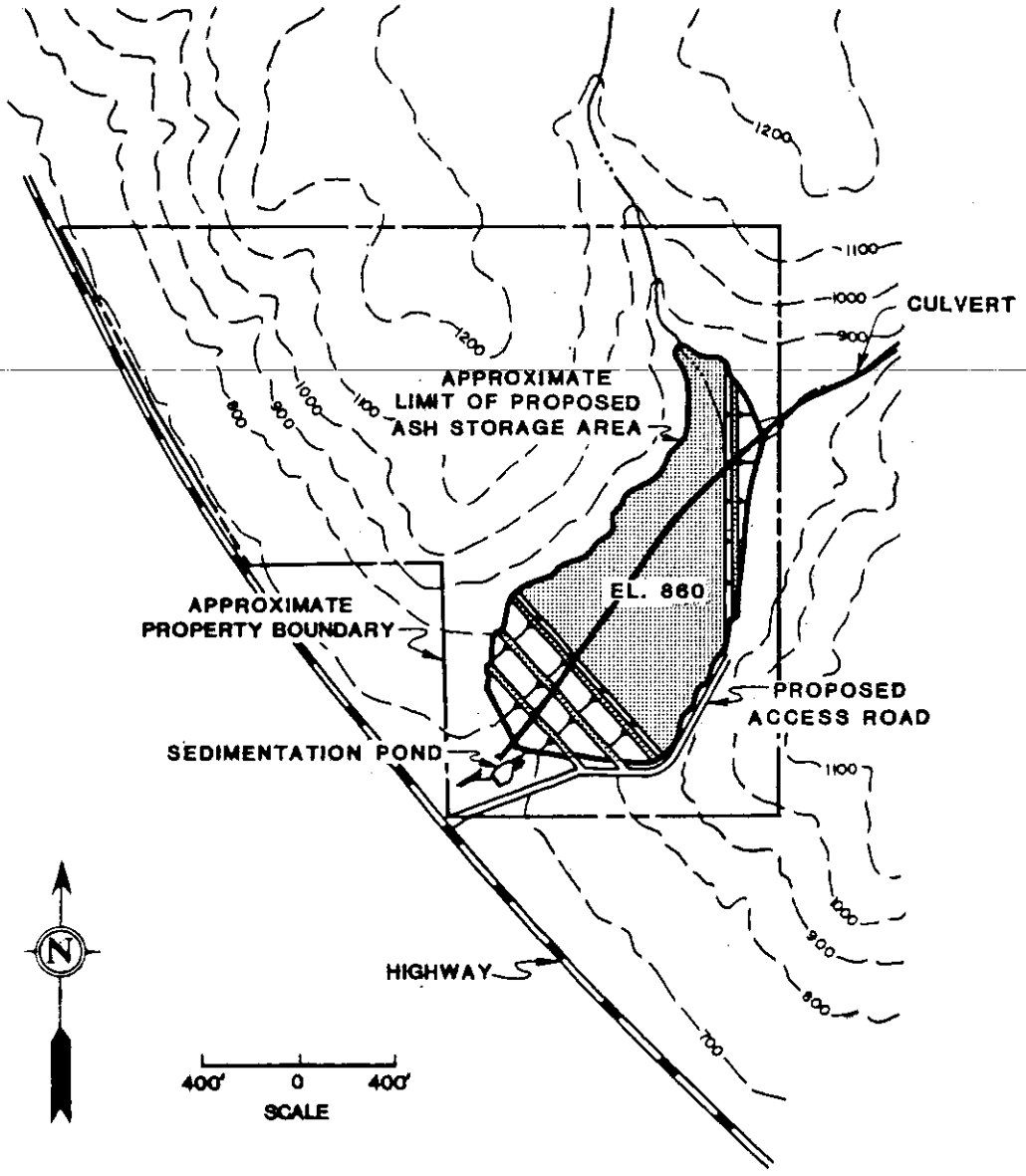

Figure 1-7. Case Study - Site 2 Conceptual Plan for Dry Ash Disposal Area

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be more difficult due to the heavily wooded nature of the site. Since a back embankment would be required, it would not be possible to carry runoff around the site in diversion ditches. A 60-inch (1.5 meter) diameter reinforced concrete bypass pipe would have to be installed in the existing stream channel to carry runoff beneath the ash fill. Consideration would have to be given to the disposal area's possible impact on the water quality of private wells downgradient of the site. Access to the site is steep and would require considerable earthwork. In addition, the location and visibility of the site would make the establishment of effective visual and audio screens difficult.

Wet storage would require dams at the front and back of the valley. The size of the dams and the length of the valley is such that insufficient storage space would remain between the two dams. Therefore, wet storage at Site 2 was considered to be an unacceptable alternative.

Site 3. Site 3 is located two and one-half miles south of the power plant and east of the highway. As shown in Figure 1-8, this site has varied topography and covers 860 acres (348 hectares). Use of the site was restricted to farming the upland plains and terraces. A commercial establishment and a few dwellings are located at the mouth of the two larger valleys. A small marina is located across the highway and slightly south of the site. A wayside park is located just north of the site on the east side of the highway.

The size and configuration offered development alternatives. Clearing operations would not be extensive, and portions of the site are well screened. However, a major drawback, as compared to Sites 1 or 2, is the distance from the site to the generating station.

The dry fly ash disposal plan developed for Site 3 is shown in Figure 1-9. It entailed the placement of ash on 38 acres (15.4 hectares) in the east valley. The capacity of this area was sufficient to satisfy the design requirements. Site preparation, operation, and abandonment would be similar to those of Site 1.

A conceptual plan for wet disposal in the large central valley of Site 3 is shown in Figure 1-10. A dam approximately 120 feet (36.6 meters) in height would be located across the mouth of the valley. Five and one-half years of fly ash production would be incorporated into the construction of the dam. The pond would have the capacity to hold 30 years of fly ash production.

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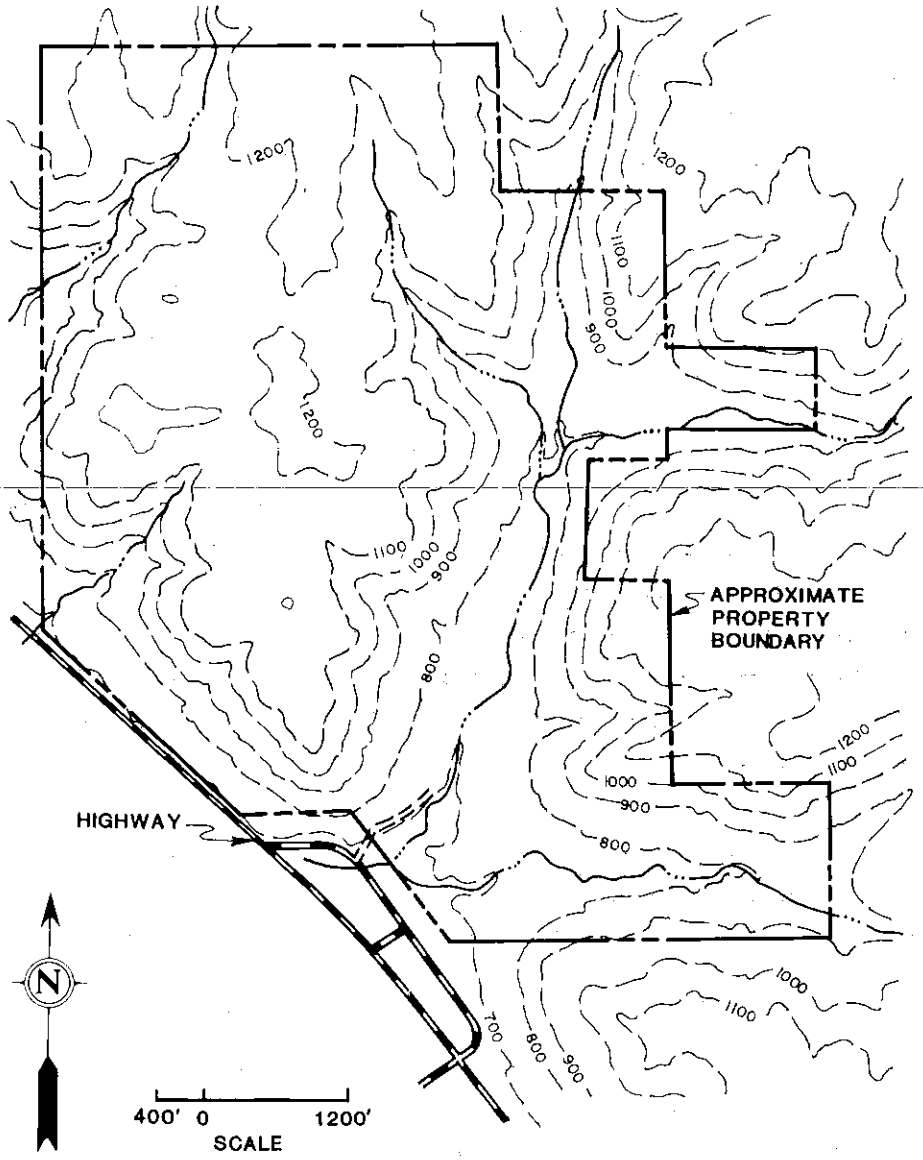

Figure 1-8. Case Study - Site 3 Existing Conditions

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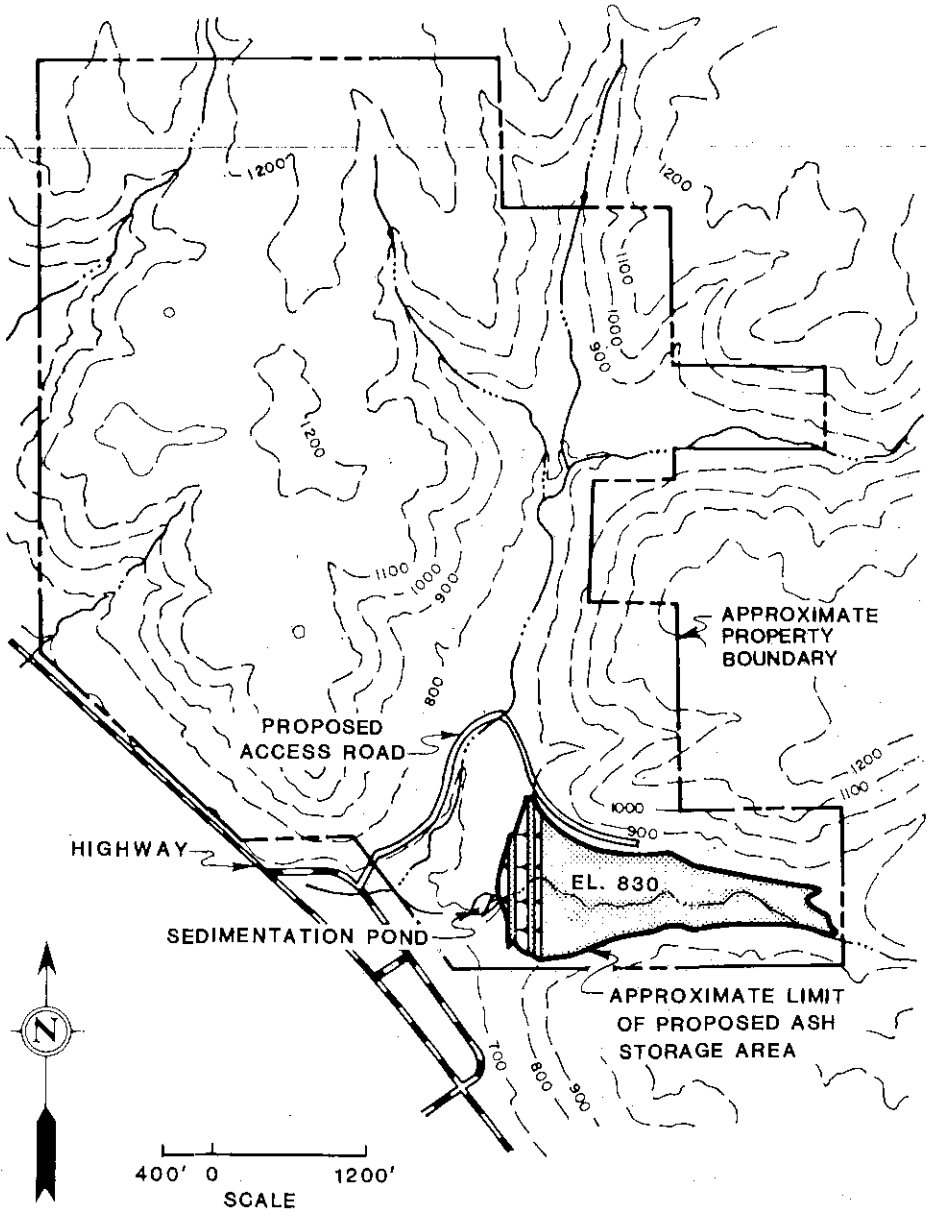

Figure 1-9. Case Study - Site 3 Conceptual Plan for Dry Ash Disposal Area

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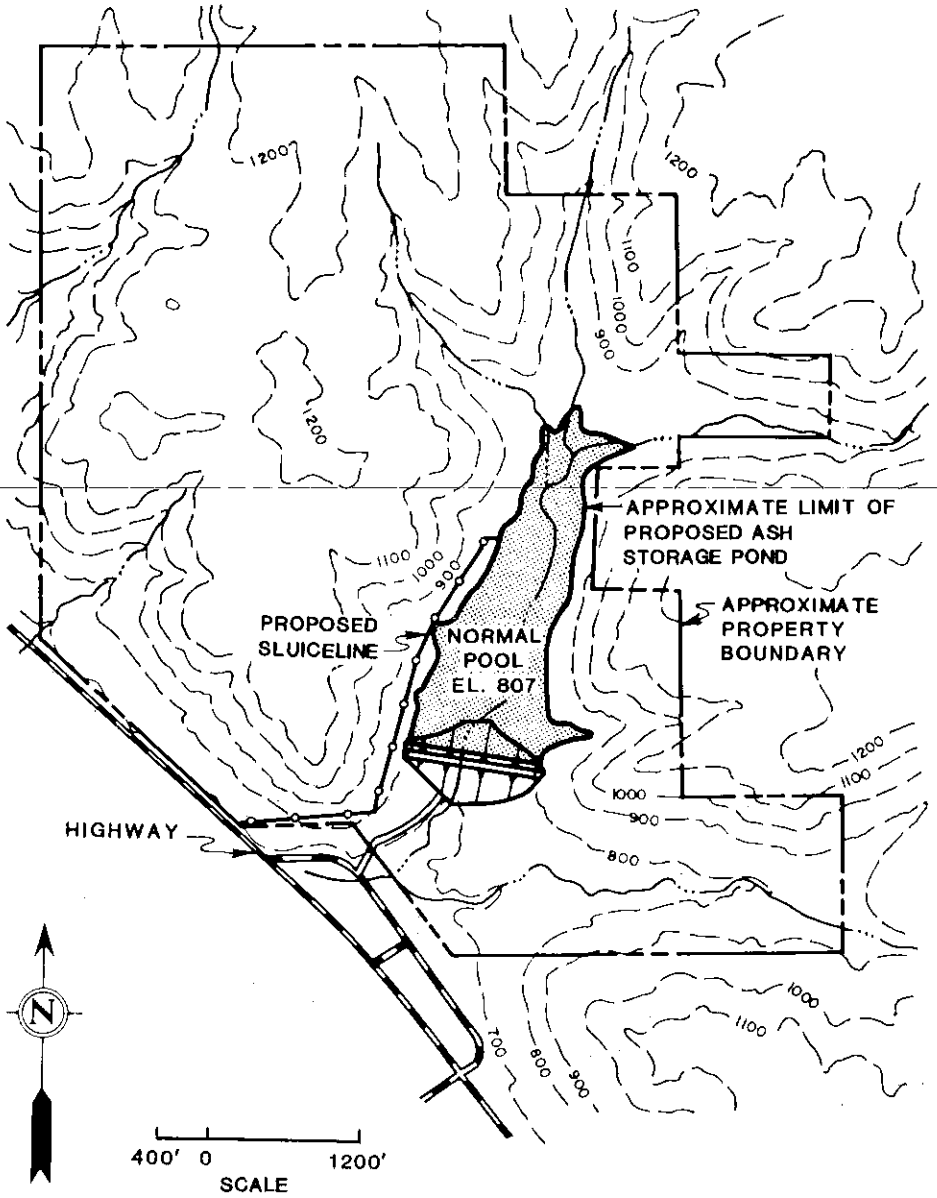

Figure 1-10. Case Study - Site 3 Conceptual Plan for Wet Ash Disposal Area

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Preparation of a wet disposal area at Site 3 would require the construction of a dam, clearing and grubbing, and stockpiling of top soil. Sluice line construction from the plant to the site would be completed at the same time the dam was completed. A backup sluice line and pump were recommended. It was anticipated that due to the settling characteristics of the coal ash, the pond discharge would meet surface water quality standards. Ash would be sluiced to the area 24 hours a day, with river water being used for sluicing water. Drainage basin runoff would keep the pond full and supply dilution water.

If reactive fly ash were to be produced by Unit 6, sluicing would be extremely difficult, if not impossible. However, wet disposal might still be possible if dry ash were hauled to the site in tank trucks and pneumatically discharged into the pond through a submerged hose.

Once the fly ash reached the design level of the pond, excess surface water would be drained off and the surface covered with soil and seeded. Upper layers of ash could be expected to drain with time. However, lower layers of ash would probably remain in a saturated condition unless provisions for draining percolated pond water were made.

Site 4. As shown in Figure 1-11, Site 4 is the area within the existing rail loop adjacent to the power plant, with the exception of the redeveloped ash pond which lies in the northernmost portion of the loop. The area between the redeveloped ash pond and the remainder of the rail loop is approximately 86 acres (34.8 hectares). About 45 acres (18.21 hectares) of the northern portion of the area had been dewatered and excavated to provide material for railroad dike construction. The remaining southern 41 acres (16.6 hectares) were undisturbed wetland forest area.

While site proximity to the plant and configuration within the railroad dikes were major advantages, some serious questions were raised concerning Site 4's suitability as a disposal area. A portion of the site lies within a wildlife and fish refuge. The site is located on a floodplain, and sloughs and channels which are classified as navigable waters are present on the site. There would be a significant potential for impact of the ash ponds on the water quality of the major river and surrounding groundwater and a disposal site there would be environmentally undesirable.

Dry disposal at Site 4 did not receive serious consideration for a number of reasons. A site liner would be required since ash cannot be placed and compacted in standing water. Dry ash could not be placed at a rapid enough rate on a liner

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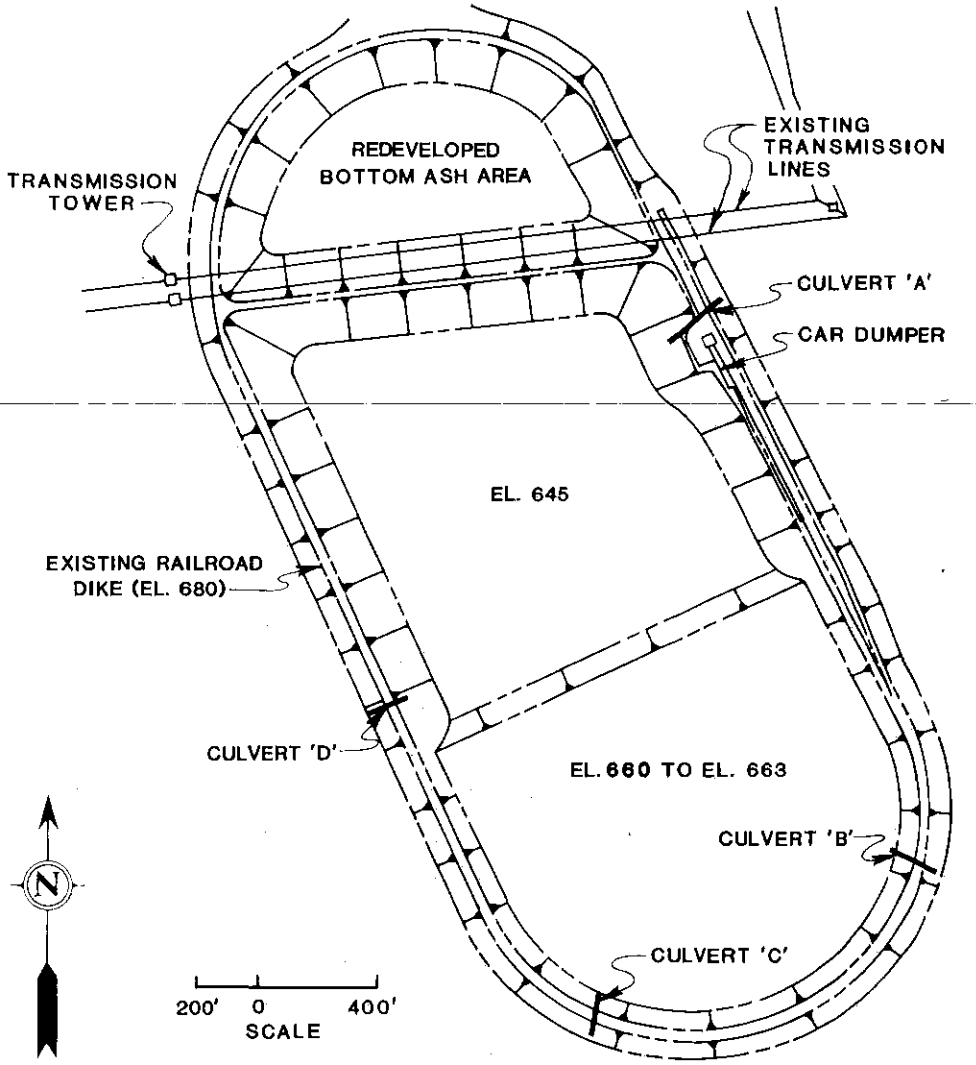

Figure 1-11. Case Study - Site 4 Existing Condition

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to counterbalance hydrostatic uplift pressures on the liner. Therefore, pumping would be required for years until the overburden weight of dry ash was sufficient to keep the liner intact. Ash transport would be by truck, which is more expensive than sluicing. The potential for flooding would offset possible reductions in groundwater contamination. Overall, wet disposal was considered more feasible.

The 45-acre (18.2 hectares) excavated portion of Site 4 had the capacity of storing 30 years of sluiced ash. Additional disposal capacity would require the excavation of the south end of the rail loop, as shown in Figure 1-12. Alternately, fly and bottom ash could be combined and sluiced to the redeveloped ash pond and the excavated area, precluding the need for further excavation. This alternative received economic and environmental evaluation in this study.

Since the redeveloped bottom ash pond was considered by regulatory agencies to be an extension of an existing disposal facility, it was thought that the site could have been developed and operated as in the past without a liner. The condition of existing pump and sluice line was not known, but it was assumed that new pumps and pipes would have to be installed. Existing culverts in the railroad dike would require plugging to prevent washout of sluiced ash through the culverts. An overflow-structure would have to be constructed.

Operation would be similar to that of the Site 3 wet disposal alternative. If Unit 6 fly ash proved to be reactive, it was thought that sluicing might still be a viable means of ash transport. This was based on the proximity of the disposal site to the plant (2500 feet) (762 meters). As an alternative to sluicing, fly ash could be conveyed pneumatically (by tanker or pipe), and pumped under water into the pond. It was recognized that reactive ash could influence the permeability of an unlined pond and also reduce the permeability of settled ash layers.

Once filled, the site could be dewatered, covered with topsoil, and seeded. Future use of the site would be limited.

Economic Analysis

Table 1-5 summarizes the life-cycle costs based on a Class I - Simplified Design for the case study sites. For this study, the life-cycle costs have been expressed as levelized cost per ton of ash disposed. These calculations were performed in accordance with the procedures outlined in Section 9 of this manual.

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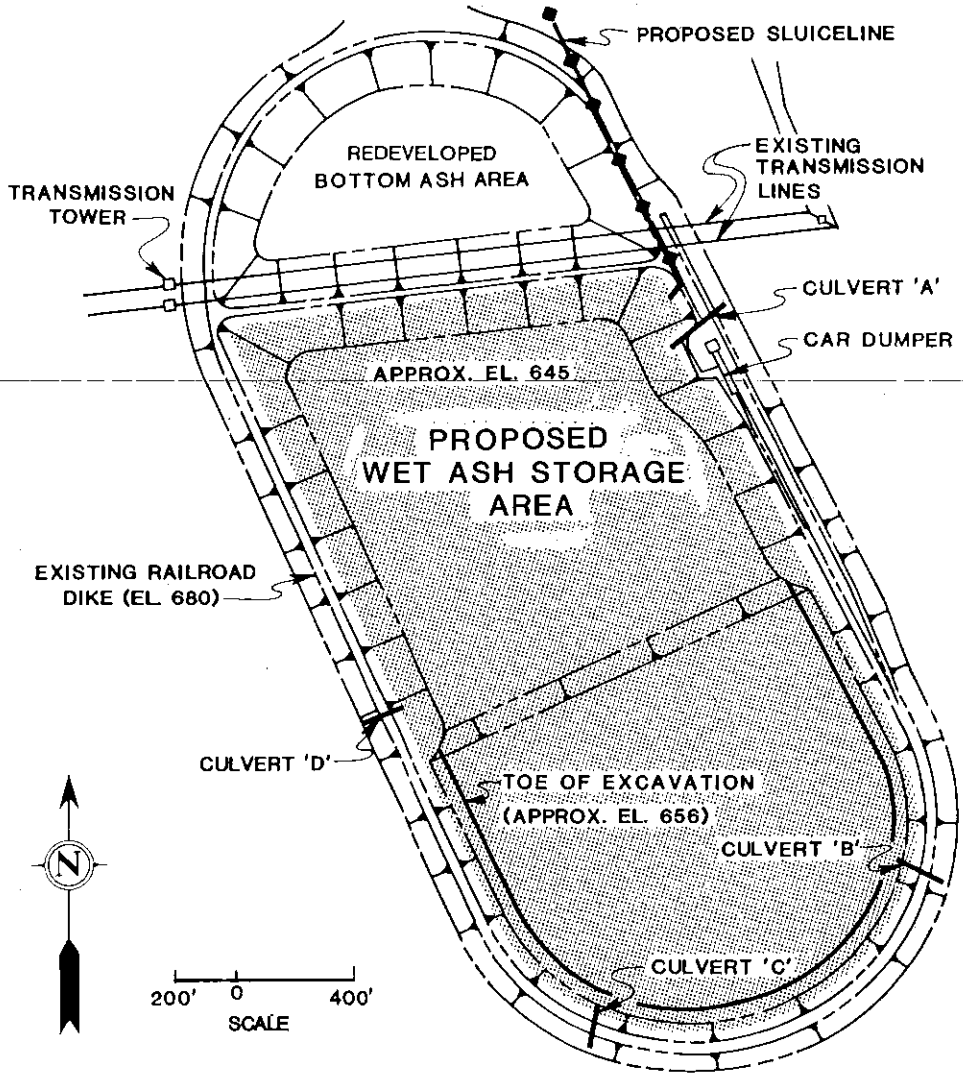

Figure 1-12. Case Study - Site 4 - Conceptual Plan for Wet Ash Disposal Area

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The levelized cost data indicate that Site 1 - Dry is the least cost alternative while Site 3 - Wet is the most expensive. However, it should be emphasized that cost estimates for Class I - Designs can have a range of ±20 to ±30 percent. For this study ±25 percent was used. As indicated by Table 1-5, the cost differences between Site 1 - Dry, Site 2 - Dry, Site 3 - Dry and Site 4 - Wet, fall within this range. Accordingly, a Class II - Preliminary Design and cost estimate were warranted. The results of the more detailed design and costing study are not presented for the sake of brevity.

Table 1-5

LEVELIZED COSTS BASED ON CLASS I - SIMPLIFIED DESIGN FOR CASE STUDY SITES

Cost Item	Site 1[a] Dry	Site 2[b] Dry	Site 3[c,d] Dry	Site 3[c,d] Wet	Site 4[3] Wet
Capital Cost	$3,650,000	$3,650,000	$4,180,000	$2,980,000	$2,854,000
First Year O&M Cost	$ 230,000	$ 235,000	$ 245,000	$1,065,000	$ 317,000
Levelized Cost per Ton of Ash	$ 15.10	$ 15.24	$ 16.73	$ 38.24	$ 16.21

a. Site 1 Dry: Narrow Valley, 1/4-mile truck transport

b. Site 2 Day: Narrow Valley, 1-1/2 mile truck transport

c. Site 3 Dry: Wide Valley, 2-1/2 mile truck transport

d. Site 3 Wet: Wide Valley, 2-1/2 mile pipeline transport

e. Site 4 Wet: Flat Land, 25' embankment, 1/2 mile pipe transport

Environmental Evaluation Matrix

The environmental evaluation of each disposal alternative was accomplished by the matrix technique previously described. Four individuals participated in the procedure: two had environmental engineering backgrounds, one had a non-engineering environmental background, and one had a general engineering background. Group consensus was reached on all decisions.

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Table 1-6

ENVIRONMENTAL EVALUATION MATRIX FOR CASE STUDY SITES

Environmental Parameter	Primary WF	Site 1 Dry C/O[1] IM	Site 1 Dry C/O[1] EFF	Site 1 Dry PC[2] IM	Site 1 Dry PC[2] EFF	Site 2 Dry C/O IM	Site 2 Dry C/O EFF	Site 2 Dry PC IM	Site 2 Dry PC EFF	Site 3 Dry C/O IM	Site 3 Dry C/O EEF	Site 3 Dry PC IM	Site 3 Dry PC EFF	Site 3 Wet C/O IM	Site 3 Wet C/O EEF	Site 3 Wet PC IM	Site 3 Wet PC EEF	Site 4 Wet C/O IM	Site 4 Wet C/O EEF	Site 4 Wet PC IM	Site 4 Wet PC EEF
Aesthetics	6	3	18	1	6	5	30	3	18	2	12	0	0	2	12	1	6	5	30	3	18
Air quality	5	2	10	0	0	3	15	0	0	2	10	0	0	1	5	0	0	0	0	0	0
Aquatic ecology/ water quality	8	1	8	2	16	1	8	2	16	1	8	2	16	3	24	1	8	5	40	5	40
Cultural resources	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land use	4	2	8	-3	-12	2	8	0	0	1	4	-3	-12	5	20	3	12	3	12	-1	-4
Noise	5	4	20	0	0	5	25	0	0	3	15	0	0	1	5	0	0	0	0	0	0
Public health and safety	9	1	9	0	0	1	9	0	0	1	9	0	0	2	18	0	0	2	18	1	9
Socioeconomics	4	-1	-4	0	0	-1	-4	0	0	-1	-4	0	0	0	0	0	0	0	0	0	0
Terrestrial ecology	5	3	15	2	10	4	20	4	20	3	15	2	10	4	20	2	10	2	10	0	0
Summary EEF			84		20		111		54		69		14		104		36		110		63
Weighted EEF[3]			71		3		94		8		59		2		88		5		94		9
Overall EEF[4]			74				102				61				93				103		

[1] C/O - construction/operation.
[2] PC - post-closure.
[3] Weighted EEF = 0.85 x summary EEF for construction/operation or 0.15 x summary EEF for post-closure.
[4] Sum of weighted EEF's.

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A scale of one to ten was selected for primary weighting factors, with increasing value indicating increasing significance or importance. Environmental parameters and primary weighting factors chosen for this evaluation are shown in Table 1-6.

It was thought that environmental parameters presented in Table 1-6 would be affected in the following ways:

- Aesthetic impacts would be primarily visual. Where possible, buffers would be established to minimize this impact.
- Air quality impacts result from the transport and placement of ash. Of primary concern were haul vehicle exhaust and dust from ash handling.
- Aquatic biology and water quality would be adversely affected by the release of fly ash leachate or slurry water into surface or groundwater. Aquatic habitats would be eliminated by filling operations in the wetlands area.
- Cultural resource impacts are related to any historical or culturally unique areas in or close to the disposal sites. None were known to exist at the time of the study.
- The impact of fly ash disposal on land use is primarily the result of using productive, or potentially productive, land for a temporary, nonproductive use. The impact of ash disposal after site abandonment was based on the potential of productive site use as compared to its potential prior to disposal operations.
- Noise impacts were expected to result from ash transportation and placement. Noise levels associated with dry disposal would be greater than with wet disposal.
- Public health and safety impacts include increased vehicular traffic between the power plant and the storage site, potential loss of life or property damage resulting from dam breach or overflow, increased flood levels due to filling operations in the floodplain, or dike breach during flooding.
- Socioeconomic impacts would include increased revenue to the surrounding area resulting from site construction and operation. Impacts after closure were not considered.
- Terrestrial ecology would be displaced by ash disposal operations. After closure the site would regain use, initially as a meadow habitat. The magnitude of post-closure impacts were based on a comparison of the pre-development and post-closure habitats.

Secondary weighting factors of 0.85 and 0.15 were assigned to construction/operation impacts and post-closure impacts, respectively. Values for impact magnitudes ranging from minus five to five were assigned to each environmental parameter, with increasing values denoting increasing negative, or damaging impact. If the impact

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was considered to be beneficial, a negative number between zero and minus five was assigned, with increasing negative value denoting increasing benefit.

The completed matrix is shown in Table 1-6. As can be seen, Site 3 - Dry had the lowest overall EEF of the five alternatives. Site 4 - Wet had the largest overall EEF, indicating that on a relative basis this site has the most serious environmental problems due to ash disposal on the wetlands.

Comparison of Disposal Alternatives

As has been illustrated in this case study, environmental and cost parameters are fundamental considerations in the comparison of site disposal alternatives. The purpose of the disposal site selection methodology up to this point was to develop numerical values for both parameters for each site alternative. Ideally, the best ash disposal site is the one with the least environmental impact and the lowest cost. Figure 1-13 illustrates the relationship of the five disposal alternatives to one another on the basis of levelized cost, expressed in dollars per ton, and environmental impact expressed as a relative numerical value. While this graphical technique provides a means of comparison, it should be noted that it is extremely difficult to assign a cost to environmental impact. The environmental impact matrix and the graphical comparison techniques outlined in this case study example provide a basis for sound decision making and documentation of the selection process. The final selection of a disposal site is a judgmental decision that weighs all considerations.

As indicated by the data shown in Figure 1-13, the Site 3 - Wet disposal alternative is significantly more expensive than the Site 4 - Wet and all three dry site alternatives. In addition, the disposal costs for Site 4 - Wet and the three dry alternatives are within the range of accuracy of a Class I Design cost estimate. However, the EEF's for Site 2 - Dry and Site 4 - Wet are significantly greater than for Site 1 - Dry or Site 3 - Dry while the EEF's for these latter two sites are reasonably close to each other. Thus, a definitive decision could not be made at this stage of study since the difference in cost and environmental impact between Site 1 - Dry and Site 3 - Dry are inconclusive.

The final decision between these two dry alternatives was based on a Class II - Preliminary Design and cost estimate. This analysis indicated that Site 3 - Dry was the optimum selection for development.

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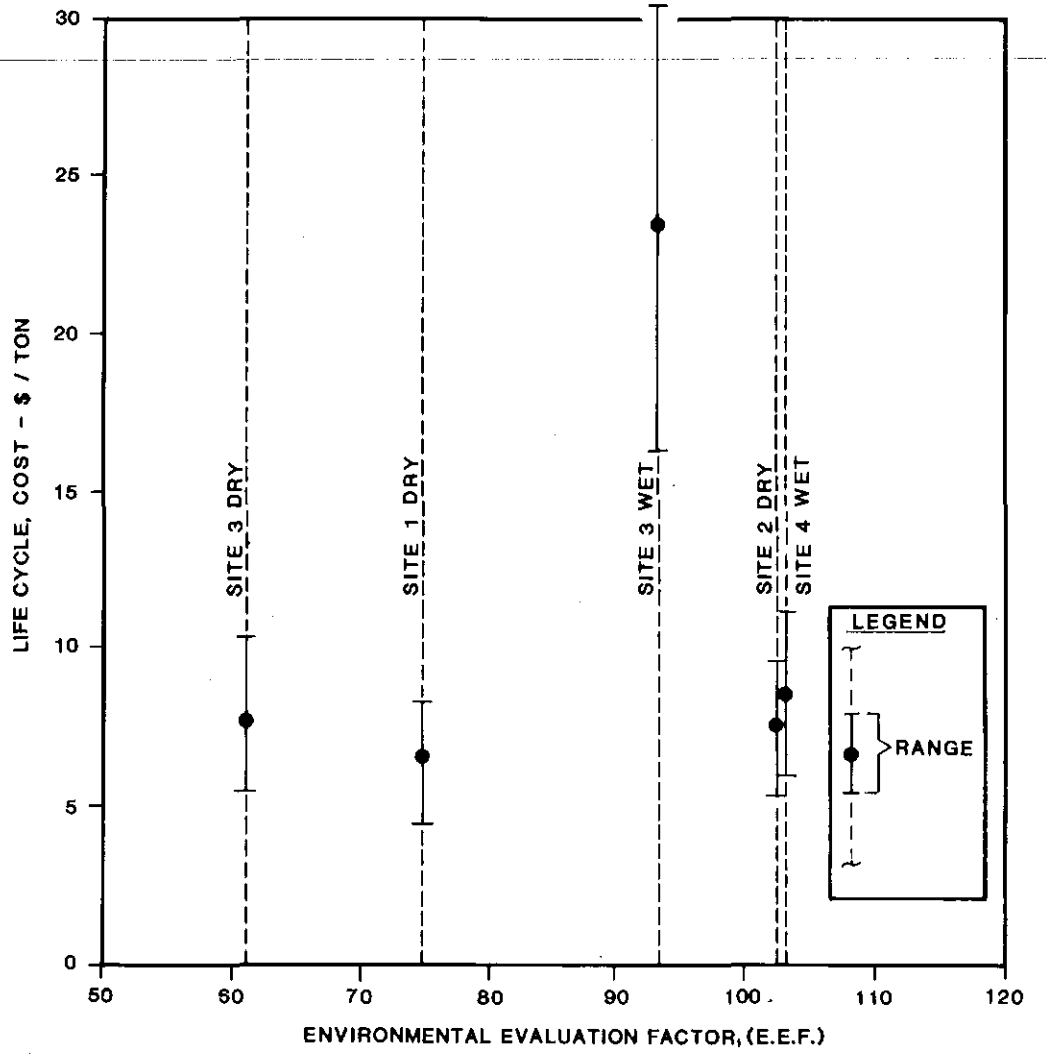

Figure 1-13. Case Study - Comparison of Alternate Disposal Site Costs and EEF's

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REFERENCES

1. FGD Sludge Disposal Manual, Second Edition. Palo Alto, Calif.: Electric Power Research Institute, September 1980. CS-1515.

2. U. S. Department of Interior. U. S. Geological Survey. A Procedure for Evaluating Environmental Impact. Reston, VA: U. S. Geological Survey National Center, 1973. Circular 645.

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Section 2

PROPERTIES OF POWER PLANT ASH

INTRODUCTION AND OVERVIEW

The chemical, physical, and engineering properties of a particular power plant ash are a function of many factors, including;

- type of coal and geographic source,
- degree of coal preparation, cleaning, and pulverization,
- design, type, and operation of the power plant boiler unit,
- collection, handling, and disposal methods.

Due to the above factors, coal ash will display a high degree of variability in its properties. Not only will the properties of an ash vary from power plant to power plant, but they will also vary from boiler to boiler at a particular plant and within an individual boiler at various times.

In this section, the variability which exists within the coal from which the ash is derived will be examined; the effect that various combustion and collection techniques have on the properties of the ash will be shown; and typical chemical and physical properties of fly ash, bottom ash, and boiler slag will be presented. Finally, an ash testing matrix is presented which identifies those tests which are pertinent to the specific transport/disposal/utilization schemes currently being utilized.

PROPERTIES OF COAL

Since the composition of ash is primarily a function of the elemental composition of the feed coal, a review of the elements (both major and trace) contained in coal and their relative magnitudes is appropriate. The composition of the feed coal is not the only factor which affects the composition of the ash. As stated earlier, the properties of the ash are also a function of the types of combustion and collection equipment used, degree of pulverization of the coal, temperature during combustion, and many other factors.

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Coal Major Elements

The major elements comprising coal are carbon, hydrogen, oxygen, nitrogen, and sulfur. These elements typically account for 70 to 97 percent of the total, and are present in varying quantities. All of the major elements form gaseous compounds when burned. These combustion products are mostly discharged with the flue gases, and have little bearing on the composition of the ash.

Coal Trace Elements

Trace elements and minor constituents in coal may originate from a number of sources. Some of these elements were accumulated in the vegetation from which the coal was formed during the growth process, other elements were deposited in the vicinity of the vegetation by mechanisms such as erosion, and still others were deposited during and after formation of the coal by geologic processes. Most of the trace elements and minor constitutents are not combustible and remain in the ash. Typical ash contents of coal vary from 3 to 30 percent.

Table 2-1 describes the trace element levels in coals which have been categorized by region. As can be seen from the above, the elemental composition of a coal can vary immensely from region to region. The composition may also vary from coal type to coal type, and even somewhat within a single seam. Table 2-2 illustrates the total range of trace element concentrations found in the United States coals.

Coal Ranking

The amount of ash generated by a boiler is a function of the ash content of the coal. In general, higher grades of coal will have less ash than lower grades; however, there are exceptions. There are two primary coal classification systems, the American Society for Testing and Materials (ASTM) Coal Classification Index and the Specific Volatile Index. Figure 2-1 describes the ASTM Coal Classification Index which defines the various coal grades. Although there are various classifications indicated, the most important are:

- Anthracite
- Bituminous
- Subbituminous
- Lignite

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Table 2-1

AVERAGE TRACE-ELEMENT CONTENTS
FOR COALS FROM VARIOUS REGIONS
OF THE U. S. (ppm)

Element	Southwest and Western Region[a]	Eastern Interior Region[b]	Northern Great Plains Region[c]	Appalachian Region[d]
Boron	33	96	116	25
Beryllium	1.1	2.5	1.5	2.5
Cobalt	4.6	3.8	2.7	5.1
Chromium	13	20	7	13
Gallium	2.0	4.1	5.5	4.9
Germanium	5.9	13	1.6	5.8
Lanthanum	6.5	5.1	9.5	9.4
Molybdenum	3.1	4.3	1.7	3.5
Nickel	14	15	7.2	14
Tin	1.3	1.5	0.9	0.4
Titanium	250	450	591	350
Vanadium	18	35	16	21
Yttrium	7.4	7.7	13	14
Zinc	108	44	59	7.6

a = 48 coals.
b = 53 coals.
c = 51 coals.
d = 73 coals.

Source: Los Alamos Scientific Laboratory. Environmental Contamination from Trace Elements in Coal Preparation Wastes. Springfield, VA: National Technical Information Service, August 1976. PB 267 339.

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Table 2-2

RANGE OF TRACE ELEMENTS IN U. S. COALS

Element	Range (ppm)
Beryllium	0 - 31
Boron	1.2 - 356
Fluorine	10 - 295
Phosphorus	5 - 1430
Scandium	10 - 100
Vanadium	0 - 1281
Chromium	0 - 610
Manganese	6 - 181
Cobalt	0 - 43
Nickel	0.4 - 104
Copper	1.8 - 185
Gallium	0 - 61
Germanium	0 - 819
Arsenic	0.5 - 106
Selenium	0.4 - 8
Bromine	4 - 52
Yttrium	<0.1 - 59
Zirconium	8 - 133
Molybdenum	0 - 73
Cadmium	0.1 - 65
Tin	0 - 51
Antimony	0.2 - 9
Lanthanum	0 - 98
Mercury	0.01 - 1.6
Lead	4 - 218
Uranium	<10 - 1000

Source: Los Alamos Scientific Laboratory. Environmental Contamination from Trace Elements in Coal Preparation Wastes. Springfield, VA: National Technical Information Service, August 1976. PB 267 339.

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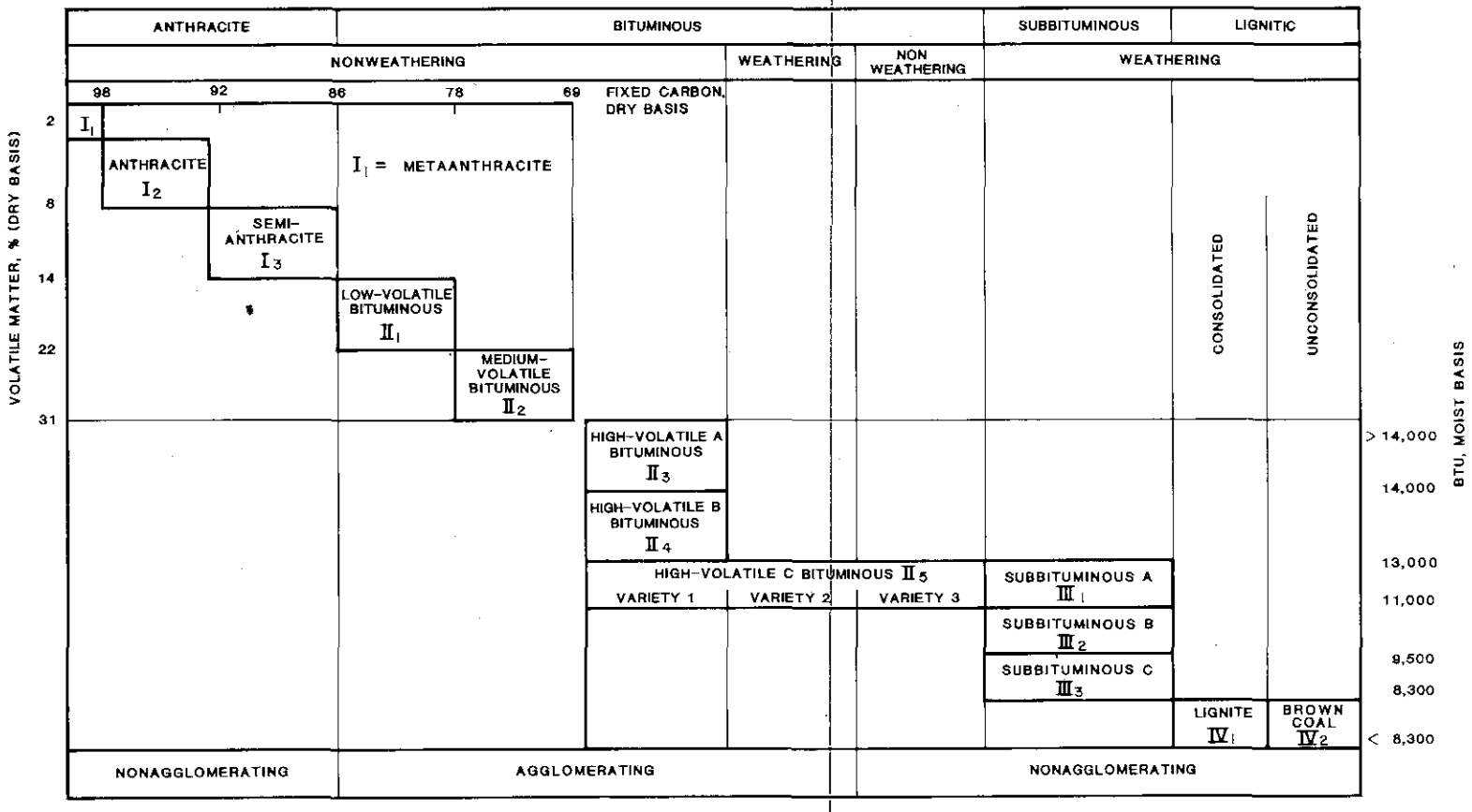

Figure 2-1. ASTM Classification of Coals by Rank

Source: S. S. Ray and F. G. Parker. Characterization of Ash from Coal-Fired Power Plants. Springfield, VA: National Technical Information Service, January 1977. EPA-600/7-77-010.

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An alternate approach, shown in Table 2-3, describes the Specific Volatile Index (SVI) which utilizes the percent volatile matter, fixed carbon, and heating value to develop a numerical value. The SVI is calculated as follows:

$$SVI = \frac{\text{Determined Btu/lb} - \text{\% Fixed Carbon} \times 145}{\text{\% Volatile Matter}}$$

Note that all values in the above equation are based on a dry, ash-free basis.

Proximate analyses, which include percent ash, volatile matter, fixed carbon, and Btu content, of various coals have been summarized and are included in Table 2-4.

COMBUSTION AND COLLECTION EQUIPMENT

Fly ash, bottom ash, and boiler slag are by-products of the combustion process necessary for the production of electrical energy at modern power stations which burn fossil fuels. Fly ash is the very fine, non-combustible residue which is carried off in the stack gases from the boiler units and collected by the flue gas cleaning equipment. It is composed of the noncombustible mineral matter present in coal and carbon in various forms due mainly to incomplete combustion. Bottom ash and boiler slag are the heavier ash particles which are collected at the bottom of the boiler. The difference between bottom ash and boiler slag will be discussed later.

Formation of Power Plant Ash

The formation of power plant ash takes place in the furnaces of the boilers which produce the steam used in generating electrical power. There are three categories of furnaces which are in use today at power stations:

- pulverized coal-fired furnaces,
- cyclone furnaces,
- stoker-fired furnaces.

Pulverized coal-fired units are widely used in the electrical power industry for installations where greater than 50,000 lb (22,700 kg) of steam per hour must be produced. They are especially prevalent in installations requiring a production of over 250,000 lb (113,500 kg) of steam per hour. The coal is dried and pulverized such that 80 percent of the particles are smaller than 0.074 mm. The pulverized coal is aerated and transferred to the burners, where combustion takes place. Oil or gas is used for ignition, and the coal is burned in conjunction with coal is burned in suspension. Oil or gas may also be burned in conjunction with coal for

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Table 2-3

SPECIFIC VOLATILE INDEX (SVI) CLASSIFICATION

SVI	Rank or Class	ASTM Rank	Typical Heat Value (Btu/lb)
Under 50	Woods	Wood	8,300 - 9,200
50 - 82	Peat	Peat	7,000
82 - 99	Brown coal (lignite)	Lignite	<8,300
99 -125	Black lignite	Lignite	<8,300
125 -160	Subbituminous	Subbituminous	8,300 - 13,000
160 -175	Bituminous C	Bituminous	11,000 - 13,000
175 -190	Bituminous B	Bituminous	13,000 - 14,000
190 -210	Bituminous A	Bitiminous	>14,000
210 -230	Super-bituminous (low volatile)	Bituminous	>14,000
230 -255	Semi-anthracite	Anthracite	>14,000
255 -300	Anthracites	Anthracite	>14,000

Source: Adapted from L. A. Munro. Chemistry in Engineering. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1964.

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Table 2-4

PROXIMATE ANALYSES OF SOME NORTH AMERICAN COALS

Rank and Source	Moisture (Percent) As Mined	Moisture (Percent) Dry Basis*	Ash (Percent) As Mined	Ash (Percent) Dry Basis*	Volatile Matter (Percent) As Mined	Volatile Matter (Percent) Dry Basis*	Fixed Carbon (Percent) As Mined	Fixed Carbon (Percent) Dry Basis*	Heat Value (Btu/lb) As Mined	Heat Value (Btu/lb) Dry Basis*
Lignite:										
Montana	37.5	0	6.1	9.8	26.8	42.9	29.6	47.3	6,580	10,528
N. Dakota	36.8	0	5.1	8.1	28.2	44.6	29.3	46.4	7,204	11,399
S. Dakota	39.2	0	8.4	13.8	24.7	40.6	27.7	45.6	6,307	10,373
Texas	33.7	0	7.3	11.0	29.3	44.2	29.7	44.8	7,348	11,083
Ontario	46.7	0	7.4	13.9	30.2	56.7	16.0	30.0	5,280	9,906
Saskatchewan	33.5	0	6.7	10.1	24.0	36.1	35.8	53.8	7,576	11,392
Subbituminous:										
Wyoming	23.4	0	3.6	4.7	33.6	43.9	39.4	51.4	9,382	12,248
Alberta	15.0	0	6.3	7.4	33.3	39.2	45.4	53.4	10,890	12,812
Bituminous:										
Utah	7.5	0	5.6	6.1	39.7	42.9	47.2	51.0	12,520	13,535
Illinois	7.9	0	9.1	9.9	40.7	44.2	42.3	45.9	11,527	12,515
British Columbia	6.7	0	11.3	12.1	34.8	37.3	47.2	50.6	11,690	12,529
Alberta	7.4	0	7.1	7.7	32.1	34.7	53.4	57.7	11,630	12,559
Pennsylvania	3.4	0	5.3	5.5	35.9	37.2	55.4	57.3	11,734	14,217
Alabama	3.9	0	7.5	7.8	35.1	36.5	53.5	55.7	13,343	13,884
Nova Scotia	4.0	0	8.4	8.8	32.2	33.5	55.4	57.7	13,340	13,896
Anthracite:										
Pennsylvania	3.2	0	11.5	11.9	9.3	9.6	76.0	78.5	13,043	13,474

*Calculated Value

Source: Adapted from L. A. Munro, Chemistry in Engineering. Englewood Cliffs, N. J.: Prentice Hall, Inc., 1964.

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flame stabilization during firing upsets. The flames may be as long as 100 feet (30 meters) to accomplish complete combustion. Ash can be removed from the bottom of the furnace in a molten state and quenched in water (boiler slag) or in a solid granular form (bottom ash). If the ash leaves the furnace in a molten state, the boiler is referred to as a wet-bottom boiler, and if the ash is removed in a solid, granular form, the boiler is called dry-bottom. The furnace is designed for a particular method of ash removal, depending upon the fusion temperature of the ash present in the coal and the variation of furnace temperature with boiler load. Ash fusion temperatures below 1800° to 2200°F (1000° to 1200°C) favor wet-bottom removal systems.

Approximately 80 percent of the ash produced in pulverized coal-fired units with dry-bottom removal systems exits from the furnace in the flue gas stream as fly ash, leaving only 20 percent of the ash to form bottom ash. Typically, 65 percent of this fly ash is finer than 0.010 mm. For units with a wet-bottom removal system, the percentage of fly ash produced drops to about 50 percent and the quantity of ash forming boiler slag increases accordingly.

Cyclone furnaces use crushed coal with a diameter of less than 1/2 inch (12.7 mm) as fuel and are comparable in steam generation capacity to pulverized coal-fired furnaces. The coal is burned by continuous swirling in a high-heat-intensity zone. Between 80 to 85 percent of the ash melts and is tapped from the furnace as boiler slag, leaving 15 to 20 percent of the ash to exit in the gas stream as fly ash. Approximately 90 percent of the fly ash which leaves the furnace in the stack gases is finer than 0.010 mm.

Stoker-fired furnaces can be used to fire boilers which generate from 10,000 to 250,000 lb (4,540 to 113,500 kg) of steam per hour. Stoker-fired boilers are practical only for power plants generating less than 40 MW of electricity. The stoker-fired units have a system which mechanically feeds the coal into the furnace, provides the appropriate quantity of air for combustion, and then mechanically removes the unburned refuse. There are three types of stokers which are used:

- underfeed stokers,
- traveling or chain-grate stokers,
- spreader stokers.

The underfeed stoker is most suitable for use with coking coals; the traveling or chain-grate stoker is used primarily for those furnaces which burn anthracite or

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Middle Western bituminous coals; and spreader stokers are used with a variety of coals.

The fly ash which is produced by stoker-fired units is coarser than the fly ash produced by pulverized coal-fired units or cyclone furnaces. Underfeed stokers and traveling grate stokers will produce 10 to 20 percent fly ash with the remainder of the ash being collected as bottom ash. Of the fly ash collected, only 5 percent will be less than .010 mm. Generally, 15 to 55 percent of the total ash produced by spreader stokers is fly ash and 10 to 45 percent of this fly ash is less than 0.010 mm.

Fly Ash Collection

There are various methods for collecting fly ash, each with its own characteristics and efficiencies. In general, currently available particulate control equipment can be classified as follows:

- wet scrubbers,
- mechanical collectors,
- fabric filters,
- electrostatic precipitators.

There are various advantages and disadvantages to the use and/or applicability of a particular type or series of particulate control devices. In general, the decision is a matter of balancing the required collection efficiency versus the overall cost of the system. Table 2-5 indicates various operating parameters for the most common particulate collectors.

One specific effect which the type of particulate control equipment has on the fly ash collected is the grain-size distribution of the collected ash. In general, the fly ash from an electrostatic precipitator or venturi scrubber will have a similar gradation, whereas fly ashes from a cyclone will have a coarser gradation due to the respective collection efficiencies.

If the fly ash is removed from the flue gas stream by a wet collector, it will be sluiced directly to a pond for dewatering or disposal. If the fly ash has been collected by mechanical collectors, fabric filters or electrostatic precipitators, it must be transported to either a temporary storage silo or the ash sluicing area. Ash transport is described in Section 5.

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Table 2-5

SEVERAL OPERATING CHARACTERISTICS OF PARTICULATE COLLECTORS

General Class	Specific Type	Typical Capacity	Pressure Loss (in. Water)[a]	Power Reqd, ($W/ft^3/min$)[b]	Overall Efficiency (%)	Fractional Efficiency in Percent For Various Size Ranges in Microns				
						0-5	5-10	10-20	20-44	>44
Mechanical collectors	Settling chamber	15-25 ft^3/min per ft^3 casing volume	0.2-0.5 (0.5-1.3)	0.03-0.10 (1-4)	-	-	-	-	-	-
	Baffle	1000-3500 ft^3/min per ft^2 of inlet area	0.5 (1.3)		60	7.5	22	43	80	90
	Conventional cyclone				65	12	35	57	82	91
	High-efficiency cyclones	2500-3500 ft^3/min per ft^2 of inlet area	3-5 (7.5-12.5)	0.5-1.0 (15-35)	95	40	79	92	95	97
Fabric filters	Automatic	1-6 ft^3/min per ft^2 of fabric area	4-6 (10-15)	1.0-1.3 (35-45)	99+	99.5	100	100	100	100
Wet scrubbers	Impingement baffle	400-600 ft^3/min per ft^2 of baffle area	2-5 (5-13)	0.2-1.0 (7-35)	-	-	-	-	-	-
	Packed tower	500-700 ft^3/min per ft^2 of bed cross-sectional area	6-8 (15-20)							
	Venturi	6000-30,000 ft^3/min per ft^2 of throat area	10-50 (25-125)	4-12 (140-425)	99+	99	99	99.5	100	100
Electrostatic precipitators	Dry, single-field	2-8 ft^3/min per ft^2 of electrode collection area	0.2-0.5 (0.5-1.3)	0.4-1.0 (15-35)	97	72	95	97	99+	100
	Wet (charged-drop scrubber)	5-15 ft^3/min per ft^2 of electrode collection area	0.5-0.7 (1.3-1.8)	0.3-0.5 (10-15)	-	-	-	-	-	-

[a] Values in parentheses under "pressure loss" are mbars.

[b] Values in parentheses under "power required" are in $W/m^3/min$.

Source: Adapted from K. Wark and C. F. Warner. Air Pollution, its Origin and Control. New York, New York: IEP a Dun-Donnelley Publisher, 1976.

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Bottom Ash/Boiler Slag Collection

In dry-bottom boilers, the bottom of the fire box has an open grate construction. The heavy ash particles (bottom ash) fall through this grate into a water filled hopper. Wet-bottom boilers and cyclone furnaces have a solid base at the bottom of the fire box. In the base is an orifice which is opened to allow the molten ash (boiler slag) to flow into a water filled hopper. The ash solidifies upon quenching and then is crushed, if necessary, to break up any large pieces of ash and aid in the handling process.

The bottom ash/boiler slag which has been collected in the hopper is typically sluiced to either a settling pond or a dewatering bin. However, mechanical systems are now on the market which are capable of removing the bottom ash, in a dewatered state, from the boiler bottom. The settling pond can be either a temporary holding facility or a final disposal site. If or disposed of at a dry landfill site, it is removed from the pond and stacked to allow the water to drain prior to shipment. In many cases when the bottom ash/boiler slag has a commercial value, it is sluiced to a dewatering bin. This type of storage structure allows for a much more rapid dewatering of the ash and facilitates the loading of the ash for transport.

CHEMICAL PROPERTIES OF POWER PLANT ASH

Fly Ash

Fly ash is comprised of very fine particles, the majority are glassy spheres, scoria, iron rich fractions, crystalline matter, and carbon. Due to its size and shape, the characteristics of fly ash are that of a high surface area to volume ratio solid that has agglomerated materials on its surface. In general, the composition of the spherical portion of the fly ash is somewhat immune to dissolution due to its glassy structure. The nature of this spherical portion is quite similar to glass, both in elemental composition and leaching properties, and as such is relatively inert. However, on the surface of the spheres exists either easily exchangeable or adsorbed molecules which, when in the presence of a liquid, become dissolved. It is this mechanism, some researchers believe, which ultimately produces leachate (1). Some of the very minute spheres may also dissolve into solution and contribute to the leachate. The elemental composition of the structure and surface material is then a function of not only the feed coal, but also the combustion sequence and method of collection.

Fly ash contains large quantities of silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3), and smaller quantities of various other oxides and alkalies. The range of

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these major chemical components, relative to coal rank, in fly ashes is illustrated in Table 2-6. Currently studies are in process to study the feasibility of using such processes as: acid leach, lime-sinter, lime-soda sinter and sinter-leach processes (calsinter and salt-soda sinter) for the recovery of alumina, iron, titanium, silica and other trace minerals present in these ashes. Table 2-7 presents data concerning the average trace element contents of ash from U.S. coals of various ranks. A review of Table 2-7 provides a rapid indication of the possibilities present in mineral recovery from ashes. If an economically practical process can be developed, the utility industry will have a valuable mineral resource which can be sold to provide income. At this time, these processes have not been economically justified. Currently, a one ton per hour metal extraction unit is proposed at Lawrenceburg, Tennessee, utilizing a patented process which is to be funded by TVA, DOE, and other sources. It must be emphasized that this is a pilot unit, and may not prove to be economical.

Carbon can also be present in various amounts. The carbon content is dependent upon the efficiency of the particular boiler unit and the fineness to which the coal is pulverized. Older boilers, stokers, etc., tend to produce higher carbon fly ash than the new, more efficient units. In this context, carbon is considered a contaminant in the ash, particularly if the ash is to be utilized.

Bottom Ash/Boiler Slag

For any particular type of coal, the chemical composition of the bottom ash or boiler slag derived from this coal will be similar to, but may have a lower carbon content than, the fly ash which is derived. Table 2-8 shows the chemical composition of five West Virginia bootom ashes and boiler slags from bituminous coal. Bottom ash consists of angular particles with a porous surface texture which are normally gray to black in color. Boiler slag is composed of black angular particles having a glassy appearance.

Trace Element Partitioning

Studies of trace elements and their distributions in the ash have shown that partitioning of the various elements occurs due to the combustion process (2). In addition to the enrichment in trace element content in the ash relative to that of the coal, the ratio of trace element concentrations also varies within the ash. As a result of this phenomenon, the trace elements can be divided into three categories:

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Table 2-6

VARIATIONS IN COAL ASH COMPOSITION WITH RANK

	Rank			
	Anthracite	Butuminous	Subbituminous	Lignite
% SiO_2	48 - 68	7 - 68	17 - 58	6 - 40
% Al_2O_3	25 - 44	4 - 39	4 - 35	4 - 26
%Fe_2O_3	2 - 10	2 - 44	3 - 19	1 - 34
%TiO_2	1.0 - 2	0.5 - 4	0.6 - 2	0.0 - 0.8
% CaO	0.2 - 4	0.7 - 36	2.2 - 52	12.4 - 52
% MgO	0.2 - 1	0.1 - 4	0.5 - 8	2.8 - 14
% Na_2O	-	0.2 - 3	-	0.2 - 28
% K_2O	-	0.2 - 4	-	0.1 - 1.3
% SO_3	0.1 - 1	0.1 - 32	3.0 - 16	8.3 - 32
% Ash	4 - 19	3 - 32	3 - 16	4 - 19

Source: Adapted from S. S. Ray and F. G. Parker. Characterization of Ash From Coal-Fired Power Plants. Springfield, VA: National Technical Information Service, January 1977. EPA-600/7-77-010.

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Table 2-7

AVERAGE TRACE-ELEMENT CONTENTS
OF THE ASH FROM U. S. COALS OF VARIOUS RANK (ppm)

Element	Anthracite	Low Volatile Bituminous	Medium Volatile Bituminous	High Volatile Bituminous	Lignite and Subbituminous
Silver	<1	<1	<1	<1	<1
Boron	90	123	218	770	1,010
Barium	866	740	896	1,253	5,027
Beryllium	9	16	13	17	6
Cobalt	81	172	105	64	45
Chromium	304	221	169	193	54
Copper	405	379	313	293	655
Gallium	42	41	--	40	23
Germanium	<20	<20	--	--	--
Lanthanum	142	110	83	111	62
Manganese	270	280	1,432	120	688
Nickel	220	141	263	154	129
Lead	81	89	96	183	60
Scandium	61	50	56	32	18
Tin	962	92	75	171	156
Strontium	177	818	668	1,987	4,660
Vanadium	248	278	390	249	125
Yttrium	106	152	151	102	51
Ytterbium	8	10	9	10	4
Zinc	--	231	195	310	--
Zirconium	688	458	326	411	245

The data in this table was determined by using atomic absorption analysis on coals which were ashed in air at 1100°F (600°C). The number of coal samples which were tested varied with the rank of the coal. A total of 57 coal samples were tested. In addition to the variations in trace element content with rank indicated, considerable variation in samples within any particular rank can also be expected.

Source: Los Alamos Scientific Laboratory. Environmental Contamination from Trace Elements in Coal Preparation Wastes. Springfield, VA: National Technical Information Service, August 1976. PB 267 339.

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Table 2-8

CHEMICAL ANALYSIS OF FIVE BOTTOM ASHES OR BOILER SLAGS

Component	Percentage of Total Composition				
	Boiler Slag 1	Boiler Slag 2	Boiler Slag 3	Bottom Ash 1	Bottom Ash 2
Silica	48.9	47.1	53.6	53.6	45.9
Alumina	21.9	28.3	22.7	28.3	25.1
Iron Oxide	14.3	10.7	10.3	5.8	14.3
Calcium Oxide	1.4	0.4	1.4	0.4	1.4
Magnesium Oxide	5.2	5.2	5.2	5.2	5.2
Sodium Oxide	0.7	0.8	1.2	1.0	0.7
Potassium Oxide	0.1	0.4	0.1	0.3	0.3
Sulfur Trioxide	-	-	-	-	-
Undetermined	7.5	7.1	5.5	6.4	7.1

Source: R. K. Seals, L. K. Moulton, and B. E. Ruth. "Bottom Ash: An Engineering Material." Journal of the Soil Mechanics and Foundations Division, ASCE, April 1972, pp. 311-325.

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- elements concentrating approximately equally in the bottom ash and fly ash,
- elements preferentially concentrated in the fly ash,
- elements tending to be discharged to the atmosphere as vapors.

Table 2-9 presents the breakdown of trace elements into each of these categories as determined in one study.

Pozzolanic Activity

Fly ash is an artifical pozzolan, i.e., a siliceous or alumino-siliceous material which is not cementitious in itself, but which in finely divided form and in the presence of moisture reacts with alkali and alkaline earth products to produce cementitious products. However, there is currently no quick and reliable test for predicting the degree of pozzolanic activity which a particular fly ash will possess (3).

A large percentage of the components in fly ash are in the form of a glass called mullite ($3\ Al_2O_3 \cdot 2\ SiO_2$). When lime and water are present with the mullite, the glass experiences an alkali attack which results in the creation of calcium silicate hydrates and calcium alumino-silicate hydrates, similar to the primary cementitious agents formed by the hydration of Portland cement. Some fly ashes contain a sufficient amount of free lime, which reacts with other components of the fly ash upon the addition of water to produce a cementitious compound. When this reaction occurs, the fly ash is referred to as self-hardening. If a fly ash has this self-hardening capability, then some of its physical and engineering properties, i.e., shear strength, compressibility, permeability, and frost susceptibility, will be affected. The shear strength will increase with time and the other three parameters will decrease.

Leachate

Leachate from ash disposal sites is of concern due to the possibility that the heavy metals and ionic complexes, such as SO_4, present in the ash may enter the groundwater system and comtaminate present or future drinking water sources. For this reason, a disposal site should be designed in such a way as to minimize this effect. Evidence is still inconclusive as to the degree of hazard of the ash materials. EPA, recognizing that coal combustion products are of relatively low concern, has defined coal ashes as being non-hazardous while they conduct a site monitoring and evaluation program, which is designed to assess the potential

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Table 2-9

PARTITION OF ELEMENTS BY THEIR TENDENCIES FOR DISTRIBUTION IN COAL COMBUSTION RESIDUES

Group I

Elements Concentrated Approximately Equally in Bottom Ash and Fly Ash

Al	Ce	Fe	La	Rb	Sm	Th
Ba	Co	Hf	Mg	Sc	Sr	Ti
Ca	Eu	K	Mn	Si	Ta	

Group II

Elements Preferentially Concentrated in the Fly Ash

As	Ga	Sb
Cd	Mo	S
Cu	Pb	Zn

Group III

Elements Tending to be Discharged to Atmosphere as Vapors

Hg	Br	Cl

Source: S. S. Ray and F. G. Parker. Characterization of Ash From Coal-Fired Power Plants. Springfield, VA: National Technical Information Service, January 1977. EPA-600/7-77-010.

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hazards associated with ash disposal. Available control technologies will be evaluated as a part of the program.

The water soluble content of fly ash ranges from very little to several percent. The principal ions contained in the leachate are calcium and sulfate, with smaller quantities of magnesium, sodium, potassium, and silicate ions present. Free lime (CaO) accounts for part of the soluble calcium. The soluble sulfate is approximately half the total sulfate (SO_4) present in the fly ash. Many of the earlier studies of fly ash leachate characterized it as being alkaline in nature with a pH value ranging from 6.2 to 11.5. Recent reports have shown, however, that some bituminous fly ashes are acidic. The pH of the leachate is believed to be controlled by the ratio of leachable lime to iron present.

The prediction of ash leachate quality is not possible at this time. In general, the quality of a leachate is governed by the physical-chemical characteristics of the ash and the soil-water matrix through which the leachate flows. To estimate the ~~leachate quality at any point, one must know the~~ laboratory leachate quality and the specific attenuation-translocation factors of the soil-ash system.

To best estimate the leachate characteristics of ash, the actual mechanism of leachate generation must be reproduced. Thus, the existing methods of lab leachate formation are based on the combination of water and ash, a specific contact period and degree of agitation, separation of ash and water, and analysis of the water for trace elements. However, there are many methods available to provide the resultant liquid. The variety of methods are necessary due to the variability of conditions which affect leachate production. In addition, some tests were devised for short-term analysis (shake test) versus long-term analysis (column leaching). Although the column leaching test is often assumed to be a more accurate representation of ash leachate generation under field conditions, the time required for this method of analysis may be on the order of years. Therefore, short-term tests were devised to attempt to rapidly predict the long-term leachate production.

Currently, two methods of leachate analysis are proposed as being standard. These methods are the ASTM and the EPA methods. The following is a brief description of these methods:

- ASTM Method - The ASTM has published Proposed Methods for Leaching of Waste Materials under the jurisdiction of Committee D-19 on Water. The ASTM leach test, which involves either a water shake extraction (Method A) or an acid shake extraction (Method B), involves the addition of approximately

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1.54 lb (700 g)* as received sample and four times by weight of Type IV Regent Water (prepared by either distillation, ion exchange, reverse osmosis, electrodialysis, or some combination of the above). This mixture is then agitated for 48 hours at 68° ± 4°F (20° ± 2°C). The resultant mixture is then separated into its aqueous and non-aqueous phases by decantation, centrifugation, or filtration. The resultant filtrate is then analyzed by appropriate methods. This method also includes an alternate sodium acetate buffer solution (pH 4.5 ± 1) for the extraction (4).

- EPA Extraction Procedure (EP) - The EP test, consists of adding coal ash to distilled, deionized water [at a ratio of 1 (fly ash) to 16 (water) by weight], then adjusting the solution pH to 5 with 0.5N Acetic Acid until a maximum of 3.83 pints of acid per pound (4 ml of acid per gram)* of solid has been added. If after adding 3.83 pints of acid per pound (4 ml of acid per gram) of solid the pH is still greater than 5, the 24-hour extraction is completed at that higher pH. This procedure is explained in detail in the May 19, 1980, Federal Register (5).

Tables 2-10 and 2-11 contain a summary of the solids analyses and actual pond discharge analyses, respectively, for fly ash and bottom ash which have been reported in recent publications. Most of the inorganic compounds shown in these tables were chosen for study because they appear in the US EPA National Interim Drinking Water Standards.

The American Society for Testing and Materials (ASTM) recently undertook a study of the proposed ASTM and EPA extraction procedures to determine if these procedures were a satisfactory means of estimating the leachate from a solid waste. As a part of this study, three samples of bituminous coal fly ash and one sample each of lignite and subbutiminous coal fly ash, bituminous coal bottom ash, and bituminous coal boiler slag were sent to laboratories across the U.S., where they were subjected to the various extraction procedures. The range of values from these analyses is presented in Table 2-12. Although various extraction procedures were utilized in this study only the EPA extraction procedure is presented due to its regulatory significance. The results of the analyses presented in Table 2-12 are based on a limited size sample and, therefore, no valid conclusions can be drawn about the quality of the leachate from ash. However, one fact is evident from this data: the variation in test results among the laboratories performing the same extraction procedure on the same waste sample can be great.

*The quantities are presented in both English and metric units for consistency within the text. The quantities as they are presented in the proposed test methods are given only in metric units.

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Table 2-10

ASH SOLIDS ANALYSES (in ppm)

Substance	Fly Ash Range	Fly Ash Avg.	Fly Ash Data Pts.
Arsenic	6 - 1,200	177	23
Barium	100 - 1,074	520.7	6
Cadmium	0.29 - 51	10	17
Chloride	-	1,000	1
Chromium	15 - 900	218.6	18
Copper	16 - 400	171	17
Fluoride	120 - 671	396	2
Iron	49,000 - 235,000	124,125	8
Lead	11 - 800	210.7	19
Manganese	100 - 1,000	389	16
Nitrate	-	85.6	1
Selenium	6.9 - 760	145	14
Silver	-	3	1
Sulfate	-	5,430	1
Zinc	50 - 9,000	1,314.3	20

Substance	Bottom Ash Range	Bottom Ash Avg.	Bottom Ash Data Pts.
Arsenic	0.5 - 18	7	14
Barium	300 - 731	481.6	7
Cadmium	0.5 - 3	1.25	12
Chloride	-	-	-
Chromium	15 - 895	213	13
Copper	12 - 300	87.2	12
Fluoride	-	10.6	1
Iron	66,000 - 211,900	116,100	9
Lead	3 - 30	13.2	11
Manganese	100 - 1,000	438.7	15
Nitrate	-	16	1
Selenium	0.08 - 20	5.45	11
Silver	-	675	1
Sulfate	-	675	1
Zinc	20 - 400	142	12

Source: D. W. Weeter and M. P. Bahor. Technical Aspects of the Resource Conservation and Recovery Act Upon Coal Combustion and Conversion Systems. Oak Ridge National Laboratory, February 1979. ORNL/OEPA-10.

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Table 2-11

ANALYSES OF ASH POND DISCHARGES (in ppm)

Substance	Fly Ash Pond Range	Avg.	Data Pts.
Arsenic	0.01 - 1.1	0.38	3
Barium	0.2 - 0.3	0.25	2
Cadmium	0.001 - 0.037	0.019	2
Chloride	6 - 7	6.5	2
Chromium	0.02 - 0.067	0.044	2
Copper	0.02 - 2.4	0.91	3
Cyanide	-	-	-
Iron	1.44 - 630	211.12	3
Lead	0.01 - 0.91	0.33	3
Manganese	0.13 - 0.48	0.31	2
Selenium	0.002 - 0.33	0.12	3
Silver	-	-	-
Sulfate	209 - 358	283.5	2
Zinc	0.06 - 2.2	1.26	3

Substance	Bottom Ash Pond Range	Avg.	Data Pts.
Arsenic	0.006 - 0.018	0.012	2
Barium	0.1 - 0.2	0.15	2
Cadmium	0.001 - 0.003	0.002	2
Chloride	7 - 8	7.5	2
Chromium	0.009 - 0.01	0.095	2
Copper	0.041 - 0.065	0.053	2
Cyanide	-	-	-
Iron	5.29 - 5.98	5.64	2
Lead	0.02 - 0.02	0.02	2
Manganese	0.16 - 0.58	0.37	2
Selenium	0.002 - 0.011	0.007	2
Silver	-	-	-
Sulfate	49 - 139	94	2
Zinc	0.09 - 0.14	0.12	2

Substance	Combined Ash Pond Range	Avg.	Data Pts.
Arsenic	0.005 - 0.038	0.038	9
Barium	0.1 - 0.2	0.19	10
Cadmium	0.001 - 0.005	0.002	6
Chloride	3 - 14	7.2	10
Chromium	0.004 - 0.043	0.015	10
Copper	0.01 - 0.08	0.042	10
Cyanide	0.01 - 0.05	0.03	3
Iron	0.23 - 2.3	0.8	10
Lead	0.01 - 0.025	0.014	10
Manganese	0.01 - 0.39	0.09	9
Selenium	0.003 - 0.065	0.016	10
Silver	-	0.01	1
Sulfate	59 - 156	109.7	10
Zinc	0.03 - 0.12	0.053	10

Source: Same as Table 2-10.

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Table 2-12
REPORTS OF THE EP LEACHATE TEST ON COAL ASH

	BITUMINOUS COAL					SUBBIT. COAL	LIGNITE COAL	EPA LIMIT	EPA HAZARDOUS WASTE NUMBER
	FLY ASH			BOTTOM ASH	BOILER SLAG	FLY ASH	FLY ASH		
	#1	#2	#3	#1	#1	#1	#1		
pH	4.87 TO 5.57	3.29 TO 4.90	4.15 TO 11.22	4.75 TO 5.30	3.60 TO 4.80	12.01 TO 13.30	4.95 TO 11.46	3 TO 12	–
CALCIUM (Ca)	36.6 TO 330.2	344 TO 950	75 TO 800	1.2 TO 47.0	1.0 TO 61.0	682 TO 1900	310 TO 1300	–	–
SILVER (Ag)	<0.01 TO 0.05	<0.01 TO 0.06	<0.01 TO 0.03	<0.01 TO 0.02	≤0.04	<0.01 TO 0.08	<0.01 TO 0.05	5	D011
ARSENIC (As)	<0.010 TO 2.046	<0.015 TO 1.110	<0.002 TO 0.150	0.002 TO 0.007	<0.010	0.003 TO 0.400	0.004 TO 1.800	5	D004
BARIUM (Ba)	≤0.5	0.01 TO 0.72	0.2 TO 0.4	<0.10 TO 0.50	0.01	0.4 TO 125.0	0.10 TO 1.98	100	D005
CADMIUM (Cd)	<0.01 TO 0.06	0.02 TO 0.21	<0.010 TO 0.034	<0.01 TO 0.02	0.002 TO 0.030	<0.010 TO 0.022	<0.01 TO 0.07	1	D006
CHROMIUM (Cr)	0.01 TO 0.39	0.06 TO 1.00	0.06 TO 0.30	<0.01 TO 0.02	0.006 TO 0.020	0.06 TO 1.30	0.031 TO 0.070	5	D007
MERCURY (Hg)	<0.001 TO 0.050	<0.0001 TO 0.0038	<0.0010 TO 0.0026	<0.0001 TO 0.0003	<0.005	<0.002 TO 0.003	<0.002	0.2	D009
LEAD (Pb)	<0.02 TO 0.70	<0.03 TO 0.17	<0.01 TO 0.30	<0.01 TO 0.10	<0.01 TO 0.30	<0.01 TO 0.20	<0.01 TO 0.40	5	D008
SELENIUM (Se)	0.10 TO 1.56	<0.02 TO 0.50	0.010 TO 1.000	<0.010 TO 0.016	<0.2	0.032 TO 0.300	0.0176 TO 0.6500	1	D010
NUMBER OF LABORATORIES PARTICIPATING	16	5	7	5	3	4	7	–	–

SOURCE: U.S. DEPARTMENT OF ENERGY AND ASTM FINAL REPORT, PHASE II COLLABORATIVE TEST PROGRAM: ANALYSIS OF SELECTED TRACE METALS IN LEACHATE FROM SELECTED FOSSIL ENERGY MATERIALS, JANUARY, 1980

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PHYSICAL ENGINEERING PROPERTIES

The physical and engineering properties of power plant ash which could be of concern when the ash is to be disposed of in a dry landfill site are:

- grain-size distribution,
- moisture content,
- density,
- shear strength,
- compressibility,
- permeability,
- capillarity,
- frost susceptibility.

Grain-Size Distribution

Grain-size distribution is important because many engineering parameters are related to the variation of particle sizes of the material. This distribution is generally presented in graphical form in a grain-size distribution curve. The particle size is plotted to a logarithmic scale on the horizontal axis, and the percent of particles smaller than a particular size is plotted to a linear scale on the vertical axis.

The characteristics of the grain-size distribution for a given material can be defined from the grain-size curve. A material having a steep curve, for example, has a very small range of particle sizes and is said to be uniformly-graded (sometimes referred to as being poorly-graded). A material having a flat curve is indicative of a well dispersed assortment of material particle sizes and the material is said to be well-graded. A well-graded material can be readily compacted to a dense condition, and will generally develop greater shear strength and lower permeability than uniformly-graded material.

As can be seen from Figure 2-2, fly ash is usually uniformly-graded material with particles primarily in the silt range (particle diameters between 0.005 mm and 0.074 mm). Figure 2-2 describes the entire spectrum of fly ashes including those from anthracite, bituminous, subbituminous and lignite coals. The grain-size distribution of the fly ash can be altered by blending it with the bottom ash or boiler slag.

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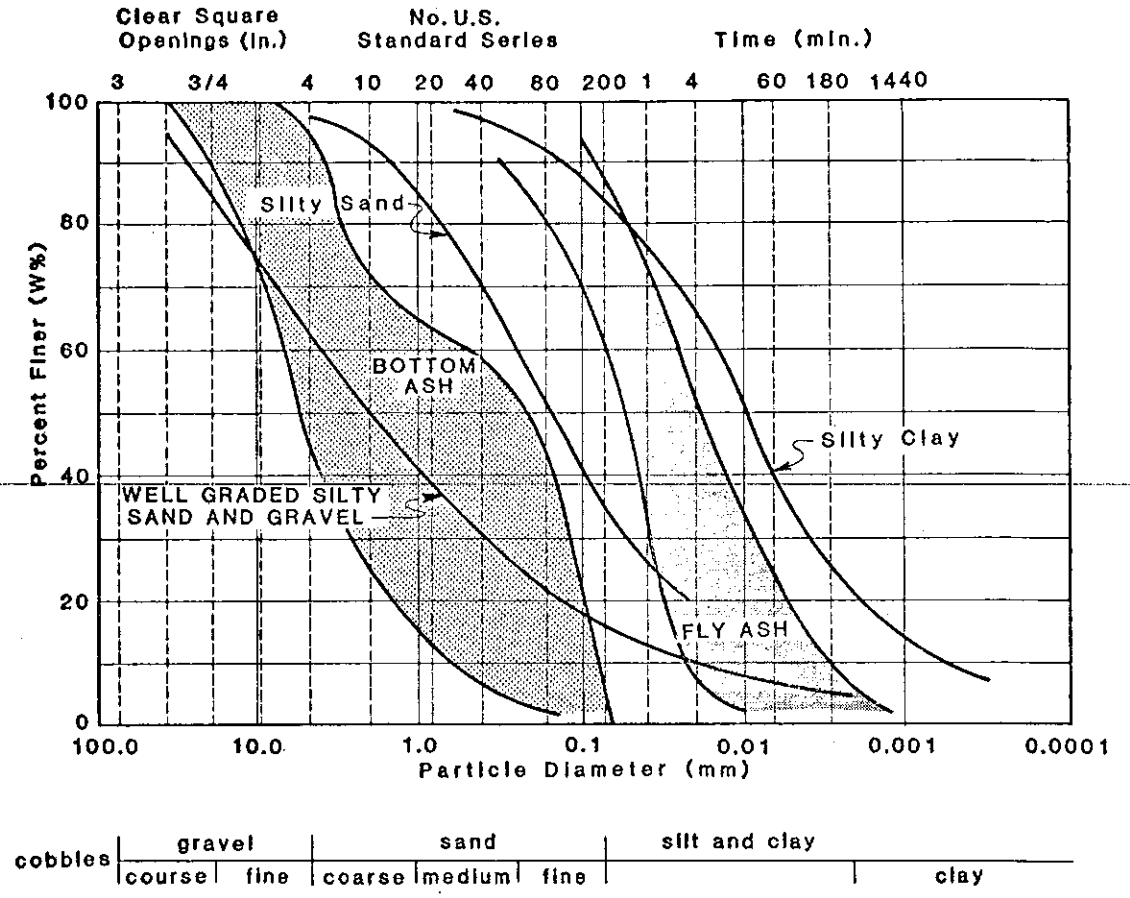

Figure 2-2. Range of Typical Ash Grain-Size Curves

Source: J.H. Faber and A.M. DiGiola, Jr. Use of Ash for Embankment Construction. Presented at the Transportation Research Board Annual Meeting, January, 1976 (2). and Seals et.al., 1972 (3).

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The particle size of fly ash ranges from 0.001 mm to 0.100 mm in diameter for the glassy spheres, with an average of 0.007 mm, and from 0.010 mm to 0.300 mm in diameter for the more angular carbon particles.

Figure 2-2 also indicates the range of grain-size distributions for bottom ash and boiler slag. As in the fly ash distribution the bottom ash curves are also representative of all available coal types. These two materials will have particles ranging in size from fine sand to fine gravel. Generally, the boiler slag will be more uniform in size than the bottom ash.

Moisture Content

The moisture content of an ash is a measure of the amount of water present in the voids in the ash. It is of interest because it determines both the weight and behavior of the ash. The weight of a quantity of ash is the sum of the weight of the solid ash particles as well as the weight of any water in the voids. Since the weight of the water can be a significant fraction of the total, and since the cost of handling and transporting ash can be weight dependent, the quantity of water included in the ash is an important consideration. The influence of moisture content on fly ash behavior can be equally important. A particular fly ash may be a dusty powder or a soupy mud, depending solely upon moisture content. Thus, moisture content will affect engineering properties such as compaction behavior and shear strength.

Moisture content is expressed as a percentage of the ash's dry weight and is determined by dividing the weight of the water in the voids by the weight of the ash when dry and then multiplying this quotient by 100. Due to this method of determination, it is quite possible to have moisture contents in excess of 100 percent. Two moisture contents are of importance to geotechnical engineers when determining the proper compaction procedures for ash to be placed in a landfill. They are the natural, or in-place, moisture content and the optimum moisture content. The optimum moisture content of an ash is discussed in the following section on density, since it is related to the maximum density obtained by compaction in the laboratory.

The in-place moisture content is a function of the deposition environment of the ash. It will principally be a function of the storage method prior to disposition in the landfill. The natural moisture content of an ash should be known, so that the quantity of water which must be added or removed to bring the ash to its optimum moisture content for compaction can be calculated, if the ash is to be

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compacted when placed in the landfill. Typical values of natural moisture content are 2 to 5 percent for silo-stored ash, and 50 to 100 percent for lagoon-stored ash.

Specific Gravity

Specific gravity is the ratio of the unit weight of the material to the unit weight of distilled water at a temperature of 39°F (4°C). The specific gravity for most soils ranges from 2.5 to 2.8. Fly ashes normally have a specific gravity which falls within the range of 2.1 to 2.9. The specific gravities of bottom ashes and boiler slags typically have a range from 2.3 to 3.0. In general, boiler slags will have higher specific gravities than bottom ashes.
Typical ranges of values are presented below:

SPECIFIC GRAVITY
TYPICAL RANGES OF VALUES

Coal-Type	Fly Ash	Bottom Ash
Bituminous	2.3 to 2.6	2.3 to 2.8
Subbituminous	2.1 to 2.6	2.3 to 2.8
Lignite	2.5 to 2.9	2.9 to 3.0

Density

Density, as defined for engineering purposes, is the weight per unit volume of material. The density of fly ash is important because it influences the permeability, stiffness, and strength of the ash which, in turn, will affect the settlement and stability of a fly ash landfill. As the density of a granular material increases, so does its strength.

A portion of the total volume of the ash is occupied by pore spaces, or voids, which can contain either air or water. If the pore spaces contain only air, then the density of the ash is referred to as the dry density. If all or part of the voids are filled with water, then the ash will have a wet density with a corresponding moisture content. If all the voids are filled with water, the ash is said to be in a saturated state.

Figure 2-3 presents ten fly ash moisture-density curves for Western Pennsylvania

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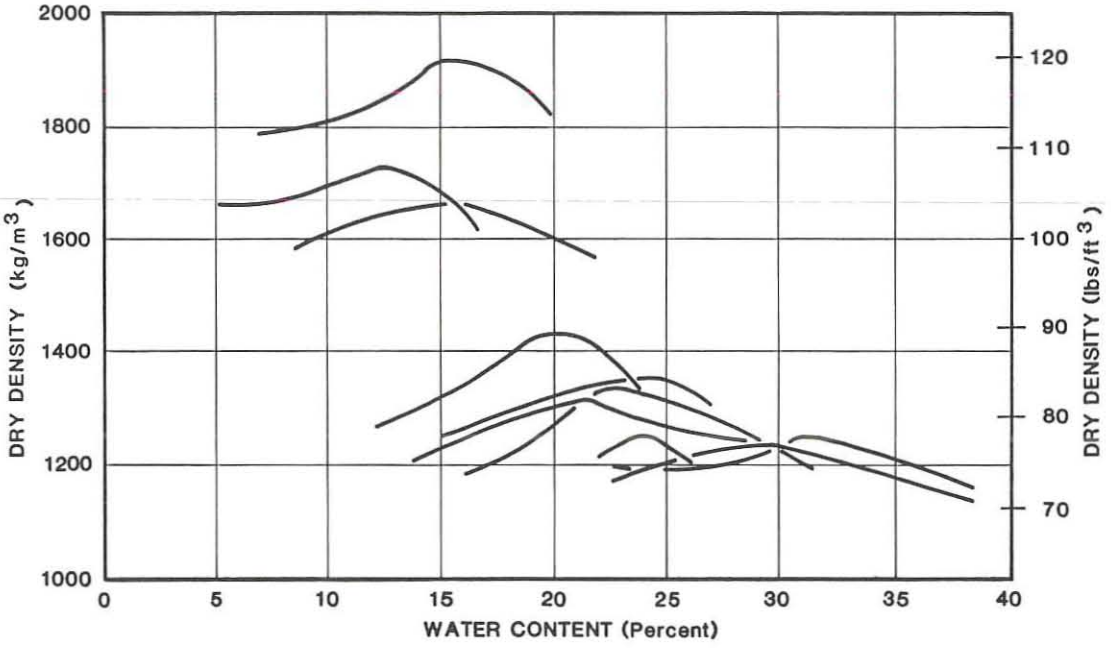

Figure 2-3. Moisture-Density Curves for Western Pennsylvania Bituminous Fly Ashes

Source: GAI Laboratory Data

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bituminous fly ashes. Figures 2-4 and 2-5 present moisture-density curves for Western United States seven lignite and subbituminous fly and bottom ashes. As can be seen from these curves, the maximum dry density, as determined by the Modified Proctor compaction test (ASTM Test Designation D1557-70), of fly ash can range from 75 to 120 pcf (1200 to 1934 kg/m^3) with corresponding optimum moisture contents of 30 to 10 percent. Typical ranges of optimum moisture contents and maximum dry densities are provided below:

OPTIMUM MOISTURE CONTENT
TYPICAL RANGES OF VALUES

Coal Type	Fly Ash	Bottom Ash
Bituminous	13 to 30%	14 to 26%
Subbituminous	14 to 20%	12 to 23%
Lignite	10 to 12%	14 to 25%

MAXIMUM DRY DENSITY* (PCF)
TYPICAL RANGES OF VALUES

Coal Type	Fly Ash	Bottom Ash
Bituminous	75-105	72-116
Subbituminous	70-102	65-76
Lignite	104-120	85-110

*As determined by the Modified Proctor Compaction Test (ASTM Test Designation D 1557-70).

Shear Strength

The shear strength of the fly ash which is placed in a landfill will determine the steepness of fill slopes which can be safely constructed and the magnitude of future loads which can be safely supported by the ash. Since the fly ash will seldom be loaded in tension or hydrostatic compression, shear strength is the primary strength parameter used in the design of fly ash landfills.

The shear strength of a soil is related to two engineering properties: cohesion and the angle of internal friction. Cohesion is a measure of the shear strength developed by the attraction of individual particles for one another. The angle of

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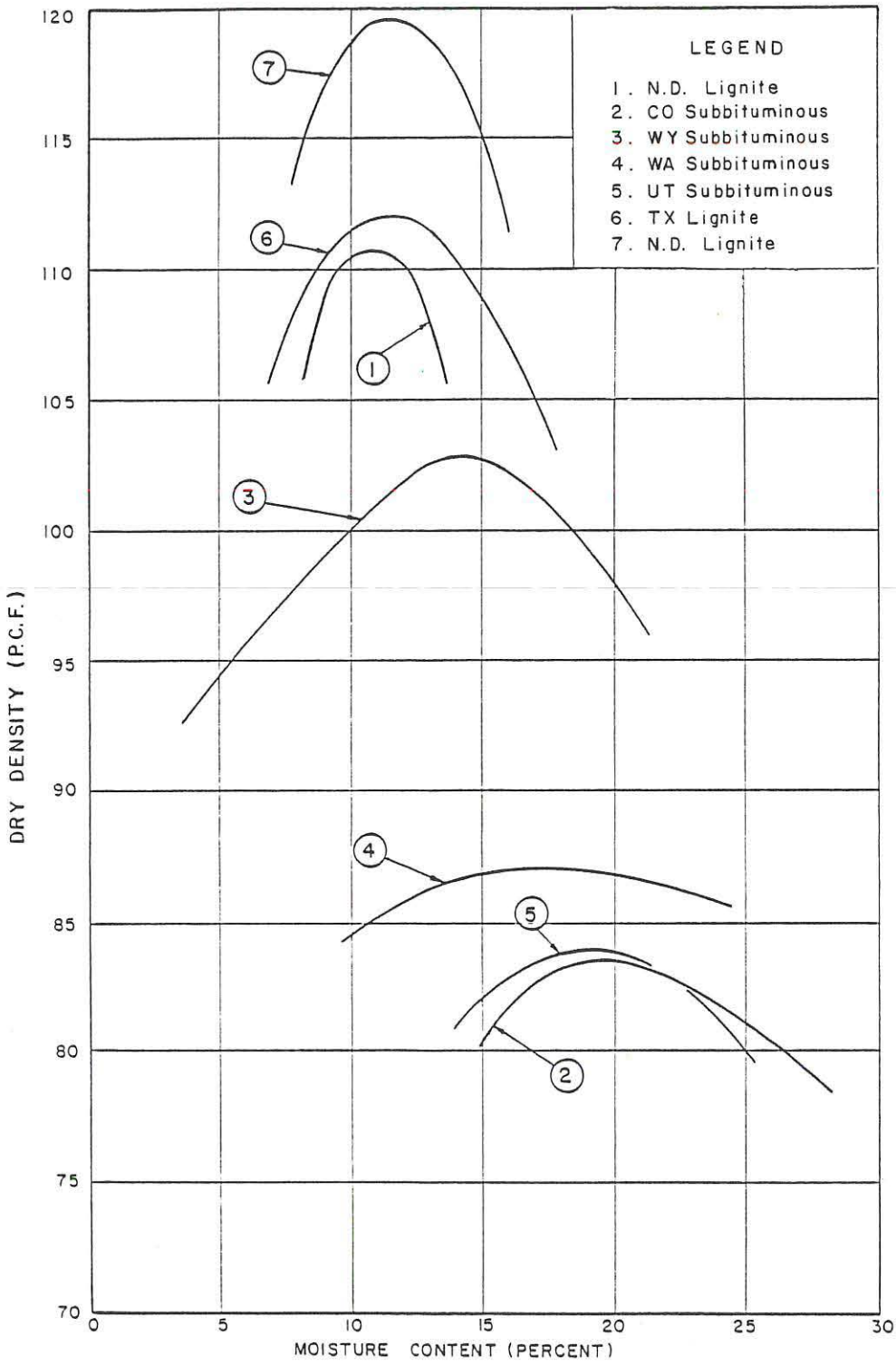

Figure 2-4. Moisture-Density Curves for Western United States Lignite and Subbituminous Fly Ash

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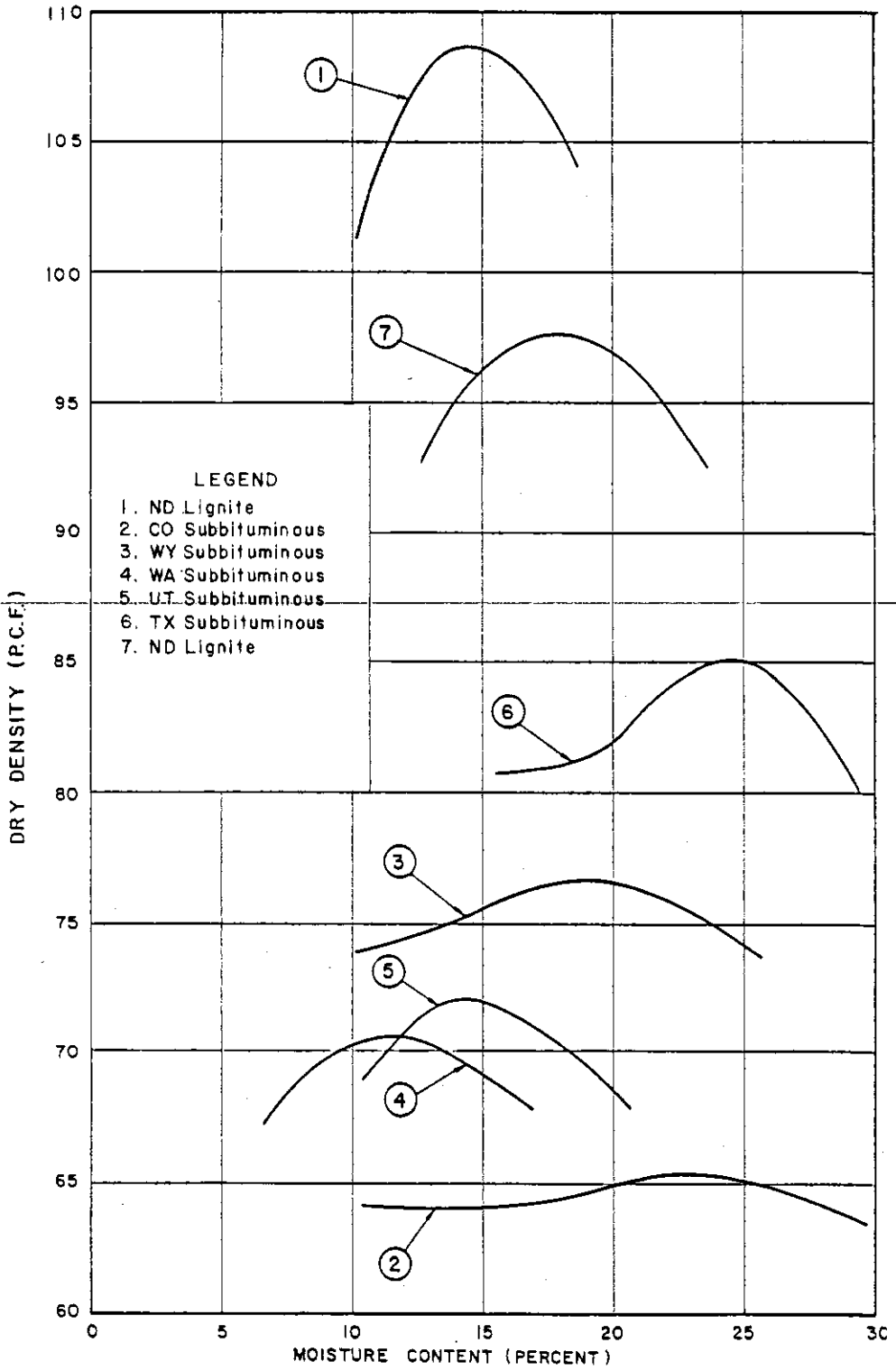

Figure 2-5. Moisture-Density Curves for Western United States Lignite and Subbituminous Bottom Ash

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internal friction is a measure of the frictional resistance between particles. The magnitude of the shear strength developed through interparticle friction is equal to the product of the normal force applied to the material and the tangent of the angle of internal friction.

Fly ashes which do not have self-hardening properties possess no cohesion; however, they may exhibit some apparent cohesion due to capillary forces produced by pore water. This apparent cohesion can be destroyed by complete drying or saturation. Fly ashes which self-harden develop a strength which is often referred to as cohesion; however, this strength more closely resembles the chemical bonding strength of cement than the cohesive strength of a soil. Typical unconfined compressive strength ranges of some self-hardening ashes are included below:

UNCONFINED COMPRESSIVE STRENGTH (PSF)
TYPICAL RANGES OF VALUES

Coal Type	0 Day Strength	7 Day Strength	28 Day Strength
Anthracite	400-1410	570-1690	900-2100
Bituminous	260-2100	320-2000	250-3230
Subbituminous	1800-2830	950-4000	1300-6500
Lignite	1300-3470	44,280-96,020	52,480-141,000

The angle of internal friction of bituminous fly ash varies with the degree of compaction and is generally in the range of 25° to 40°. As with fly ash, the shear strength of bottom ash and boiler slag will vary with the degree of compaction. The angle of internal friction for bottom ash and boiler slag in a loose condition can vary from 38° to 42.5° (6).

Compressibility

The compressibility of a fly ash fill determines the rate and magnitude of settlement of a structure which may be founded on the fill. Non-self-hardening fly ash behaves similar to a cohesive soil in terms of consolidation and settlement. The stress is initially shared by the soil structure and pore water upon application of a vertical pressure. The excess pore water pressure gradually decreases as the water is squeezed out of the pores, and as the pore water pressure decreases, the load is transferred to the fly ash structure, producing a volume change. Laboratory consolidation tests have indicated that compaction can significantly reduce the

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compressibility of fly ash. Typical ranges are presented below:

COMPRESSIBILITY*
TYPICAL VALUES

Bottom Ash	1.4
Fly Ash	1.8

*Percent of Original Height @ 50 psi (345k Pa)

The amount of settlement that a foundation will experience from the load it applies to a fly ash fill is proportional to the logarithm of the change in pressure caused by the foundation load and the Compression Index, Cc. The compression index for Western Pennsylvania bituminous fly ashes has been seen to range from 0.10 to 0.25 (7).

Permeability

A material is considered permeable if it has interconnected pores, cracks, or other passageways through which water or gas can flow. Clean gravels can have a coefficient of permeability as high as 3.12×10^{7} ft/yr (30 cm/sec) and clays can have a coefficient of permeability as low as 0.00104 ft/yr (10^{-9} cm/sec).

The coefficient of permeability applies to the flow of water and was developed as a convenient means of estimating the quantity of water which will seep through a mass of earth in a given time period. The permeability of a soil mass is a function of the viscosity of the water, the size and shape of the soil grains, the degree of compaction, and the number of discontinuities present in the soil mass. The range of permeabilities of coal ash compacted to its maximum dry density is reported as follows:

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PERMEABILITY (cm/sec)
TYPICAL RANGES OF VALUES

Coal Type	Fly Ash	Bottom Ash
Bituminous	10^{-4} to 10^{-7}	3×10^{-2} to 9×10^{-2}
Subbituminous	1×10^{-5} to 3×10^{-6}	1×10^{-3} to 6×10^{-3}
Lignite	9×10^{-6} to 1×10^{-7}	1×10^{-3} to 7×10^{-3}

The permeabilities of self-hardening ashes, from subbituminous and lignite coals, may decrease with time due to the chemical reactions occuring within the material. Typical permeability values relative to curing times for several self-hardening ashes are presented below:

PERMEABILITY CHANGES OF SELF-HARDENING ASHES
(ALL VALUES IN CM/SEC)

Coal Type	0 Day	7 Day	28 Day
Subbituminous	2.8×10^{-5}	5.2×10^{-6}	4.4×10^{-6}
	7.3×10^{-6}	3.0×10^{-6}	3.0×10^{-6}
	1.6×10^{-5}	1.9×10^{-5}	7.7×10^{-6}
	3.6×10^{-5}	2.6×10^{-5}	1.8×10^{-5}
Lignite	8.6×10^{-6}	7.9×10^{-7}	1.2×10^{-6}
	2.5×10^{-6}	4.8×10^{-7}	4.7×10^{-7}
	2.0×10^{-6}	1.4×10^{-7}	3.2×10^{-7}

Capillary Rise

Capillary rise is the physical phenomenon in which a liquid, such as water, is drawn into a tube of very small diameter due to the surface tension forces. Because of its grain-size distribution, this same activity will occur in fly ash. Capillary rise is of concern in the design of a fly ash fill because the fly ash can become saturated by groundwater which is drawn up into the ash by capillary action. If this occurs, the ash will lose some of its strength and the landfill could become unstable. To eliminate the problem of capillary rise, a drainage blanket is normally placed between the fly ash and the existing ground surface to intercept the groundwater before it can enter the fly ash.

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In one study, it was computed that the capillary rise in fly ash could range from 6 to 32 feet (1.8 to 9.6 m). Little if any information concerning the capillary rise which has occurred at existing sites has been published.

Frost Susceptibility

Materials with a grain-size distribution, such as fly ash, are generally susceptible to frost heave when exposed to freezing temperatures and a source of water. Frost heave in soils is caused by the freezing of the water in the soil pores. The magnitude of heave is greatly influenced by the flow of ground water by osmosis into the soil pores as the zone of freezing advances downward. The susceptibility of a soil to frost heave is a function of the tensile strength of the soil and its permeability. As the tensile strength increases and permeability decreases, the ability of the material to resist frost heave increases. For this reason, self-hardening fly ashes are less susceptible to the problems of frost heaving than are the non-self-hardening ashes. The only means of accurately determining if a particular fly ash will be frost susceptible is to perform laboratory tests under freezing conditions. Bottom ash and boiler slag have a low susceptibility to frost heave when well drained.

ASH TESTING MATRIX

The selection of an ash management program which will provide the least cost option to the utility is highly dependent on a number of factors. Of significant importance is a knowledge of the ash properties such that viable disposal/marketing scenarios may be developed. However, various ash properties are of importance to each disposal/utilization option and only upon review of those properties will the viable options be known. To this end, an ash testing matrix, shown in Figure 2-6, delineates those primary and secondary properties which must be considered and shows that each option may require additional analyses, etc. prior to initiation. However, the properties and analyses contained herein will provide that initial overview which will allow a logical selection of alternatives.

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			TEST METHOD			TRANSPORT SYSTEMS			UTILIZATION															DISPOSAL				
																								LANDFILL				
			ASTM	AASHTO	OTHER	IN-PLANT	OUT-OF-PLANT	STORAGE	BULK FILL	STRUCTURAL FILL	WASTEWATER TREATMENT	SOIL NEUTRALIZATION	STABILIZED BASE COURSE	AGGREGATE SUB-BASE	BITUMINOUS FILLER	MINERAL FILLER	UNDERDRAIN		POZZOLAN	READY MIX CONCRETE	MASS CONCRETE	CONCRETE PRODUCTS	GROUT	METAL EXTRACTION	COMPACTED	UNCOMPACTED	POND	OCEAN	
PHYSICAL PROPERTIES	SPECIFIC GRAVITY		D854-58*	T100-75		X	X	X	X	X	X		X	X	X	0			X	X			0	0	X	X	X	X	
	GRAIN SIZE DISTRIBUTION		D422-63*	T88-79I		X		X	X	X	X		X	X	X	X	X		X	X				0	X	X	X	X	
	MOISTURE CONTENT		D2216-71*			X	X	X	X	X	X		X	X	X				X	X					X	X			
	DENSITY	STANDARD (A)	D698-78*	T99-80I					X	X			X	X			0								X				
		MODIFIED (A)	D1557-78*	T180-74					X	X			X	X			0								X				
		RELATIVE	D2049-69*				X	X	0	0															0	0			
	SHEAR STRENGTH	UNCONFINED COMPRESSION	D2166-66*	T208-70									X						0	0	0	0	X						
		DIRECT SHEAR	3080-72*			0	0	0	0	0			0	0											0	0			
		TRIAXIAL SHEAR	D2435-70*	T216-80I		0	0	0	0	0			0	0											0	0			
	PERMEABILITY		D2434-68*	T215-70						0				X			X								X	X			
	CAPILLARY RISE							0	0	0															X	X			
	ABRASION	WATER	G6-77*				X																						
		AIR	D658			X	0		0	0																			
	TEMPERATURE					X		X																					
CHEMICAL PROPERTIES	CORROSION POTENTIAL					X	X	X	X	X	X	X					0				X	X	X		X	X	X	X	
	SELF HARDENING					X	X	X	0	0	X	X	X	0					X	X			0		0	0	0	0	
	REACTIVITY					X	X	X		0	0	0								X					0	0	0	0	
	POZZOLANIC ACTIVITY		C311-77*										0	0					X	X	X	X	X	X					
	LOSS ON IGNITION										0		X			X			X	X	X	X	X	X	X	X	X	X	
	ELEMENTAL ANALYSIS	SiO_2	D2795-69													X			X	X	X	X	X	X	X	X	X	X	
		Al_2O_3	D2795-69													X			X	X	X	X	X	X	X	X	X	X	
		Fe_2O_3	D2795-69								X					X			X	X	X	X	X	X	X	X	X	X	
		CaO	D2795-69								X	X	X			X			X	X	X	X	X	X	X	X	X	X	
		MgO	D2795-59								X	X				X			X	X	X	X	X	X	X	X	X	X	
	LEACHATE ANALYSIS				EPA, EP		0	0	0	0	X	X	X	X			0							X	X	X	X	X	

* JOINT ANSI TEST METHOD

(A) USE OF EITHER STANDARD OR MODIFIED MOISTURE DENSITY RELATIONSHIP IS ACCEPTABLE IN MOST INSTANCES

X REQUIRED ANALYSIS FOR THE SPECIFIED PURPOSE

0 OFTEN TESTED, BUT NOT ABSOLUTELY FOR THE SPECIFIED PURPOSE

Figure 2-6. Coal Ash Testing Matrix

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3. R. C. Joshi. "Source of Pozzolanic Activity in Fly Ashes: A Critical Review." In Proceedings of the Fifth International Ash Utilization Symposium, Atlanta, Georgia, February 1979.

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6. R. K. Seals, L. K. Moulton, and B. E. Ruth. "Bottom Ash: An Engineering Material" Journal of the Mechanics and Foundation Division, ASCE, April 1972, pp. 311-325.

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Section 3

CURRENT DISPOSAL PHILOSOPHIES

INTRODUCTION

In selecting a new coal ash disposal system, it is helpful to look at existing ash disposal systems and review, if possible, the rationale involved in the selection of their location, ash handling method, and overall management practices. This section presents an overview of current utility ash disposal systems, summarizes state and regional ash disposal practices, and discusses ash disposal trends.

While most coal ash is currently handled in wet systems, the national trend is away from wet disposal systems toward dry handling methods. A number of factors are responsible for this change, including recent environmental regulations. Two federal laws and their resulting regulations have been deemed most significant with respect to their effect on coal ash disposal practices: the Federal Water Pollution Control Act as amended by the Clean Water Act of 1977 and the Resource Conservation and Recovery Act of 1976. The impact of federal guidelines on state regulations for solid waste disposal is discussed in Section 4 of this manual. These guidelines will also significantly affect future coal ash disposal practices. Additional regulations implemented by individual states will result from these two laws and will also greatly influence future coal ash disposal practices.

ASH UTILIZATION

An alternative to disposal of coal ash is utilization of the ash. A wide variety of uses has been found for power plant ash. For some of the applications, criteria have been established to specify the properties that a particular ash must have to perform adequately in the given application. Other uses have not been as well documented or researched, and detailed material specifications have not been developed; however, many have been performed successfully. The categories listed represent areas of utilization:

- Fill and cover material,
- Soil improvement,
- Roadways and pavements,

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- Drainage,
- Pozzolan,
- Structural products,
- Lightweight aggregate,
- Grout and mortar, and
- Metal extraction.

Pozzolan applications have historically represented the largest outlet for fly ash, but the other areas are utilizing increasing amounts of coal ash as natural resources continue to decrease in supply or availability.

DISPOSAL SYSTEM ALTERNATIVES

Ash disposal systems can be classified as wet, dry, or a combination of wet and dry. The purpose of the following descriptions of these systems is to provide an overview of physical characteristics, operation, and advantages/disadvantages.

Wet Systems

Wet ash disposal systems hydraulically transport ash from the power plant to an ash disposal pond or ponds which function as large-scale sedimentation basins. Bottom ash and fly ash can be placed in the same pond, in different ponds, or sluiced to different areas of the same pond to enhance ash segregation. In general, bottom ash, economizer and air heater ash, and pyrites (if not segregated from the ash disposal system) are transported by the same sluicing system.

Fly ash is pneumatically transported from particulate removal devices and collected in a central area for sluicing. Ash sluicing systems are typically designed for each generating unit in the plant, and incorporate special materials to resist erosion by the ash slurry. Transport distances from the plant to the disposal area are commonly less than one mile.

Ash entering the disposal pond settles, leaving a supernatant. The supernatant can be treated and discharged, recycled, evaporated, or impounded. Local climate, receiving stream water quality, and environmental regulations strongly influence supernatant disposal. Ash cenospheres do not settle, and can cause operational problems if present in a quantity sufficient to impede outlet weir and skimmer functions. Cenospheres have to be collected, on an occasional basis, and removed

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from the disposal site for landfill or sale. The area may either be operated as a permanent disposal area, or may be sequentially filled, drained, and dredged as discussed below under Combination Systems.

Wet site construction requires the building of an embankment, pond excavation, or a combination of these methods. The possibility of groundwater pollution by ash leachates may, in the future, lead to regulations requiring the siting of ash basins in impermeable soils or the installation of liners. Exposed embankments should be protected from erosion by vegetation or rip rap. Site closure normally involves the placement of a soil cover over the pond surface and the diversion of surface water from the site. For additional discussion of wet site design considerations, see the EPRI FGD Sludge Disposal Manual (1).

Due to the difficulties and expense of slurry transport over long distances, wet sites are often located in the immediate proximity of power plants. Selection factors center around environmental and cost considerations. In general, wet disposal system advantages and disadvantages are as follows:

Advantages

- Wet disposal operations are unaffected by transportation strikes,
- Noise, dust, and traffic are reduced at the site and along transportation routes,
- Slurry transport systems are unaffected by rising petroleum (fuel) prices.
- Ash transportation and site operation are simpler and generally less expensive than those of dry disposal.

Disadvantages

- High site development costs,
- Liner costs (if required),
- Larger quantities of leachate generated than with dry systems,
- Larger disposal site volume required than with dry methods,
- Value of fly ash for reuse reduced,
- Operation inflexible with regard to future changes,
- Use of land after site closure, perhaps difficult and costly,
- Potential for spills of slurry,

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- Cenosphere collection and disposal problems,
- Cannot be used to transport self hardening fly ash over long distances.

Dry Systems

Dry disposal systems essentially entail the landfilling of ash conditioned with a sufficient amount of water to aid placement. Bottom ash, usually hydraulically transported from the boiler bottom to a dewatering bin or pond, is commonly transported separately from fly ash. Fly ash is collected in storage silos for transport to the disposal site. Bottom ash is relatively inert (see Section 2 - Properties of Power Plant Ash) and has good porosity. As such, it is sometimes used to construct drainage blankets and filters. Fly ash can be delivered to disposal areas and spread with conventional earth moving equipment. Depending on economic considerations and plans for the future use of the site after closure, the ash can be compacted. If compacted, the required storage volume is reduced accordingly and the site can be used for development such as housing, parks, golf courses, and industrial sites, since compacted ash is capable of supporting moderate foundation loads. Ash stored in this manner also usually retains its chemical properties. Thus, dry disposal provides ash stockpiles for future uses, such as metal and mineral extraction or construction additives. It can also serve as a source of material for projects requiring structural fill material.

Dry sites can be designed and constructed to minimize the quantity of leachate produced and other environmental problems such as wind and water erosion. Should natural site conditions not appear adequate to protect groundwater, a liner can be installed or a drainage blanket can be used to collect leachate and relieve hydrostatic pressures within the fill. Surface water should be diverted around the site. If the site is located in a valley, an earthfill dam or embankment may be constructed at the toe of the disposal area to serve as a starter dike or to improve stability. In addition, the site should be developed to the uphill limit of the valley so that surface water can be diverted around the site, thus avoiding the installation of a buried storm water drainage system. For additional discussion on dry site design considerations, see the EPRI FGD Sludge Disposal Manual (1).

While the transportation of dry ash is most commonly done by truck, it can also be moved by rail, belt or pneumatic conveyors. Commonly used systems are discussed in Section 5. For a more detailed discussion of transportation systems see the EPRI FGD Sludge Disposal Manual (1).

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As ash arrives at the site, it is usually dumped in piles and spread in layers. It may be compacted to reduce the overall volume required or as part of the site development plan. The addition of water at the site is sometimes necessary to achieve sufficient moisture content for dust control and proper compaction. The amount of water required depends upon local weather, ash characteristics, and water added prior to transport. Ideally, compacted fly ash fill slopes should be maintained at 2 or 3 horizontal to 1 vertical to assure adequate slope stability, while uncompacted fly ash slopes (placed and spread in layers) should have 3 to 5 horizontal to 1 vertical slope ratios. To control erosion and runoff, the slopes should be benched at regular intervals. As each section is completed, it should receive a topsoil cover and vegetation.

Dry disposal systems may be the only economical disposal alternative when the available ash disposal sites are distant from power plants, as discussed in Section 9. During the process of site selection, transportation and operational considerations should be incorporated with cost/environmental assessments. Advantages and disadvantages of dry disposal are:

Advantages

- Lower development costs since extensive dams and dikes are not required,
- More efficient use of disposal area and volume,
- Possible reclamation of site for a specific land use after closure,
- Flexibility in operation,
- Reduced leachate quantities,
- Easier reclamation of ash for utilization than with wet disposal.

Disadvantages

- Need to control noise and dust problems,
- Operation subject to possible transportation strikes,
- Higher operational costs in most cases,
- Operational costs subject to rising fuel costs,
- Increased visual impact along transportation routes.

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Combination Systems

Several combinations of wet and dry disposal systems are possible, depending upon ash characteristics and in-plant collection and handling systems. For example, a combination system might involve pumping the ash slurry to a pond located close to the power plant site. After dewatering, the coal ash can be excavated and transported to a dry site for final disposal.

Another example of a combination system involves the handling of very reactive fly ash. One method of handling the reactive ash is to transport it dry to the disposal site. At the disposal site the fly ash is mixed with water and deposited into ponds where it cures and hardens.

OVERVIEW OF CURRENT UTILITY ASH DISPOSAL PRACTICE

The estimated total national ash production in 1979 (2) was 58.4 million tons (53 million metric tons).* Approximately 9.7 million tons (9 million metric tons) were utilized, and 48.7 million tons (44.2 million metric tons) required disposal. 25.1 million tons (22.8 million metric tons) were placed in wet disposal areas, while 24.4 million tons (22.1 million metric tons) were placed in dry and mine disposal sites. Table 3-1 summarizes disposal practices by state and by EPRI region for 1979.

Regional Disposal Practices

Region 1, Northeast, includes Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, Delaware, Maryland, Virginia, and West Virginia. Overall Region 1 produced 22 percent of the national ash production. Coal-fired plants are concentrated primarily in Pennsylvania, West Virginia, Maryland, and Virginia. Pennsylvania produced 6 million tons of ash in 1979 (5.4 million metric tons), which was 10 percent of the national production. A total of 4.3 million tons of Region 1 ash (3.9 million metric tons) were placed in wet disposal sites, and 6.1 million tons of ash (5.5 million metric tons) were placed in dry disposal sites.

Region 2, Southeast, includes Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Florida. Region 2 produced approximately 11.7 million

* This estimate was based on a survey of power plants, larger than 200 MW, performed by Michael Baker, Jr., Inc., (2).

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TABLE 3-1

U.S. ASH PRODUCTION 1979

Source: Michael Baker, Jr., Inc., EPRI Utility Survey, 1980

STATE	TOTAL ASH DISPOSED: TOTAL ASH	TOTAL BOTTOM ASH	USED BOTTOM ASH	TOTAL FLYASH	FLYASH UTILIZED	LANDFILL AND MINE: TOTAL ASH	TOTAL BOTTOM ASH	BOTTOM ALONE ASH	TOTAL FLYASH	FLYASH ALONE	BOTTOM ASH AND FLYASH	POND: TOTAL ASH	TOTAL BOTTOM ASH	BOTTOM ALONE ASH	TOTAL FLYASH	FLYASH ALONE	BOTTOM ASH AND FLYASH
REGION 1																	
Del.	124	57	57	67	0	67	0	0	67	67	0	0	0	0	0	0	0
Md.	1395	594	100	801	0	1035	284	134	751	257	487	260	210	0	50	0	260
N.H.	77	58	58	19	10	9	0	0	9	9	0	0	0	0	0	0	0
N.J.	284	135	134	149	145	5	1	1	4	4	0	0	0	0	0	0	0
N.Y.	674	120	66	554	3	606	55	0	551	151	454	0	0	0	0	0	0
Pa.	5995	1519	352	4476	203	3421	783	99	2638	97	3225	2019	384	104	1635	785	1130
Va.	277	37	0	240	14	109	3	0	106	0	109	164	34	0	120	0	164
W.Va.	3809	777	234	3032	887	823	170	0	653	0	823	1865	373	373	1492	1492	0
TOTAL	12,635	3297	1001	9338	1262	6074	1295	234	4779	585	5098	4298	1001	477	3297	2277	1644
REGION 2																	
Ala.	2372	452	53	1920	36	52	52	52	0	0	0	2221	337	0	1884	248	1973
Fla.	1220	313	190	907	327	302	0	0	302	302	0	401	123	77	278	0	324
Ga.	1656	342	34	1368	110	46	11	0	35	0	46	1520	297	0	1223	0	1520
Miss.	311	41	13	270	81	10	1	0	9	0	0	207	27	8	180	45	154
N.Car.	2636	621	38	2015	132	0	0	0	0	0	0	2466	583	0	1883	0	2466
S.Car.	521	145	0	522	234	0	0	0	0	0	0	433	145	0	288	0	433
Tenn.	2727	669	428	2058	64	19	19	19	0	0	0	2287	293	43	1994	258	1986
TOTAL	11,714	2583	756	9060	984	439	93	81	346	302	46	9535	1805	128	7730	551	8856
REGION 3																	
Ill.	3875	1634	360	2241	156	2155	932	560	1223	317	1062	1205	342	39	863	36	1042
Ind.	2223	750	282	1473	22	868	169	107	699	227	305	1051	299	82	752	41	928
Ky.	3426	1033	141	2393	83	846	583	533	263	209	104	2405	358	36	2047	301	1680
Mich.	2429	484	114	1945	255	1534	350	0	1184	0	1534	528	20	0	506	395	131
Ohio	4221	673	290	3348	137	2703	330	533	2373	492	2211	1382	315	135	838	119	899
Wis.	1210	323	75	887	655	646	125	0	521	0	646	303	123	48	180	11	244
TOTAL	17,384	5097	1262	12,287	1307	8752	2489	1733	6263	1245	5882	6872	1457	340	5186	903	4924
REGION 4																	
Iowa	718	162	16	556	72	0	0	0	0	0	0	630	148	34	484	109	487
Kans.	188	40	3	148	54	131	37	0	94	0	24	0	0	0	0	0	0
Minn.	799	194	75	605	113	111	37	0	74	0	111	500	82	82	418	101	0
Mo.	1906	657	305	1049	73	124	89	80	35	0	0	1904	463	0	941	15	1389
Neb.	239	48	31	191	123	85	17	0	68	0	85	0	0	0	0	0	0
N.Dak.	821	409	30	412	113	282	188	0	94	0	0	306	191	0	205	0	295
S.Dak.	175	61	0	114	1	174	61	0	113	0	174	0	0	0	0	0	0
TOTAL	4846	1771	460	3075	549	907	429	80	478	0	394	2930	882	116	2048	225	2171
REGION 5																	
Ark.	64	18	0	46	12	34	0	0	34	34	0	18	18	18	0	0	0
Okla.	68	17	0	51	0	68	17	0	61	0	68	0	0	0	0	0	0
Texas	4601	1321	431	3280	669	3428	856	297	2572	417	68	114	42	24	72	0	90
TOTAL	4733	1356	431	3377	681	3530	873	297	2657	451	136	132	60	42	72	0	90
REGION 6																	
Ariz.	1022	216	0	806	306	406	128	0	278	0	406	310	88	31	222	0	0
Colo.	782	193	0	589	150	632	193	45	439	133	233	0	0	0	0	0	0
Mont.	186	46	0	140	0	0	0	0	0	0	0	186	46	0	140	0	186
Nev.	508	148	0	360	270	238	148	0	90	0	238	0	0	0	0	0	0
N.Mex.	1627	326	0	1301	8	1159	233	0	926	0	1159	460	93	93	367	0	0
Utah	800	200	1	600	0	799	199	0	600	0	0	0	0	0	0	0	0
Wash.	827	331	59	496	145	623	272	0	351	0	623	0	0	0	0	0	0
Wyo.	1292	356	0	936	90	826	268	0	558	0	552	386	88	23	298	94	269
TOTAL	7044	1818	60	5228	959	4683	1441	45	3242	133	3211	1342	315	147	1027	94	455
TOTAL USA THOUSAND TONS	58,397	15,920	3,970	42,365	5,742	24,385	6,620	2,470	17,765	2,716	14,747	25,109	5,520	1,250	19,360	4,050	18,040

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tons of ash in 1979 (10.6 million metric tons), 20 percent of the national ash production. Eighty-one percent of the ash generated was placed in wet disposal areas, and 4 percent was placed in dry disposal areas. The remaining 15 percent was sent to utilization projects.

Region 3, East Central, includes Ohio, Kentucky, Indiana, Illinois, Michigan, and Wisconsin. Region 3 produced 17.4 million tons of ash in 1979 (15.8 million metric tons), 30 percent of the national production. Ohio produced 24 percent of Region 3 ash, and 7 percent of the national ash production. Forty percent of Region 3 ash was placed in wet disposal sites, and 50 percent was placed in dry disposal sites.

Region 4, West Central, includes Minnesota, Iowa, Missouri, Kansas, Nebraska, South Dakota, and North Dakota. Region 4 produced 4.8 million tons of ash in 1979 (4.4 million metric tons), 8 percent of the national production. Sixty percent of Region 4 ash was placed in wet disposal sites and 19 percent was placed in dry disposal sites.

Region 5, South Central, includes Arkansas, Louisiana, Oklahoma, and Texas. Region 5 produced 4.8 million tons of ash in 1979 (4.4 million metric tons), 8 percent of the national ash production. Three percent was placed in wet disposal sites, and 74 percent was placed in dry disposal sites.

Region 6, West, includes Wyoming, Montana, Colorado, New Mexico, Arizona, Utah, Idaho, Washington, Oregon, Nevada, and California. Region 6 produced 7.0 million tons of ash in 1979 (6.4 million metric tons), 12 percent of the national production. Nineteen percent was placed in wet disposal areas, and 66 percent was placed in dry disposal areas.

ASH DISPOSAL TRENDS

Overall, wet ash disposal, 43 percent of the national production, is used slightly more than dry ash disposal, 42 percent of the national production. Wet disposal is predominant in the Southeast and West Central regions of the country, while dry ash disposal is predominant in the Northeast, East Central, South Central, and West regions of the country. As discussed in Section 9 of this manual, there are several factors which influence ash disposal practices and costs. These factors include:

- Disposal site topography,

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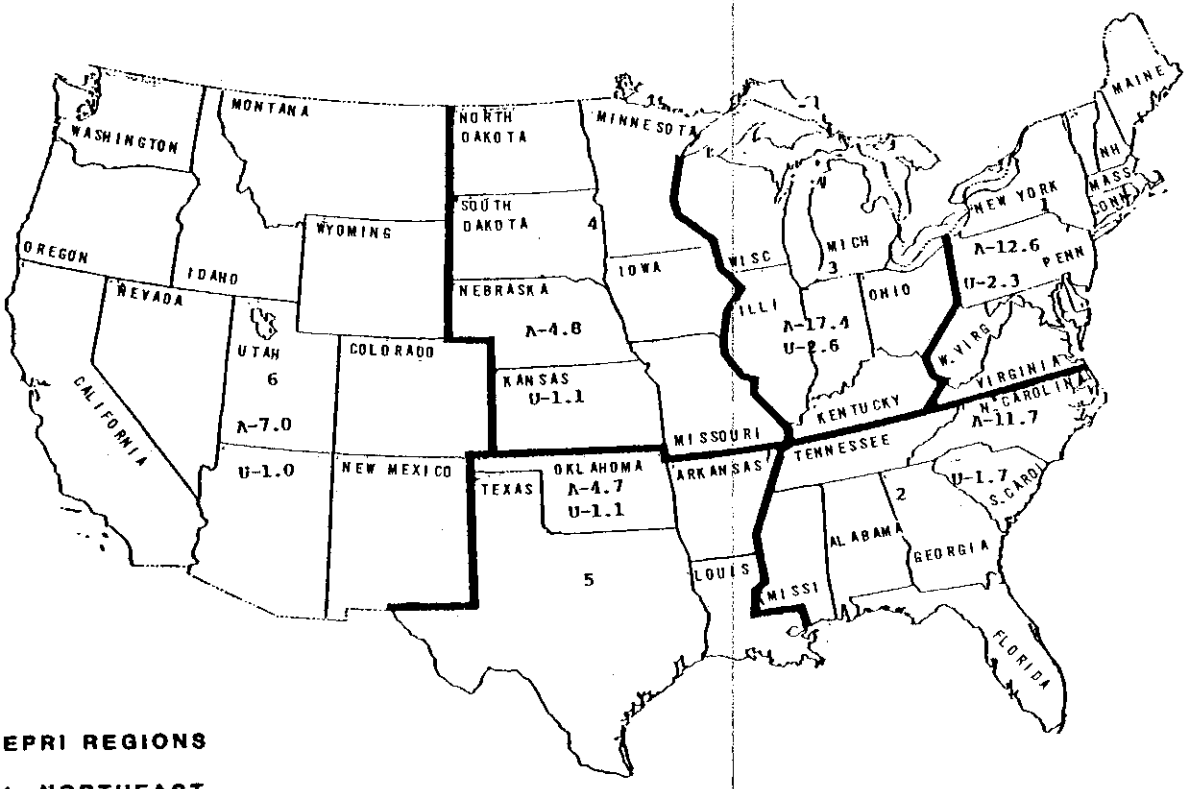

Figure 3-1. Regional Breakdown of U.S. Electrical Utility Ash Production, 1979
Source: Michael Baker, Jr., Inc., EPRI Utility Survey, 1980 (2).

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- Land availability and location,
- Water availability,
- Ash properties.

Generally, wet ash disposal is the lowest operating cost alternative when the disposal site can be located near the power plant (less than 1 mile), and the disposal site topography lends itself to embankment construction. For instance, a narrow valley could be easily developed into a wet disposal site with a minimum of embankment construction.

Future Trends

Coal-fired electrical generating capacity is expected to increase during the 1980s (see Table 3-2). While difficult to predict, ash disposal for new sites will probably be dry rather than wet. Reasons for this trend include:

- Increased ash marketability,
- Increasingly stringent environmental regulations for surface water and groundwater protection.

Ash marketability, particularly for fly ash, is likely to increase for several reasons. Section 6000 of RCRA currently proposed regulations are intended to stimulate the use of ash in concrete used by the federal government. The current classification of ash as non-hazardous, discussed in Section 4 of this manual, may help to increase the use of ash as landfill and construction material.

Currently proposed New Source Performance Standards for ash transport water, discussed in Section 4 of this manual, would require either the recycling or treatment of fly ash sluicing water. The cost of a recycle or treatment system for ash transport water would increase the cost of wet ash disposal. Further additional wet disposal costs could be brought about by site liner requirements. Wet disposal sites require a larger disposal volume than do dry sites, due to lower in-place ash densities; therefore, wet sites usually require a larger surface area than dry sites, and larger site liners for groundwater protection. In addition, liners for wet sites are usually placed under the entire site prior to site operation, while dry site liners can be developed in stages as the site develops.

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Table 3-2

EXISTING, PROJECTED, AND CONVERTED COAL
GENERATING CAPACITY - APRIL 1979

State	Existing		Converted from Oil		Projected New Construction		Total	
	MW	Rank	MW	Rank	MW	Rank	MW	Rank
Alabama	10412	9	-	-	5138	10	15550	7
Alaska	54	40	-	-	115	40	169	46
Arizona	2987	20	-	-	2753	25	5740	26
Arkansas	512	36	-	-	2800	23	3312	35
California	0	-	-	-	1600	33	1600	38
Colorado	2846	23	-	-	8874	4	11720	14
Connecticut	0	-	934	5	0	-	934	41
Delaware	341	39	392	10	446	39	1179	40
Florida	4528	15	616	8	6678	7	11822	13
Georgia	10566	8	163	12	3814	12	14543	9
Hawaii	0	-	-	-	0	-	0	-
Idaho	0	-	-	-	0	-	0	-
Illinois	16750	3	520	9	3932	11	21202	6
Indiana	14706	4	-	-	9233	3	23939	3
Iowa	4247	17	-	-	3347	18	7594	20
Kansas	3647	24	-	-	3010	21	5657	27
Kentucky	12337	6	-	-	10676	2	23013	4
Louisiana	0	-	-	-	6702	6	6702	24
Maine	0	-	99	14	568	37	667	42
Maryland	1780	28	668	6	2046	32	4494	31
Massachusetts	0	-	2785	2	0	-	2785	36
Michigan	10348	10	641	7	2782	24	13771	10
Minnesota	4473	16	-	-	3550	13	8023	19
Mississippi	1283	32	-	-	2496	29	3779	34
Missouri	10265	11	-	-	3007	22	13272	12
Montana	939	35	-	-	1556	34	2495	37
Nebraska	1151	33	-	-	2710	26	3861	33
Nevada	1978	26	-	-	2550	28	4528	30
New Hampshire	459	38	150	13	0	-	609	43
New Jersey	1687	30	1593	3	1100	35	4380	32
New Mexico	2927	21	-	-	3398	16	6325	25
New York	2547	25	3876	1	2460	30	8883	17
North Carolina	11259	7	-	-	2217	31	13476	11
North Dakota	1705	29	-	-	3390	17	5095	29
Ohio	23379	1	-	-	3213	19	26592	1
Oklahoma	1144	34	-	-	7015	5	8159	18
Oregon	0	-	-	-	560	38	560	44
Pennsylvania	18706	2	230	11	6447	8	25383	2
Rhode Island	0	2	62	15	0	-	62	47
South Carolina	3511	18	-	-	3430	15	6941	22
South Dakota	488	37	-	-	0	-	488	45
Tennessee	10048	12	-	-	0	-	10048	15
Texas	7880	13	-	-	14783	1	22663	5
Utah	1847	27	-	-	5700	9	7547	21
Vermont	30	41	-	-	0	-	30	48
Virginia	2899	22	1454	4	840	36	5193	28
Washington	1330	31	-	-	0	-	1330	39
West Virginia	12605	5	-	-	2668	27	15273	8
Wisconsin	5880	14	-	-	3206	20	9086	16
Wyoming	3410	19	-	-	3488	14	6898	23
TOTAL	228891		14183		154298		397372	

Source: U. S. Department of Energy. Inventory of Power Plants in the United States - April 1979
Energy Information Administration, AOE/EIA-0095, May 1979

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REFERENCES

1. FGD Sludge Disposal Manual, Palo Alto, California; Electric Power Research Institute, September 1980, CS-1515.

2. Michael Baker Jr., Inc., EPRI Utility Survey, 1980.

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Section 4

IMPACT OF SOLID WASTE DISPOSAL REGULATIONS ON NEW DISPOSAL SITES

INTRODUCTION

Increased public awareness of the potential consequences of solid waste disposal has led to increased government regulation of siting, design, operation, closure, and financial aspects of solid waste disposal sites. Prior to the current regulations, solid waste disposal was administrated primarily by state and local agencies. Generally in the past, if a solid waste regulation existed, it was most likely based on "garbage" disposal and included requirements such as daily cover to prevent rodent infestation and uncontrolled fires. Clearly, these regulations did not apply to coal ash.

This section discusses, in overview, federal legislation and regulations which pertain to utility coal ash disposal. Further summary information of state solid waste regulations for siting, design, and closure criteria are presented for the ten greatest ash producing states in the United States.

FEDERAL LEGISLATION

The federal government has recently taken an active role in the control of coal ash disposal. Discharge of the ash pond supernatant and landfill runoff to surface waters had previously been allowed with only minimal requirements concerning water quality. Similarly, the potential for groundwater contamination by leachate from ash disposal sites has only recently become an area of concern. Other aspects of ash disposal which have received recent attention include concern for its use in filling wetlands and abandoned mines, and the handling and transportation of the material. Table 4-1 summarizes federal legislation which could affect ash handling and disposal.

Many of the laws listed in Table 4-1 apply only in special cases. For example, the provisions of the Federal Coal Mine Health and Safety Act are only applicable to situations where ash is disposed in, or adjacent to, coal mines. In addition to the federal laws listed in the table, state and local laws, and regulatory decisions may apply to ash disposal practices.

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Table 4-1

FEDERAL REGULATORY FRAMEWORK FOR DISPOSAL OF COAL ASH

Possible Environmental Impact	Legislation	Administrator
Surface water contamination	Clean Water Act of 1977	Environmental Protection Agency
Groundwater contamination	Resource Conservation and Recovery Act of 1976	Environmental Protection Agency
	Safe Drinking Water Act of 1974	
Waste stability/ consolidation	Dam Safety Act of 1972	Army Corps of Engineers
	Surface Mining Control and Reclamation Act of 1977	Office of Surface Mining Reclamation and Enforcement
	Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration
	Federal Coal Mine Health and Safety Act of 1969	Mining Enforcement Safety Administration
Fugitive air emissions	Clean Air Act	Environmental Protection Agency
	Hazardous Materials Transportation Act of 1969	Department of Transportation
	Federal Coal Mine Health and Safety Act of 1969	Mining Enforcement Safety Administration
	Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration
Contamination of marine environment	Marine Protection Research and Sanctuaries Act of 1972	Environmental Protection Agency

Source: J. W. Jones, "Disposal of Power Plant Wastes," In Proceedings of Energy/Environment III, The Third National Conference on the Interagency RED Program, Washington, D. C., 1978, EPA-600/9-78-022.

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The two federal laws which have the greatest impact on coal ash disposal are:

- The Resource Conservation and Recovery Act of 1976, (RCRA).
- The Clean Water Act of 1977 (CWA).

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act was enacted on October 21, 1976, with the stated principal objectives of promoting the protection of human health and the environment, and conserving valuable material and energy resources. These objectives are to be achieved by:

- Providing technical and financial assistance to state and local governments for the development and implementation of solid waste management plans.
- Providing training grants in solid waste occupations.
- Prohibiting future open dumping on land and requiring upgrading or closing of existing open dumps.
- Regulating the treatment, storage, transportation, and disposal of hazardous wastes.
- Promulgating guidelines for solid waste management practices and systems.
- Conducting a research and development program for improved solid waste management and resource conservation techniques.
- Demonstrating improved solid waste management and resource conservation and recovery systems.
- Establishing a cooperative effort among federal, state, and local governments and private enterprises.

The RCRA was preceded by two other laws which dealt with the handling of solid wastes. These laws were the Solid Waste Disposal Act of 1965, PL 89-272 and the Resource Recovery Act of 1970, PL 91-512.

The Solid Waste Disposal Act was an amendment to existing air pollution legislation. The primary objective of the act was to identify and quantify the municipal solid waste disposal problem. Coal ash was placed in the same category as sanitary landfills. Under this act, the 1968 National Survey of Solid Waste Practices discovered that only around six percent of land disposal facilities met minimum sanitary landfill criteria. Based on the results of the survey, the Resource Recovery Act of 1970 was passed to provide the information needed by Congress to determine which type of federal legislation would be most effective in the area of

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solid waste management.

The Resource Recovery Act called for a comprehensive report on hazardous wastes and provided for the promulgation of guidelines for resource recovery, collection, and disposal. However, these guidelines were mandatory only for federal facilities and had no impact on the utility industry. As a result of the information obtained under this Act, the Resource Conservation and Recovery Act was passed in 1976.

The intent of the RCRA is to "close the loop" in pollution control. Although enacted in 1976, initial hazardous waste regulations were not finalized until May 19, 1980, and then only in part. Based on these regulations, fly ash and bottom ash have been defined as non-hazardous materials. However, the Environmental Protection Agency (EPA) is currently studying the impact of coal ash on the environment. Ultimately coal ash's regulatory status will be based on the results of these studies. Table 4-2 summarizes the EPA regulations pursuant to RCRA.

Table 4-3 presents the organization and contents of the subtitles which comprise the RCRA. As can be seen in Table 4-3, non-hazardous material disposal is regulated by RCRA Subtitle D, Section 4000, and the implementation and enforcement of the section is to be accomplished by the states. Hazardous waste disposal is regulated by RCRA Subtitle C, Section 3000, and the implementation and enforcement of this section is by the EPA. Figure 4-1 provides a flowchart for the identification of those regulations pertaining to a particular waste.

Current EPA Study. The EPA is currently studying utility waste disposal practices and plans to publish the results in late 1983. As part of this overall study, the EPA is undertaking a two-part study of coal ash disposal practices. The first part of the study was conducted in the spring of 1979 and involved a survey of ash disposal site characteristics and management practices. The purpose of the survey was to identify representative sites for detailed future study. The second part of the study will include field testing and groundwater monitoring at selected sites. The purpose of these field studies is to assess the environmental impact of current disposal practices with an emphasis on groundwater quality. The results of these studies will influence future revisions of the RCRA regulations concerning disposal of utility solid wastes.

To overview the EPA studies and comment on the rule-making process, a group of utilities has formed an ad hoc organization called the Utility Solid Waste Advisory Group (USWAG), under the auspices of the Edison Electric Institute

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Table 4-2

SUMMARY OF EPA REGULATIONS PURSUANT TO THE RESOURCE CONSERVATION AND RECOVERY ACT OF 1976

40 CRF Part	Corresponding RCRA Section and Descriptive Title	Federal Register Date
122 and 124	Section 3005: Permits for Treatment, Storage, and Disposal of Hazardous Waste	5/19/80 Part X
123	Section 3006: Guidelines for Authorized State Hazardous Waste Programs	5/19/80
241	Section 1008: Landfill Disposal of Solid Wastes - Proposed Guidelines	3/26/79 Part II
256	Sections 4002 and 4003: Guidelines for Development and Implementation of State Solid Waste Management Plans	7/31/79 Part III
257	Sections 1008 and 4004: Criteria for Classification of Solid Waste Disposal Facilities and Practices	9/13/79 Part IX (as corrected 9/21/79)
260	Definitions used in other Parts corresponding to the 3001 through 3004 rules, and general provisions applicable to these Parts	5/19/80 Part II
261	Section 3001: Identification and Listing of Hazardous Waste	5/19/80 Part III
262	Section 3002: Standards Applicable to Generators of Hazardous Waste	5/19/80 Part V
263	Section 3003: Standards Applicable to Transporters of Hazardous Waste	5/19/80 Part VI
264	Section 3004: Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	5/19/80 Part VII
	Supplemental Notice of Proposed Rulemaking	10/8/80
265	Section 3004: Interim Status Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	5/19/80 Part VII

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Table 4-3

RESOURCE CONSERVATION AND RECOVERY ACT
ORGANIZATION AND CONTENTS

Subtitle A - General Provisions

Sections 1001 through 1008
Contains table of contents, objectives, definitions, etc. Under Section 1008, guidelines for minimum acceptable solid waste management practices are mandated.

Subtitle B - Office of Solid Waste; Authorities of the Administrator

Sections 2001 through 2006
Establishes an Office of Solid Waste within EPA

Subtitle C - Hazardous Waste Management

Section 3001
Authorizes EPA criteria for identifying hazardous wastes and a listing of wastes presumed hazardous

Section 3002
Standards for generators of hazardous wastes

Section 3003
Standards for transporters of hazardous wastes

Section 3004
Standards for siting and operation of hazardous waste treatment, storage and disposal facilities

Section 3005 and 3011
Defines permitting requirements and federal and state authority

Subtitle D - State or Regional Solid Waste Plans

Sections 4001 through 4009
Contains provisions for State Regulatory control of non-hazardous solid wastes in compliance with federal standards. Section 4004 provides for minimum standards for non-hazardous solid waste disposal sites.

Subtitle E - Duties of the Secretary of Commerce in Resource and Recovery

Sections 5001 through 5004
Establishes Department of Commerce as lead agency in encouraging resource recovery.

Subtitle F - Federal Responsibilities

Sections 6001 through 6004
Deal with responsibilities of government agencies

Subtitle G - Miscellaneous Provisions

Section 7001 through 7009
Contains provisions for citizen suits, dealing with imminent hazards, judicial review, etc.

Subtitle H - Research, Development, Demonstration and Information

Sections 8001 through 8007
Authorizes and funds research studies demonstration projects and dissemination of information

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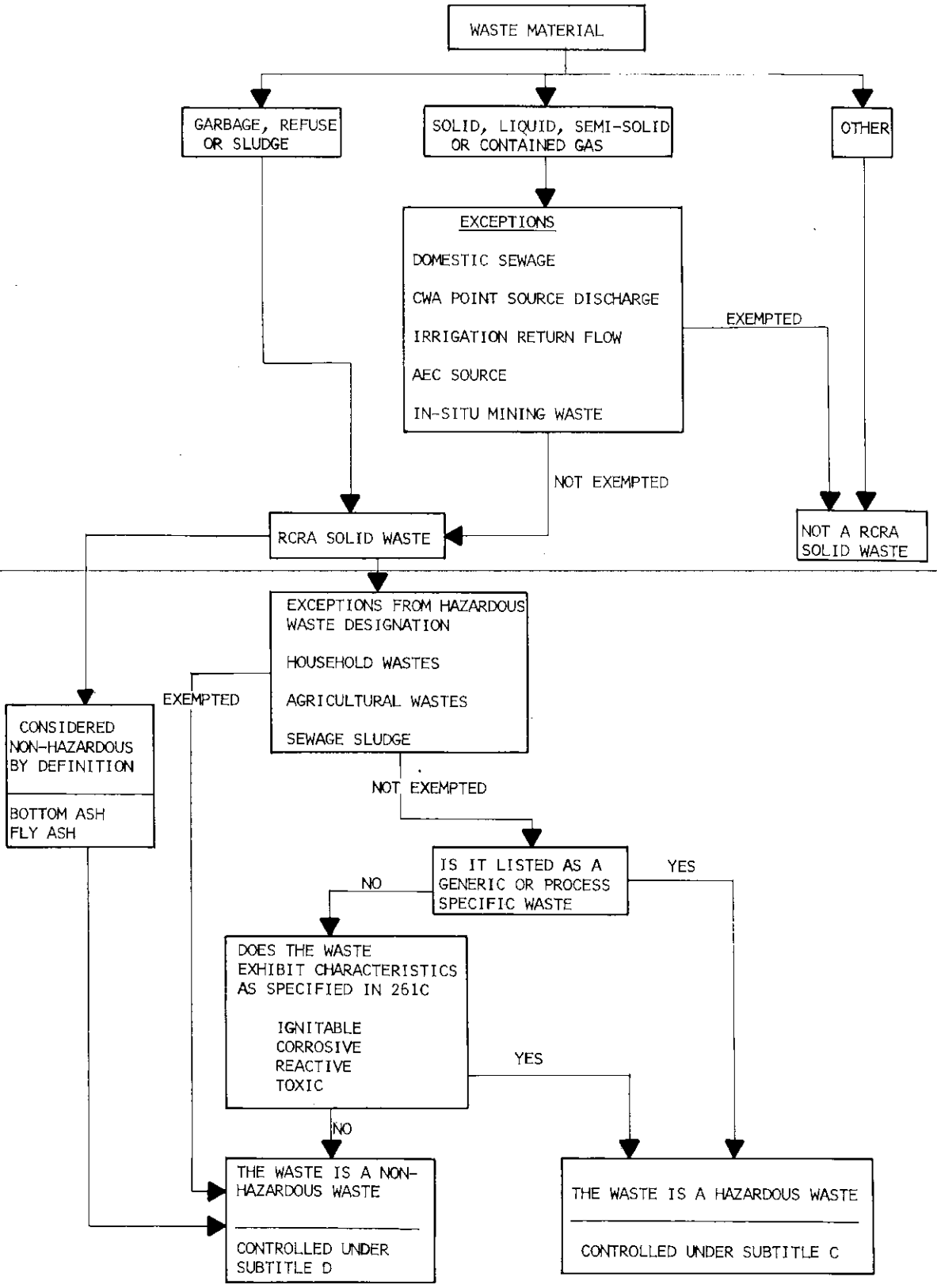

Figure 4-1. Flow Chart For Determining Applicable RCRA Regulations

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(EEI). Other organizations are also conducting studies as to the effect of proposed RCRA regulations and coal ash disposal practices. These include the American Society for Testing and Materials (ASTM), the Department of Energy, and the Electric Power Research Institute (EPRI).

If the EPA's study concludes that coal ash is a hazard to human health or the environment then coal ash may be subject to Subtitle C requirements.

Subtitle C Regulations. Subtitle C, Section 3000, calls for the promulgation of regulations to identify those wastes which are hazardous, and to control the transportation, treatment, storage, and disposal of such wastes.

To determine whether a solid waste is hazardous and subject to the disposal regulations of Section 3004, or non-hazardous and subject to the less stringent disposal requirements of Section 4004, the EPA has developed a hazardous waste classification criteria. These criteria are described in the Federal Register, May 19, 1980. A waste is classified as hazardous if it exhibits the characteristics described below:

- Ignitability

  --A waste is ignitable if a representative sample of the waste is liquid and has a flash point less than 140°F (60°C) as determined by using ASTM Standard D93-79 or D3278-78; is not liquid and can cause a fire through friction, absorption of moisture, spontaneous chemical change, such that when ignited to burn so vigorously and persistently that it creates a hazard; is not liquid and when ignited will burn vigorously enough to create a management hazard; or is an ignitable compressed gas. Fly ash and bottom ash are not ignitable wastes.

- Corrosivity

  --A waste is corrosive if a representative sample of the waste is aqueous and has a pH less than or equal to 2.0, or greater than or equal to 12.5. Another proposed criteria is if the waste corrodes SAE 1020 steel at a rate greater than 0.250 inch per year at a temperature of 130°F (55°C) as determined by using the National Association of Corrosion Engineers Standard TM-01-69. Some slurried fly ash can have a pH as low as 2.0 or as high as 12.5. However, values of either extreme are not common.

- Reactivity

  --A waste is reactive if a representative sample of the waste is normally unstable and will undergo violent chemical change without detonating; reacts violently with water or forms potentially explosive mixtures with water or generates toxic gases when mixed with water in a quantity sufficient to present

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a danger to human health or the environment; is capable of detonation or explosive reaction; or can be classified as an explosive under other federal regulations.

- Toxicity

--A waste is classified as toxic if the extract of that waste, obtained by using the Extraction Procedure (EP), has a contaminant concentration in excess of 100 times the drinking water standards. The extract is analyzed for contaminant concentrations by using the atomic absorption techniques described in "Methods for Analysis of Water and Wastes," Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, March 1979, (EPA-600/4-79-020) and "Methods for Benzidine, Cholorinated Organic Compounds, Pentachlorophenol, and Pesticides in Water and Waste water," September 1978, Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. The values for the allowable contaminant extract level listed in Table 4-4 are based on 100 times the National Interim Primary Drinking Water Standards. Some coal ash leachates may exhibit heavy metal toxicity. However, as presently regulated, even if the extract of a particular fly ash or bottom ash has a contaminant concentration in excess of the allowable limits given in Table 4-4, it would be classified as a non-hazardous waste and be subject to regulation under Section 4004 of RCRA.

Subtitle D Regulations. Subtitle D, Section 4000 is of specific interest to the electric utility industry. It calls for the EPA to publish guidelines for the development of comprehensive state of regional non-hazardous solid waste management programs. These wastes include fly ash and bottom ash generated from the combustion of coal. The exclusion of these ashes from hazardous listing could be temporary, as mentioned before, pending the results of the comprehensive utility waste study being conducted by the EPA.

Section 4004 of Subtitle D is important to utilities since it specified minimum performance standards for non-hazardous solid waste disposal areas. The criteria established by the EPA are discussed later in this section.

Solid Waste Disposal Guidelines. Subtitle A, Section 1008 of RCRA contains guidelines which identify and describe available solid waste management practices that provide for the protection of public health and the environment. The proposed guidelines entitled "Guidelines for the Landfill Disposal of Solid Wastes," were issued by the EPA on March 26, 1979 (44 FR 18138). These guidelines will replace 40 CFR 241. The proposed rule states "The purpose of these guidelines is to suggest preferred methods for the design and operation of those solid waste disposal facilities which employ landfilling techniques. The decision as

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Table 4-4

MAXIMUM CONCENTRATION OF CONTAMINANTS FOR
CHARACTERISTICS OF EP TOXICITY*

EPA Hazardous Waste#	Metal	National Interim Primary Drinking Water Standard mg/l	Allowable Extract Level, mg/l
D004	Arsenic	0.05	5.0
D005	Barium	1.0	100.0
D006	Cadmium	0.01	1.0
D007	Chromium	1.05	5.0
D008	Lead	0.05	5.0
D009	Mercury	0.002	0.2
D010	Selenium	0.01	1.0
D011	Silver	0.05	5.0
D012	Endrin	0.0002	0.02
D013	Lindane	0.004	0.4
D014	Methoxychlor	0.1	10.0
D015	Toxaphene	0.005	0.5
D016	2,4-D	0.1	10.0
D017	2,4, 5-TP Silvex	0.01	1.0

*Source: May 19, 1980, Federal Register, Page 33122, which is based on 100 times the Primary Drinking Water Standards.

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to what mix of these and other practices will be required to meet regulatory standards for land disposal will be a matter of state concern." The guidelines are intended, therefore, to assist the states in the development of their solid waste management plan.

The EPA's Solid Waste Disposal Guidelines are divided into the following sections: site selection, design criteria, leachate control, gas control (not a problem with ash), runoff control, site operation, and monitoring. A brief summary of each section of the guidelines which may be applicable to ash disposal are contained in the following paragraphs.

Site Selection. Site selection for solid waste disposal sites is to be based upon an evaluation of ground and surface water conditions; geology, soils, and topographic features; solid waste type and quantity; and social, geographic, and economic factors. Aesthetic and environmental impacts are also to be considered. To insure that these factors are given proper consideration, the EPA has recommended the following site selection procedures:

- Environmentally sensitive areas, while not prohibited, should receive lowest priority as potential disposal sites.
- Applicable requirements of the Clean Water Act and the Endangered Species Act must be complied with.
- Zones of active faults and karst terrain should be avoided.
- Cost effectiveness should be considered.
- Sites traversed by sewage, water, or other pipes should be rejected.
- On-site soils should be evaluated with respect to their effect on performance and operation of the site.
- Sites should be accessible in all weather conditions.
- The socio-economic effect of the disposal site on neighborhoods in which the site is located and through which vehicles must travel should be evaluated.

Design Criteria. The EPA has outlined the following steps for the design of non-hazardous solid waste disposal sites:

- The quantity of waste to be disposed should be used as a basis for design.

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- Groundwater resources in the vicinity of the site should be surveyed to establish background data on water quality; depth, direction, and rate of flow of groundwater; and potential interaction between the landfill and ground and surface waters; and hydraulic conductivity and attenuating capacity of the site soils.
- The quality, quantity, source, and seasonal variations in the surface waters of the area should be determined.
- The location of the 100-year floodplain should be determined.
- A water balance for the site should be established.
- Leachate control measures should be incorporated as required.
- An analysis of environmental impacts, economic factors, future use, and waste characteristics and their impacts should be included.
- Minimum requirements for design, construction, operation and maintenance plans are also included in the guidelines.

Leachate Control. The guidelines identify two approaches which can be taken in the management of leachate. One approach involves relying solely on the attenuating capacity of soil while the other relies on containment of leachate generated at the site by liners. Under the guidelines, leachate control systems which adopt either of these approaches or fall somewhere between these extremes may be used. The four alternate designs shown in Figure 4-2 are included in the guidelines. The following are also recommended:

- Unless the groundwater in the area is already unusable, the bottom of the landfill should be maintained at least 5 feet (1-1/2 meters) above the seasonal high water table.
- Runoff diversion structures, capable of diverting all runoff from a 10-year, 24-hour storm, should be constructed.
- If needed, dikes to prevent inundation by the 100-year flood should be included.
- Final grade of the landfill should be between 2 and 30 percent so that erosion and infiltration are minimized.
- Terraces should be included at 20-foot (6 meter) vertical intervals.
- The final soil cover should be seeded to minimize erosion and maximize evapotranspiration.
- Either low permeability or high permeability soils should be used as cover depending upon design considerations for leachate control.

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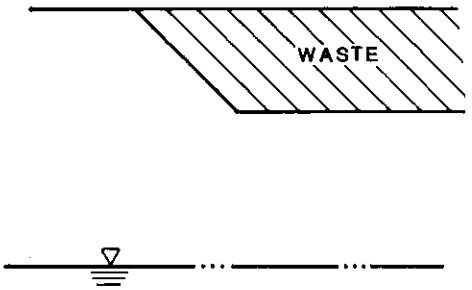
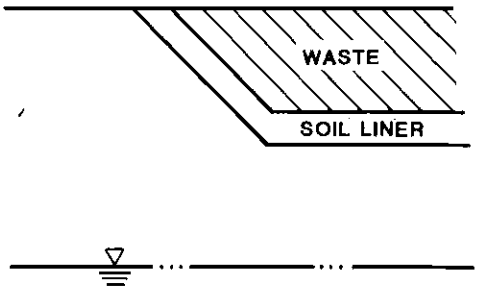


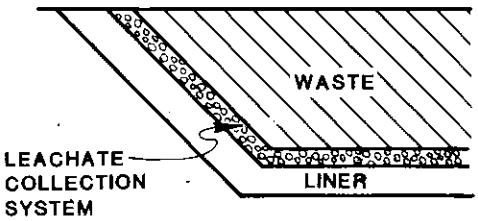
CASE I

NATURAL HYDROGEOLOGIC CONDITIONS SUFFICIENT TO PREVENT CONTAMINATION, NO CONTROL REQUIRED



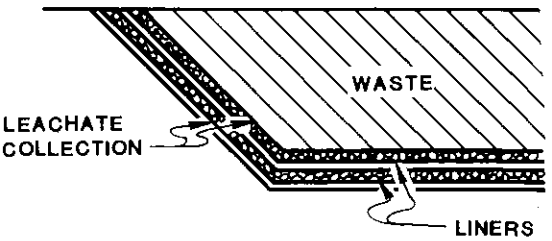
CASE II

LINER REDUCES AND CONTROLS LEACHATE QUANTITY AND IMPROVES QUALITY BY SOIL ATTENUATION. ADDITIONAL LEACHATE IMPROVEMENT BY DILUTION OR ATTENUATION IN SITE SOILS



CASE III

NATURAL CONDITIONS PROVIDE ONLY MINIMUM LEACHATE IMPROVEMENT. LINER AND LEACHATE COLLECTION REQUIRED.



CASE IV

NATURAL CONDITIONS PROVIDE LITTLE OR NO LEACHATE IMPROVEMENT. MULTIPLE LINERS AND LEACHATE COLLECTION REQUIRED.

Figure 4-2. Leachate Control Methods for Non-Hazardous Waste Disposal Sites

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- Liner materials should have a coefficient of permeability of 0.1 ft/year (1 x 10^{-7} cm/sec) or less.
- Minimum thickness for in-place or constructed soil liners is 12 inches (30 centimeters) and for synthetic membranes is 20 mils.
- Synthetic liners should rest on and be covered by sufficient granular material to prevent puncture.
- Liner grades of one percent or more are required.
- Collected leachate must be treated before discharge.

Runoff Control. The following requirements for runoff control are also included:

- Locate the landfill in an area where drainage from adjacent lands onto the site is minimal.
- Construct suitable runoff diversion ditches surrounding the site.
- Slope the landfill surface to grades not in excess of 30 percent.
- Use well compacted, fine-grained soil for final cover.
- Route off-site runoff and uncontaminated on-site runoff to a sedimentation basin prior to discharge. Contaminated on-site runoff must be collected and decontaminated prior to discharge.

Site-Operation. Many of the recommended operating procedures are not relevant to ash disposal sites since they are directed primarily toward sanitary landfill practices. A few which are applicable to ash include:

- The completed landfill should be covered with 6 inches (15 centimeters) of clay and 18 inches (45 centimeters) of soil capable of supporting vegetation.
- The waste should be compacted to conserve site capacity.
- Records of waste received, both quantitative and qualitative, should be maintained.
- An on-site source of water for dust control should be provided.
- The landfill should be maintained in an aesthetic manner.
- Upon site closure, a long-term maintenance program should be instituted.

Site Monitoring. A groundwater monitoring system should be installed if the landfill has potential for discharge to underground drinking water sources. No groundwater or leachate monitoring wells should be installed through the

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bottom of the landfill. Samples should be collected from the monitoring wells prior to commencement of disposal operations at the site so that a background level for water quality can be established. Refer to Section 7 for a discussion of monitoring practices.

Criteria for Solid Waste Disposal. The EPA has also published "Criteria for Classification of Solid Waste Disposal Facilities," promulgated under Subtitle D, Section 4004 of the RCRA, which establish performance standards for the land disposal of solid waste. The criteria were issued by the EPA on September 13, 1979 (44 FR 53438). The criteria are designed to define the level of health and environmental protection which a land disposal facility must achieve to avoid the designation of an "open dump."

The test for compliance with the criteria is whether there will be "no reasonable probability of adverse effects on health or the environment" associated with disposal of solid waste at a facility. This is a case by case decision based on the particular circumstances found at each site.

The relationship between the guidelines and the criteria is that "the guidelines are an informational resource which can assist state officials and site operators in determining the particular set of waste management practices which are needed to achieve compliance with the criteria at each site." A site could also satisfy the criteria by employing an approach not discussed in the guidelines, such as an innovative technology.

The criteria consist of eight performance standards or operational techniques which are designed to accomplish the goal of no adverse effect on health or the environment. These criteria include:

- Floodplains,
- Endangered Species,
- Surface Water,
- Groundwater,
- Land Application,
- Disease,
- Air,
- Safety.

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Not all the criteria specifically relate to utility ash disposal. The following is a brief summary of those that do:

- Floodplains - maintenance of the disposal area outside of the 100 year floodplain.
- Endangered Species - facility shall not cause or contribute to the taking of an endangered or threatened species.
- Surface Water - discharge shall not exceed National Pollutant Discharge Elimination System (NPDES) or state water quality requirements.
- Groundwater - facility shall not contaminate an underground drinking water source. Standards are listed in Table 4-5, secondary standards are proposed.
- Air - shall not violate applicable sections of the Clean Air Act.
- Safety - minimize adverse effects involving potential accidents which could be caused by solid waste disposal activities.

A review of the current engineering practice used in the design and construction of disposal sites should be performed prior to design and construction of future sites. Considerable detail on site design is contained in the EPRI FGD Sludge Disposal Manual, CS-1515, and the EPRI Fly Ash Structural Fill Handbook, EA-1281. Federally Mandated Use of Fly Ash in Cement and Concrete. A promising alternative to fly ash disposal is its utilization as a partial replacement in Portland cement and concrete. This utilization has been increasing for several years, but there remains a potential for an even greater utilization, especially if the EPA promulgates its currently proposed guidelines for Federal procurement.

Section 6002 of RCRA calls for the Federal government to mandate its own use of materials recovered from solid waste. This would be done by requiring all Federal agencies (and Federally funded state and local agencies) to maximize the percentages of recovered materials in their day to day procurement. The EPA started to prepare procurement guidelines to meet the requirements of Section 6002, but it was soon apparent that development of these guidelines was an impossible task. The EPA therefore decided to concentrate its efforts on recoverable materials that would have the greatest national benefit. Recovered fly ash, recycled paper products, construction materials, and composted sewage sludge were selected to contribute to the intent of Section 6002. Fly ash was selected for the following reasons:

- Significant solid waste problem.

  In 1978, 48 million tons of fly ash were generated, of which 82 percent was disposed of as waste. Estimates for 1985 are 70 to 80 million tons annually.

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Table 4-5

MAXIMUM GROUNDWATER CONTAMINANT LEVELS*

Parameter	Maximum Level
Interim Primary	
Arsenic	0.05 mg/l
Barium	1.0 mg/l
Cadmium	0.01 mg/l
Chromium (VI)	0.05 mg/l
Fluoride	1.4-2.4 mg/l
Lead	0.05 mg/l
Mercury	0.002 mg/l
Nitrate	10.0 mg/l
Selenium	0.01 mg/l
Silver	0.05 mg/l
Endrin	0.002 mg/l
Lindane	0.004 mg/l
Methoxychlor	0.1 mg/l
Toxaphene	0.005 mg/l
2,4-D	0.01 mg/l
2,4,5-TP Silvex	0.01 mg/l
Radium	5 pci/l
Gross Alpha	15 pci/l
Coliform Bacteria	1/100 ml
Turbidity	1/TU
Secondary (proposed)	
Chloride	250 mg/l
Copper	1 mg/l
Foaming Agents	0.5 mg/l
Hydrogen Sulfide	0.05 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Sulfate	250 mg/l
Total Dissolved Solids	500 mg/l
Zinc	5 mg/l
Color	15 Color Units
Corrosivity	Non-corrosive
Odor	3 Threshold Odor Number
pH	6.5-8.5

*Based on the EPA Interim Primary and Proposed Secondary Drinking Water Standards.

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- Feasible methods of recovery.

  Two-thirds of coal-fired stations have collection and loading facilities for fly ash.

- Technically proven uses.

  The U.S. Army Corps of Engineers has used fly ash concrete in dams for many years. The Georgia Department of Transportation has placed over 3 million cubic yards of fly ash concrete pavement and performance has been good.

- Federal purchasing power.

  Federal funds account for two-thirds of public construction nationally, translating to approximately 23 million tons of cement annually.

In addition to these criteria, the use of fly ash shows many environmental and economic benefits. The primary advantages are:

- Reduced energy consumption, especially in the Portland cement industry, which accounts for two percent of the total energy used by U.S. industry,
- Reduced cement cost, largely a result of energy savings,
- Reduced amount of land used for fly ash disposal, cement raw material mining, and cement waste products disposal,
- Reduced air and water pollution.

In light of this reasoning, and the Section 6002 requirement, the EPA proposed a "Guideline for Federal Procurement of Cement and Concrete Containing Fly Ash" on November 20, 1980 in the Federal Register (p. 76906; 40 CRF 249). The EPA was undecided whether to require or encourage fly ash use and invited public comment on the matter. It was reasoned that a fly ash requirement would be counterproductive and unnecessary, considering that the economics of fly ash use allow it to compete fairly in the open market. The guideline, in effect, would actually deregulate fly ash use somewhat by recommending the elimination of current Federal specifications that discriminate against the use of recovered materials, or that require virgin materials. Some of the highlights of the proposed guideline are listed below:

- Designation of fly ash use in cement as a product area requiring affirmative procurement.
- Elimination of agency specifications that (1) exclude fly ash as a component in cement or concrete, or (2) require virgin materials.

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- Requirement that in purchases of $10,000 or more, agencies must use fly ash cement or concrete unless: (1) such cement is not available, (2) such cement is unreasonable priced, (3) the purchase will result in an unsatisfactory level of competition, or (4) such cement does not meet reasonable performance standards.
- Certification by vendors of the amount of fly ash incorporated in their product, although no minimum or maximum level is specified.
- Recommendation for lengthening of the time periods used in evaluating concrete strength standards.
- Responsibility for providing a satisfactory product remains with the contractor.

The status of the proposed guideline as of June, 1981, remains unchanged. The public comment period closed in January, 1981, and the guideline is expected to be finalized in September, 1981. The greatest change between the proposed and final versions is the possibility of shifting from requirement to encouragement of fly ash use.

Clean Water Act

The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, established regulations directed toward attaining the goal of zero discharge of water pollutants in the United States by 1985. Under this law the Environmental Protection Agency established discharge limits for various industries and for various pollutants. This act was amended again in 1977 as the Clean Water Act with implementation via the National Pollutant Discharge Elimination System.

The current new source performance standards (NSPS) for steam-electric power plant ash disposal ponds are set at the following discharge limits:

	Bottom Ash Transport Water	Fly Ash Transport Water
pH	6-9	6-9
PCB (mg/l)	0	0
Total Suspended Solids (mg/l)	100/30*	100/30*
Oil and Grease (mg/l)	20/15**	20/15**

*100/30 designates a monthly maximum of 100 mg/l with a monthly average of 30 mg/l.

**20/15 designates a monthly maximum of 20 mg/l with a monthly average 15 mg/l.

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The current new source performance standards for discharge (runoff) from dry ash disposal sites are less stringent than the discharge limits for ash ponds. The NSPS for dry coal ash disposal area runoff have been set at a monthly average of 50 milligrams per liter total suspended solids. While less stringent than the standards for coal ash ponds, the dry disposal site runoff standards are strict and will dictate that considerable attention be paid to site restoration and vegetation. Additional details on these subjects are contained in Section 8 of this manual.

On October 14, 1980, the EPA proposed the following NSPS for steam-electric power plant ash disposal ponds:

	Bottom Ash Transport Water	Fly Ash Transport Water
pH	6-9	6-9
PCB (mg/l)	0	0
Total Suspended Solids (mg/l)	100/30*	-
Oil and Grease (mg/l)	20/15**	-
Copper (Cu) (mg/l)	-	detectible limit (0.005)
Nickel (Ni) (mg/l)	-	detectible limit (0.010)
Zinc (Zn) (mg/l)	-	detectible limit (0.010)
Arsenic (As) (mg/l)	-	detectible limit (0.003)
Selenium (Se) (mg/l)	-	detectible limit (0.004)

*100/30 designates a monthly maximum of 100 mg/l with a monthly average of 30 mg/l.

**20/15 designates a monthly maximum of 20 mg/l with a monthly average of 15 mg/l.

These proposed standards will considerably limit the ability to discharge from new fly ash ponds without treatment of the effluent, due to the allowable metal concentration requirements.

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The NSPS proposed by the EPA did not specifically include dry coal ash disposal area discharges. These standards may be defined by the states operating the NPDES system or imposed by the permit writer, based on his best engineering judgement. Table 4-6 identifies those states and territories which have approved NPDES permit programs.

SUMMARY OF FEDERAL LEGISLATION

The resource Conservation and Recovery Act (RCRA) is the federal regulation with the greatest degree of impace on coal ash disposal. However, the Clean Water Act (CWA) could also significantly affect coal ash disposal.

Fly ash and other coal combustion wastes are currently excluded from hazardous waste regulation under Subtitle C of RCRA. These wastes are regulated under Subtitle D of RCRA, State, and/or Regional Solid Waste Plans. Although the regulations which will control ash disposal in the future have not been promulgated to date, the following can be concluded:

- Some coal ashes may ultimately be classified as hazardous based on RCRA toxicity criteria. This classification would most possibly be due to their heavy metal/trace element contents. How much ash will be classified as hazardous on this basis is presently unknown. Two other possible areas under which some ash may be classified as a hazardous waste are mutagenicity and radioactivity.

- The EPA is currently conducting studies to determine which disposal regulations are appropriate for coal ashes. The results of these studies are expected in late 1983.

- Disposal of coal ash classified as non-hazardous will be regulated by the states. State regulations governing disposal of non-hazardous solid waste are to be consistent with proposed EPA guidelines, published in the Federal Register, March 26, 1979. These guidelines are more comprehensive and stringent than most current state regulations.

- Whether ash is classified as a hazardous waste and controlled by the EPA, or classified as a non-hazardous waste and controlled by the states in compliance with federal guidelines, it appears likely that future regulations will be more stringent than those governing ash disposal in the past. These regulations will affect most aspects of ash disposal including siting, protection of groundwater and surface water, monitoring, operation, and closure.

- Current NPDES discharge requirements for both dry and wet disposal are not prohibitive and can usually be met without treatment. However, the proposed NSPS could possibly eliminate discharge (without treatment) from fly ash ponds due to the metal concentration standards.

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Table 4-6

FEDERAL NPDES PERMIT PROGRAM

(Effective 1/15/81)

States and Territories
(alphabetical listing)

Approved	Not Approved
1. Alabama*,**	1. Alaska
2. California*	2. American Samoa
3. Colorado	3. Arizona
4. Connecticut	4. Arkansas
5. Delaware	5. District of Columbia
6. Georgia*	6. Florida
7. Hawaii*	7. Guam
8. illinois*	8. Idaho
9. Indiana*	9. Kentucky
10. Iowa*	10. Louisiana
11. Kansas	11. Maine
12. Maryland	12. Massachusetts
13. Michigan*	13. New Hampshire
14. Minnesota*,**	14. New Jersey
15. Mississippi	15. New Mexico
16. Missouri*	16. Oklahoma
17. Montana	17. Puerto Rico
18. Nebraska*	18. Rhode Island
19. Nevada*	19. South Dakota
20. New York*	20. Texas
21. North Carolina	21. Trust Territories
22. North Dakota	22. Utah
23. Ohio	23. West Virginia
24. Oregon*	
25. Pennsylvania*	
26. South Carolina*	
27. Tennessee	
28. Vermont	
29. Virgin Islands	
30. Virginia	
31. Washington	
32. Wisconsin*,**	
33. Wyoming	

*Approved to regulate Federal Facilities under NPDES.

**Approved State Pretreatment Program.

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- The overall impact of other federal regulations is unclear. It appears that they would only be significant on a site by site basis.

STATE PROGRAMS

The EPA has published the "Guidelines for Development and Implementation of State Solid Waste Management Plans," issued July 31, 1979 (44 FR 45066), which outlines the minimum requirements for state solid waste management plans, as required by Section 4003 of the RCRA. The EPA will provide financial assistance to help the states develop and implement these plans.

Congress intended that the states and localities retain the overall responsibility for the planning and operation of solid waste management programs under Subtitle D of the RCRA. In accepting a Subtitle D grant, the state agrees to develop a plan for closing or upgrading existing open dumps (facilities found to be in violation of the criteria), and to prohibit new open dumps. The state also agrees to work toward development of regulatory powers to implement the plan.

The annual state grant application (the "work program") will be developed with public participation and include a list of those facilities which the state intends to evaluate against the criteria during the year.

State Coal Ash Disposal Regulations

As defined by the RCRA Subtital D, regulations pertaining to the disposal of non-hazardous wastes are to be promulgated by individual states with guidance from Epa. Due to the non-hazardous status of coal ashes as currently defined, these state regulations will, for the immediate future at least, define their disposal requirements. Based on those criteria published by EPA, states must comply with the following minimum requirements for those waste disposal facilities:

- May not restrict the flow of or be washed out by a 100-year flood.
- May not disrupt any endangered species or their habitats.
- May not cause point or non-point surface water pollution under the Clean Water Act; i.e., NPDES requirements must be met.
- May not contaminate groundwater beyond the property boundaries. Maximum contaminant levels are currently based on the interim primary drinking water standards. However, it has been proposed that the proposed secondary drinking water standards be added to the maximum contaminant levels. The primary and secondary drinking water standards were delineated in Table 4-5.

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Requirements for surface and groundwater monitoring are not stated exactly. However, monitoring is implied in the performance standards and by the requirement that the site owner must prove that the waste is not polluting the groundwater. Monitoring is the best practical way to document compliance.

In reviewing individual state regulations, the ten states that have the greatest coal-fired generating capacity were surveyed. These states and their generating capacities are:

State	Existing Coal Generating Capacity-1979 (MW)
Ohio	23,379
Pennsylvania	18,706
Illinois	16,750
Indiana	14,706
West Virginia	12,605
Kentucky	12,337
North Carolina	11,259
Alabama	10,412
Missouri	10,265
Tennessee	10,048

The regulations in these states vary widely. Only one state, Pennsylvania, has regulations specifically for coal ash. There are some generalizations that may be made:

- Most states loosely apply sanitary landfill regulations to coal ash disposal. Because of their special nature, and large volumes, ash disposal operations are invariably evaluated for permits on a case by case basis.

- Many of the regulations designed for municipal wastes are not sensible or necessary when applied to coal ash disposal. These requirements are usually waived or altered. Some examples:

  --Daily Cover

  --Vector Control

  --Organic Leachate Control

  --Open burning

  Conversely, there may be properties of fly ash that cause special problems not anticipated in sanitary landfill rules.

- There are certain sanitary landfill rules that do apply to coal ash and are common to a majority, if not all, of the ten states:

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--Location of the fill outside of the 100-year floodplain

--No contamination of ground or surface water

--Control of leachate

--Diversion of on-site runoff and run-on precipitation

--Dust control

--Two feet of final topsoil cover with revegetation

--Erosion and sediment control

--A permit

A detailed description of the disposal plan is required before permitting and construction. This plan may include most or all of the following information:

--Pre- and post-construction topography

--Aerial photographs

--Existing land uses

--Public and private utilities

--Excavation plans

--Residential dwellings and water wells

--Hydrological, hydrogeological, and geotechnical details

--Soil and permeability data

--Water table levels

--Surface and groundwater quality and quantity

--Meteorology

--Types and quantities of waste

--Leachate estimates and leachate control plans

--Liner properties

--Intended final use of the land

--Post-closure care

--Financial responsibility

Even though this information is used for determining acceptance or denial of a permit, the technical criteria used by each permitting agency are usually not

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complete in a state's published regulations. Once again, all information is integrated on a case by case basis.

- In the wake of RCRA, most states are now considering more stringent and more specialized solid waste regulations. Some states are writing specific rules for coal ash.

- As with the EPA, coal ash is not considered hazardous by any state. However, a few states may require testing of ash for toxicity to determine if any state hazardous waste regulations apply.

Table 4-7 has been compiled to summarize the siting, design, and closure regulations for the ten states. The following are summaries of the status of each of the ten states' solid waste regulations.

- Alabama

  --Current regulations are fairly general and coal ash is not mentioned. These regulations are somewhat dated (1972), but new regulations are currently being drafted. For ash, the new regulations will require weekly wetting and compacting, leachate analysis, and groundwater monitoring.

- Illinois

  --Coal ash is considered a special waste in Illinois. Hazardous waste is a subcategory of special wastes, and coal ash could be considered hazardous, depending upon toxicity. The current regulations (1973) are being revised; at present, they do not mention coal ash. Currently, Illinois ash is subject to sanitary landfill rules with special provisions included on a case by case basis.

- Indiana

  --The current solid waste regulations in Indiana (1974) are now being revised and may include coal ash guidelines. Presently ash disposal operations are considered case by case, and certain unnecessary rules are relaxed. The prime concerns are groundwater pollution and dust control.

- Kentucky

  --Coal ash in Kentucky will fall under the category of "non-hazardous" or "special". Regulations for high volume, low toxicity, special wastes are now being written. Current regulations (1975) do not provide specific guidelines for ash, so modified sanitary landfill rules are followed.

- Missouri

  --The current regulations (1973) do not specify coal ash, but designs are encouraged such that the ash may lie uncovered for 60 days, and then the final cover be placed. The regulations are currently being revised.

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Table 4-7

Solid Waste Disposal Regulation Summary

		FEDERAL	ALABAMA		ILLINOIS	
LAWS AND REGULATIONS	NAME OF LAW	RESOURCE CONSERVATION AND RECOVERY ACT	SOLID WASTE DISPOSAL DISPOSAL ACT #77(1969)		ENVIRONMENTAL PROTECTION ACT	
	CURRENT REGULATIONS	40 CFR 257	TITLE 22 SECTIONS 346-351		ILLINOIS POLLUTION CONTROL BOARD CHAP. 7	
	EFFECTIVE DATE	OCTOBER 15, 1979	SEPTEMBER 17, 1972		JULY 27, 1973	
	NAME AND ADDRESS OF REGULATORY AUTHORITY	USEPA OFFICE OF SOLID WASTE WASHINGTON, D.C. 20460 (202) 755-9206	DEPARTMENT OF PUBLIC HEALTH DIV. OF SOLID WASTES MONTGOMERY, ALABAMA 36104 (205) 832-6728		ILLINOIS EPA DIV. OF LAND POLLUTION CONTROL SPRINGFIELD, ILLINOIS 62705 (217) 782-6760	
	CLASSIFICATION OF FLY ASH	NON-HAZARDOUS	NON-HAZARDOUS		SPECIAL WASTE; COULD BE HAZARDOUS, DEPENDING ON TOXICITY	
	THE FOLLOWING CRITERIA APPLY TO:	NON-HAZARDOUS SOLID WASTE	N-H SOLID WASTE	FLY ASH	N-H SOLID WASTE	FLY ASH
SITING CRITERIA	FLOODPLAIN	100 YEAR				
	LAND USE					
	VERTICAL PROXIMITY TO GROUNDWATER					
	PROXIMITY TO SURFACE WATER					
	PRE-OPERATION WATER MONITORING	ENCOURAGED				
	SOIL AND PERMEABILITY					
	OTHER	ENDANGERED SPECIES				
DESIGN CRITERIA	GROUNDWATER MONITORING	ENCOURAGED		X	X	
	SURFACE WATER MANAGEMENT	NPDES PERMIT REQUIRED				
	SEPARATION BETWEEN FILL AND WATER TABLE					
	LEACHATE CONTROL	NO GROUND OR SURFACE WATER CONTAMINATION		X	X	
	LINERS					
	RUNOFF/RUN-ON DIVERSION					
	TEMPORARY COVER			WEEKLY	DAILY	
	DUST CONTROL				X	
	OTHER					
CLOSURE CRITERIA	FINAL COVER		2 FT.		2 FT.	
	MINIMUM SLOPE					
	MAXIMUM SLOPE					
	REVEGETATION		X			
	EROSION & SEDIMENT CONTROL					
	POST-CLOSURE MAINTENANCE PERIOD				3 YRS.	
	POST-CLOSURE LEACHATE CONTROL				3 YRS.	
	PROPOSED LAND USE STATEMENT				X	
	CORRECTIVE MEASURES				3 YRS.	
	FINANCIAL RESPONSIBILITY				OWNER	
	OTHER					

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Table 4-7
(Continued)

		FEDERAL	INDIANA		KENTUCKY	
LAWS AND REGULATIONS	NAME OF LAW	RESOURCE CONSERVATION AND RECOVERY ACT	REFUSE DISPOSAL ACT, ENVIRONMENTAL MANAGEMENT ACT		KENTUCKY REVISED STATUTE 224 "ENVIRONMENTAL PROTECTION"	
	CURRENT REGULATIONS	40 CFR 257	RULE 330 IAC 4		401 KAR 2:010	
	EFFECTIVE DATE	OCTOBER 15, 1979	AUGUST 15, 1974		JUNE 4, 1980 (HAZARDOUS) MARCH 13, 1975 (SOLID)	
	NAME AND ADDRESS OF REGULATORY AUTHORITY	USEPA OFFICE OF SOLID WASTE WASHINGTON, D.C. 20460 (202) 755-9206	INDIANA STATE BOARD OF HEALTH SOLID WASTE MGMT. SECTION INDIANAPOLIS, INDIANA 46206 (317) 633-0176		DEPT. OF NATURAL RESOURCES DIV. OF HAZ. MATERIALS AND WASTE MGMT., FRANKFORT, KY 40601 (502) 564-6716	
	CLASSIFICATION OF FLY ASH	NON-HAZARDOUS	NON-HAZARDOUS		EITHER NON-HAZARDOUS OR SPECIAL	
	THE FOLLOWING CRITERIA APPLY TO:	NON-HAZARDOUS SOLID WASTE	N-H SOLID WASTE	FLY ASH	N-H SOLID WASTE	FLY ASH
SITING CRITERIA	FLOODPLAIN	100 YEAR	100 YR. W/ APPROVAL		5 YR., 100 YR. WITH PERMISSION	5 YR., 100 YR. WITH PERMISSION
	LAND USE		ZONING		LOCAL ZONING	LOCAL ZONING
	VERTICAL PROXIMITY TO GROUNDWATER		X		2 FT. OR MORE	2 FT. OR MORE
	PROXIMITY TO SURFACE WATER		X		200 FT.	200 FT.
	PRE-OPERATION WATER MONITORING	ENCOURAGED			X	X
	SOIL AND PERMEABILITY		X		1 FT/1 X 10^{-7} CMS	1 FT/1 X 10^{-7} CMS
	OTHER	ENDANGERED SPECIES	600 FT. FROM DWELLING		WETLANDS, HISTORICAL, ENDANGERED SPECIES, ENCOURAGE USE OF ABANDONED LANDS	
DESIGN CRITERIA	GROUNDWATER MONITORING	ENCOURAGED	COD, PH, PE, CL, COND., OTHERS	X	X	CASE-BY-CASE
	SURFACE WATER MANAGEMENT	NPDES PERMIT REQUIRED			DIVERSION	DIVERSION
	SEPARATION BETWEEN FILL AND WATER TABLE		X		2 FT.	2 FT.
	LEACHATE CONTROL	NO GROUND OR SURFACE WATER CONTAMINATION	X		CONTAINED ON SITE	CONTAINED ON SITE
	LINERS				X	X
	RUNOFF/RUN-ON DIVERSION		X		10 YR./24 HR. STORM	10 YR./24 HR. STORM
	TEMPORARY COVER		6 INCHES		DAILY 6"	AS NEEDED
	DUST CONTROL		X	X	NO FUGITIVE DUST	NO FUGITIVE DUST
	OTHER				DAILY COMPACTION	COMPACTION IN THIN LIFTS
CLOSURE CRITERIA	FINAL COVER		2 FT.		30 IN. OR MORE	30 IN. OR MORE
	MINIMUM SLOPE		2%		3%	3%
	MAXIMUM SLOPE				3:1	3:1
	REVEGETATION		X		LEGUMES AND PERENNIAL GRASSES	X
	EROSION & SEDIMENT CONTROL		X		X	X
	POST-CLOSURE MAINTENANCE PERIOD				2 YRS.	2 YRS.
	POST-CLOSURE LEACHATE CONTROL		NOT TREATED		X	X
	PROPOSED LAND USE STATEMENT		REQUESTED		X	X
	CORRECTIVE MEASURES				X	X
	FINANCIAL RESPONSIBILITY		NONE		OWNER POSTS BOND	OWNER POSTS BOND
	OTHER		RECORD LANDFILL WITH LOCAL LAND RECORDING AUTHORITY		MONITORING ON CASE-BY-CASE BASIS	

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Table 4-7
(Continued)

		FEDERAL	MISSOURI		NORTH CAROLINA	
LAWS AND REGULATIONS	NAME OF LAW	RESOURCE CONSERVATION AND RECOVERY ACT	MISSOURI SOLID WASTE MANAGEMENT LAW		SOLID WASTE MANAGEMENT ACT	
	CURRENT REGULATIONS	40 CFR 257	TITLE 10 DIVISION 80		10 NCAC 10 C	
	EFFECTIVE DATE	OCTOBER 15, 1979	JUNE 30, 1973		MAY 15, 1978	
	NAME AND ADDRESS OF REGULATORY AUTHORITY	USEPA OFFICE OF SOLID WASTE WASHINGTON, D.C. 20460 (202) 755-9206	DEPT. OF NATURAL RESOURCES DIV. OF ENVIRONMENTAL QUALITY JEFFERSON CITY, MO 56101 (314) 751-4422		DIV. OF HEALTH SERVICES SOLID WASTE BRANCH RALEIGH, NC 27602 (919) 733-2178	
	CLASSIFICATION OF FLY ASH	NON-HAZARDOUS	NON-HAZARDOUS			
	THE FOLLOWING CRITERIA APPLY TO:	NON-HAZARDOUS SOLID WASTE	N-H SOLID WASTE	FLY ASH	N-H SOLID WASTE	FLY ASH
SITING CRITERIA	FLOODPLAIN	100 YEAR	100 YR.		100 YR.	
	LAND USE		ZONING		ZONING ORDINANCES	
	VERTICAL PROXIMITY TO GROUNDWATER				X	
	PROXIMITY TO SURFACE WATER				X	
	PRE-OPERATION WATER MONITORING	ENCOURAGED			X	
	SOIL AND PERMEABILITY		X		X	
	OTHER	ENDANGERED SPECIES				
DESIGN CRITERIA	GROUNDWATER MONITORING	ENCOURAGED	X		X	
	SURFACE WATER MANAGEMENT	NPDES PERMIT REQUIRED	MISSOURI CLEAN WATER COMMISSION		MONITOR AT LEAST ANNUALLY	
	SEPARATION BETWEEN FILL AND WATER TABLE				X	
	LEACHATE CONTROL	NO GROUND OR SURFACE WATER CONTAMINATION	X		X	
	LINERS		X			
	RUNOFF/RUN-ON DIVERSION		X		X	
	TEMPORARY COVER			60 DAYS	DAILY	
	DUST CONTROL		X		X	
	OTHER		ON-SITE DRAINAGE DESIGN FOR 20-YEAR STORM			
CLOSURE CRITERIA	FINAL COVER		2 FT.		2 FT.	
	MINIMUM SLOPE				X	
	MAXIMUM SLOPE		33%		X	
	REVEGETATION		X		X	
	EROSION & SEDIMENT CONTROL				X	
	POST-CLOSURE MAINTENANCE PERIOD				PERPETUAL	
	POST-CLOSURE LEACHATE CONTROL		LONG AS NECESSARY			
	PROPOSED LAND USE STATEMENT				X	
	CORRECTIVE MEASURES				PERPETUAL	
	FINANCIAL RESPONSIBILITY					
	OTHER		FILE SITE WITH COUNTY RECORDER OF DEEDS			

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Table 4-7
(Continued)

		FEDERAL	OHIO		PENNSYLVANIA	
LAWS AND REGULATIONS	NAME OF LAW	RESOURCE CONSERVATION AND RECOVERY ACT			SOLID WASTE MANAGEMENT ACT OF 1980, ACT 97	
	CURRENT REGULATIONS	40 CFR 257	OAC - 3745-27 AND 37		CHAP. 75 - SW MANAGEMENT 75.37 - FLY ASH	
	EFFECTIVE DATE	OCTOBER 15, 1979	JULY 29, 1976		SEPTEMBER 5, 1980	
	NAME AND ADDRESS OF REGULATORY AUTHORITY	USEPA OFFICE OF SOLID WASTE WASHINGTON, D.C. 20460 (202) 755-9206	OHIO EPA DIV. OF SOLID WASTES COLUMBUS, OHIO 43215 (614) 466-8934		DEPT. OF ENVIRONMENTAL RES. DIV. OF SOLID WASTE MGMT. HARRISBURG, PA 17120	
	CLASSIFICATION OF FLY ASH	NON-HAZARDOUS	SOLID WASTE IF TOXIC, UNREGULATED IF NON-TOXIC		NON-HAZARDOUS	
	THE FOLLOWING CRITERIA APPLY TO:	NON-HAZARDOUS SOLID WASTE	SOLID WASTE	FLY ASH	N-H SOLID WASTE	FLY ASH
SITING CRITERIA	FLOODPLAIN	100 YEAR	100 YR.		100 YR.	
	LAND USE		NOT IN SAND OR GRAVEL PIT OR QUARRY			
	VERTICAL PROXIMITY TO GROUNDWATER		- 5 FT. -			
	PROXIMITY TO SURFACE WATER		200 FT.			
	PRE-OPERATION WATER MONITORING	ENCOURAGED	X			
	SOIL AND PERMEABILITY		X		$<1 \times 10^{-7}$ CM/S	X
	OTHER	ENDANGERED SPECIES	NOT TO BE LOCATED WITHIN 1000 FT OF A WATER WELL IN USE			
DESIGN CRITERIA	GROUNDWATER MONITORING	ENCOURAGED	SEMI-ANNUAL		MINIMUM 3 WELLS QUARTERLY SAMPLING	
	SURFACE WATER MANAGEMENT	NPDES PERMIT REQUIRED			CLEAN STREAMS LAW	CLEAN STREAMS LAW
	SEPARATION BETWEEN FILL AND WATER TABLE				4 FT.	
	LEACHATE CONTROL	NO GROUND OR SURFACE WATER CONTAMINATION	X		X	X
	LINERS				VERY DETAILED SPECIFICATIONS	
	RUNOFF/RUN-ON DIVERSION		X		X	X
	TEMPORARY COVER					
	DUST CONTROL		X		X	
	OTHER				DRAINAGE: 10 YR.-1HR.	2 FT. LAYERS & COMPACTION
CLOSURE CRITERIA	FINAL COVER		2 FT.		2 FT.	2 FT.
	MINIMUM SLOPE		1%		1%	1-3%
	MAXIMUM SLOPE		25%		15%	15-33%
	REVEGETATION		X		X	X
	EROSION & SEDIMENT CONTROL		3 YRS.		10 YRS.	AS LONG AS NECESSARY
	POST-CLOSURE MAINTENANCE PERIOD		3 YRS.		ESTIMATE AMT. OF LEACHATE FOR 10 YRS.	AS LONG AS NECESSARY
	POST-CLOSURE LEACHATE CONTROL		X			
	PROPOSED LAND USE STATEMENT		X			AS LONG AS NECESSARY
	CORRECTIVE MEASURES				OWNER POSTS BOND, AMT. SET BY DER	
	FINANCIAL RESPONSIBILITY					
	OTHER				PREMATURE SITE CLOSING OR ABANDONMENT FORFEITS BOND	

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Table 4-7
(Continued)

		FEDERAL	TENNESSEE		WEST VIRGINIA	
LAWS AND REGULATIONS	NAME OF LAW	RESOURCE CONSERVATION AND RECOVERY ACT	TENNESSEE SOLID WASTE DISPOSAL ACT		WATER POLLUTION CONTROL ACT	
	CURRENT REGULATIONS	40 CFR 257	TENN. CODE SEC. 53-4301 TO 53-4315 AND 53-4321		CHAPTER 20, ARTICLE 5A WEST VIRGINIA CODE	
	EFFECTIVE DATE	OCTOBER 15, 1979	JULY 1, 1977		MARCH 12, 1978	
	NAME AND ADDRESS OF REGULATORY AUTHORITY	USEPA OFFICE OF SOLID WASTE WASHINGTON, D.C. 20460 (202) 755-9206	DEPT. OF PUBLIC HEALTH DIV. OF SOLID WASTE MGMT. NASHVILLE, TN 37219		DEPT. OF NATURAL RESOURCES DIV. OF WATER RESOURCES CHARLESTON, WV 25311 (304) 348-0375	
	CLASSIFICATION OF FLY ASH	NON-HAZARDOUS	NON-HAZARDOUS		CLASS I (WATER POLLUTION POTENTIAL)	
	THE FOLLOWING CRITERIA APPLY TO:	NON-HAZARDOUS SOLID WASTE	N-H SOLID WASTE	FLY ASH	INDUSTRIAL WASTE	FLY ASH GUIDELINES
SITING CRITERIA	FLOODPLAIN	100 YEAR	100 YR.		100 YR.	
	LAND USE		ZONING ORDINANCES			
	VERTICAL PROXIMITY TO GROUNDWATER				X	
	PROXIMITY TO SURFACE WATER					
	PRE-OPERATION WATER MONITORING	ENCOURAGED				
	SOIL AND PERMEABILITY				X	
	OTHER	ENDANGERED SPECIES				
DESIGN CRITERIA	GROUNDWATER MONITORING	ENCOURAGED			X	CASE BY CASE
	SURFACE WATER MANAGEMENT	NPDES PERMIT REQUIRED	IN WATER QUALITY CONTROL ACT OF 1971		MONITORING	WATER POLLUTION CONTROL PERMIT
	SEPARATION BETWEEN FILL AND WATER TABLE					
	LEACHATE CONTROL	NO GROUND OR SURFACE WATER CONTAMINATION			TREATMENT REQUIRED	
	LINERS				ENCOURAGED	
	RUNOFF/RUN-ON DIVERSION		X		100 YR. 24 HR. STORM	100 YR. 24 HR. STORM
	TEMPORARY COVER		DAILY			
	DUST CONTROL		X			
	OTHER				ALTERNATIVE EMERGENCY STORAGE	
CLOSURE CRITERIA	FINAL COVER		2 FT.		X	X
	MINIMUM SLOPE				X	
	MAXIMUM SLOPE				X	50%
	REVEGETATION					X
	EROSION & SEDIMENT CONTROL				X	<50 MG/L SOLIDS IN DISCHARGE
	POST-CLOSURE MAINTENANCE PERIOD					
	POST-CLOSURE LEACHATE CONTROL				X	
	PROPOSED LAND USE STATEMENT		1 YR.		X	
	CORRECTIVE MEASURES		OPERATOR POSTS BOND			
	FINANCIAL RESPONSIBILITY					
	OTHER					

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- North Carolina

  --Most of the coal ash in North Carolina is placed into ponds; the remainder is handled as a routine solid waste. The current regulations are fairly recent (1979) and there are no anticipated major revisions. Coal ash is not specified in these regulations, therefore ash disposal sites are handled on a site by site basis.

- Ohio

  --In Ohio, coal ash is a solid waste if it is toxic. If it is not toxic, it is not considered a solid waste, and therefore not regulated by the Ohio EPA. If this is the case, ash disposal would probably be governed by federal definition and subject to landfilling. The current regulations were effective in 1976 and do not specify regulations governing coal ash. However, there may soon be guidelines available for ash disposal.

- Pennsylvania

  --Pennsylvania is the only state of the ten that details coal ash disposal. Ash is subject to all solid waste regulations except when superseded by the coal ash section of the regulations. Also included are provisions for incorporating slag and FGD sludge into the fly and bottom ash. The regulations are very recent (1980) and there are no upcoming revisions.

- Tennessee

  --Coal ash in Tennessee is considered a solid waste, except for certain waivers. The current regulations are relatively dated (1972) and coal ash is not mentioned. Groundwater monitoring will probably be incorporated into any upcoming revisions.

- West Virginia

  --Coal ash in West Virginia is regulated by the Water Resources Division of the Department of Natural Resources. However, coal ash is not directly addressed in the regulations. (Solid Waste Regulations, 1974; Water Quality Regulations, 1980.) There may be upcoming guidelines for coal ash.

REFERENCES

1. The Impact of RCRA on Solid Waste Streams Generated by the Electric Power Industry - A Technical Planning Study. Palo Alto, California: Electric Power Research Institute, May 1978. TPS-78-779.

2. C. E. Chris, G. L. Fisher, and J. E. Lammert. "Mutagenicity of Filtrates from Respirable Coal Fly Ash." Science, January 6, 1978, pp. 73-75.

3. S. J. Morris and G. Bobrowski. "The Determination of 226 Ra, 214 Pb, and 214 Bc in Fly Ash Samples from Eighteen (18) Coal-Fired Power Plants in the United States." in Proceedings of the Fifth International Ash Utilization Symposium, February 1979.

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4. Landfill Disposal of Solid Waste - Proposed Guideline, published in the March 26, 1979 Federal Register (44 FR 18138).

5. Guidelines for Development and Implementation of State Solid Waste Management Plans, published in the July 31, 1979 Federal Register (44 FR 45066).

6. Criteria for Classification of Solid Waste Disposal Facilities and Practices; Final, Interim Final, and Proposed Regulations, published in the September 13, 1979 Federal Register (44 FR 53438).

7. Classifying Solid Waste Disposal Facilities, publication SW-828, March 1980, Office of Water and Waste Management, U.S. Environmental Protection Agency.

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Section 5

CONCEPTUAL DESIGN OF ASH DISPOSAL SYSTEMS

INTRODUCTION

In developing cost estimates for coal ash disposal, it is first necessary to create a conceptual design of the ash disposal system as a whole, including in-plant handling, out-of-plant transport, and ash placement at the disposal site. This section outlines the following items involved in an ash disposal system:

- Determination of ash quantities,
- In-plant handling of the ash,
- Out-of-plant transport of the ash,
- Ash placement at the disposal site,
- Liner installation procedures.

The intent is to provide background information necessary for site selection as outlined in Section 1, and for cost estimating as discussed in Section 9. In general, ash quantities are used to size disposal system components which, in turn, are used to estimate operating and capital costs. Comparison of conceptual ash disposal systems can be used both as a means of optimizing disposal costs, and as an aid in disposal site selection.

Ash disposal schemes are generally categorized as either wet or dry. Possible combinations of ash disposal system components were described in Section 3. Section 1 examined the factors which influence the selection of a disposal system (ash characteristics, site characteristics, disposal regulations, etc.). Section 4 describes criteria and guidelines to be considered in the design of wet and dry systems and Section 6 illustrates actual disposal systems.

DETERMINATION OF ASH QUANTITIES

An integral part of developing an ash disposal system is the estimation of the amount of ash requiring disposal. The quantity of ash produced is determined by the amount of coal burned, ash content of the coal, boiler type, collection system efficiency, and operating load. The operating load will vary over the life of the

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plant. Generally, there are two operating conditions which warrant consideration when calculating ash quantities: average lifetime load and peak load. The expected average lifetime load is used to calculate the total disposal volume required. Peak loads and available surge capacity are used to size ash transport and placement systems. For instance, if a seven-day ash storage capacity is available at the power plant, the maximum weekly load would be used to determine transportation requirements.

The steps in estimating ash quantities can be summarized as follows:

Step 1: Calculate average annual coal consumption

Tons coal burned/year = [power plant generating unit rating, (kW)]

$$\times \frac{\text{days}}{\text{year}} \times \frac{\text{hours}}{\text{day}} \times \text{average lifetime load}$$

$$\times \text{heat rate, } \left(\frac{\text{Btu}}{\text{kWh}}\right)] \div \left(\frac{\text{lb}}{\text{ton}} \times \frac{\text{Btu}}{\text{lb}}\right)$$

Step 2: Calculate annual ash quantity

Tons ash/year = tons coal burned/year x % ash in coal

Step 3: Calculate annual fly and bottom ash quantities

Tons fly ash/year = tons ash/year x % fly ash in ash
x overall collection efficiency (%)

Tons bottom ash/year = tons ash/year x % bottom ash in ash

Knowing the tons of ash produced, it is possible to calculate the required disposal volume for fly and bottom ash from the in-place dry density of the ash. The dry density of fly and bottom ashes is variable, as mentioned in Section 2. Sluiced ash typically has a lower dry density than landfilled ash. Compaction of dry ash can substantially increase the dry density of ash, thereby reducing disposal volumes.

The following example problem illustrates the methodology used to calculate ash quantities and required disposal volume over the plant life. It should be noted that the wet disposal volumes calculated do not include provisions for freeboard, variations in pond arrangement, residual water stored after abandonment, or size requirements to ensure adequate particle settlement. It is also assumed that the total wet disposal volume is the sum of the fly and bottom ash volumes.

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Example Problem: Find the dry and wet disposal volumes required for a power plant with characteristics listed below. No ash will be utilized.

Given: 1000 MW Coal Fired Power Plant
2 units rated @ 500 MW each
70% average capacity or lifetime load factor over 30-year life
Heat rating 9,000 Btu/kWh

Coal
10,500 Btu/lb
12% ash
80:20 fly ash:bottom ash ratio
99% fly ash removal efficiency (electrostatic precipitators)

1. Estimate Average Annual Coal Consumption

$$\text{Tons coal burned/year} = \left(1{,}000{,}000\ \text{kW} \times \frac{365\ \text{days}}{\text{yr}} \times \frac{24\ \text{hr}}{\text{day}} \times 0.70 \times 9{,}000\ \frac{\text{Btu}}{\text{kWh}}\right) \div \left(2000\ \frac{\text{lb}}{\text{ton}} \times 10{,}500\ \frac{\text{Btu}}{\text{lb}}\right)$$

$$= 2{,}628{,}000\ \text{tons/year}$$

2. Estimate Annual Ash Quantities

Tons ash/year = 2,628,000 tons coal burned/year x 12% ash in coal
= 315,360 tons/year

3. Estimate Fly Ash and Bottom Ash Quantities

Tons fly ash/year = 315,360 tons ash/year x 80% fly ash in ash
x 99% collection efficiency
= 250,000 tons/year
or 7,500,000 tons in 30 years

Tons bottom ash/year = 315,360 tons ash/year x 20% bottom ash in ash
= 63,000 tons/year
or 1,900,000 tons in 30 years

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4. Estimate Required Disposal Volumes for 30 year storage

Dry Disposal

Fly Ash - (in place dry density = 70 lb/ft^3)

$$\text{Disposal Volume} = \left(7{,}500{,}000 \text{ tons} \times 2{,}000 \frac{lb}{ton} \div \left(70 \frac{lb}{ft^3}\right.\right.$$

$$\left.\left. \times 27 \frac{ft^3}{yd^3}\right) = 8{,}000{,}000 \text{ } yd^3\right.$$

Bottom Ash - (in place dry density = 90 lb/ft^3)

$$\text{Disposal Volume} = \left(1{,}900{,}000 \text{ tons} \times 2{,}000 \frac{lb}{ton}\right) \div \left(90 \frac{lb}{ft^3}\right.$$

$$\left. \times 27 \frac{ft^3}{yd^3}\right) = 1{,}500{,}000 \text{ } yd^3$$

Total Disposal Volume = 9,500,000 yd^3

Wet Disposal

Fly Ash - (in place dry density = 60 lb/ft^3)

$$\text{Disposal Volume} = \left(7{,}500{,}000 \text{ tons} \times 2{,}000 \frac{lb}{ton}\right) \div \left(60 \frac{lb}{ft^3}\right.$$

$$\left. \times 27 \frac{ft^3}{yd^3}\right) = 9{,}300{,}000 \text{ } yd^3$$

Bottom Ash - (in place dry density = 70 lb/ft^3)

$$\text{Disposal Volume} = \left(1{,}900{,}000 \text{ tons} \times 2{,}000 \frac{lb}{ton}\right) \div \left(70 \frac{lb}{ft^3}\right.$$

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$$\times 27 \frac{ft^3}{yd^3}) = 2{,}000{,}000\ yd^3$$

$$\text{Total Volume} = 11{,}300{,}000\ yd^3$$

IN-PLANT ASH HANDLING SYSTEMS

Ash must be transported away from the boiler area to prevent the shutdown of the generating system. For the majority of utility coal fired power plants, the major sources of ash are:

- Fly ash from particulate removal systems,
- Ash deposited in the economizer and air heater hoppers,
- Bottom ash from the boiler bottom.

The major components available for in-plant ash handling systems are delineated below. General design information is provided, but specific system design is beyond the scope of this report.

General Design Criteria

In developing preliminary designs for ash handling systems, there are a number of factors to consider. These include the following:

- Ash quantities, physical, and chemical properties,
- Plant layout,
- Boiler design and configuration,
- Distribution of ash between fly ash, bottom ash, economizer ash and air heater ash,
- Plant geographical location,
- Type, configuration, and location in the exhaust gas stream of particulate removal devices.

Since ash handling is of critical importance in ensuring generating system operation, ash handling systems are typically designed to carry in a 6 to 8-hour shift the daily maximum volume of ash produced. This is to allow adequate time for maintenance on ash handling systems. The design of ash handling systems for 24-hour operation is also possible. Backup or duplicate systems can also be installed to provide an additional factor of safety in operation.

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Fly Ash Handling Systems

Fly ash is commonly removed from the flue gas by either electrostatic precipitators or baghouses, and deposited into hoppers located directly beneath the collection equipment. From these hoppers, dry fly ash is either transported to an ash storage/transfer silo or to a mixing device, where water is added to form a slurry. An alternative method for fly ash collection is a wet scrubbing system. This system has the advantage of avoiding the use of pneumatic ash handling equipment by creating a slurry, which can be directly pumped to the disposal area. However, wet scrubbers have a limited use due to their high operation cost and limited collection efficiency. Other wet scrubber disadvantages include the formation of sludge and a low pH, corrosive liquor.

Pneumatic transport systems, utilizing negative pressure, positive pressure, or a combination of both, are used for dry fly ash handling. A brief description of these fly ash handling systems follows:

- Negative Pressure (Vacuum)

  --Fly ash is transported from ash collection hoppers through a hydraulic vacuum producer to an air separation tank. The fly ash is then sluiced to a wet disposal area.

  --Fly ash is transported from collection hoppers to a dry storage silo. Hydraulic or mechanical exhausters are used to create the vacuum. From the silo, fly ash is transported to a dry disposal area.

- Positive Pressure

  --Fly ash is transported from collection hoppers to a dry storage silo or transfer station, and subsequently transported to a dry disposal area.

  --Fly ash is transported from collection hoppers to a wetting device and subsequently sluiced to a wet disposal area.

- Combination

  --Fly ash is transported from collection hoppers to a transfer station by a vacuum system. From the transfer station, fly ash is transported to a dry storage silo by a pressure system.

Vacuum systems have a limit on the effective distance to which they can transport fly ash. This distance is dependent upon the configuration of the system and its altitude above sea level. Pressure systems are generally used where the conveyance length or altitude is too great for a vacuum system. The efficiency of these dry

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ash conveyance systems is dependent on the particle size and density of the material being transported.

Economizer and Air Heater Ash Handling Systems

Economizer and air heater ash can be handled by systems previously described for fly ash. It is necessary to either provide crushers or secondary hoppers, installed under each economizer and air heater hopper, to facilitate pneumatic transport, due to the tendency of this ash to sinter.

With wet ash disposal, it is possible to collect economizer and air heater ash in water filled tanks, from which it is periodically pumped. Once wet, this ash is difficult to dewater. Therefore, hydraulic handling of economizer and air heater ash precludes the use of dry ash disposal.

Bottom Ash Handling Systems

Bottom ash is collected in hoppers located directly beneath the boilers. The description of a "wet" bottom boiler describes the physical state of the bottom ash within the boiler. Thus, the bottom ash from a wet bottom boiler is in a molten state when removed. Bottom ash from a dry bottom boiler is in a solid state when removed. For both types of boilers the bottom ash is typically dropped into a water filled hopper. This shatters the molten ash leaving the wet bottom boiler. It reduces the ash's temperature for future handling in either case. The number of bottom ash hoppers per boiler depends upon the boiler type and the ash melting temperature. A minimum of two is required. Bottom ash hoppers are typically arranged in "V" or "W" configurations. Discharge from bottom ash hoppers is usually automatic, but manual discharge facilities are incorporated to provide a backup discharge system.

Bottom ash leaving the hoppers is usually passed through a clinker grinder for size reduction, then pumped to either a dewatering area for dry disposal or directly to a wet disposal pond. Bottom ash pumps can be jet or centrifugal types. Jet pumps cannot be air bound, require no sump pit, and are capable of handling overloads. They are limited by head and are subject to increased wear in closed-loop sluice water systems, where there is an increase in suspended solids. Centrifugal pumps can be placed in series for high head applications, and are relatively unaffected by the quality of recirculated water. Centrifigal pumps require a sump pit and must be oversized to account for loss of efficiency due to wear, and to handle overloads.

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OUT-OF-PLANT ASH TRANSPORT

There are a number of methods available to transport the ash from the storage silo, dewatering bin, or slurry pump to the disposal area. These ash transport systems require a large capital expenditure and warrant careful design. The degree of variation in transport systems is typified by the following list of options:

- Truck
- Rail
- Barge
- Pipeline
- Belt Conveyor
- Pneumatic Conveyor

Each transport option also includes several alternatives. An important consideration to be made in conjunction with the method of out-of-plant ash transport is whether the bottom ash and fly ash will be transported jointly or separately. Most transport systems can be designed for combined transport. Combined transport of the ash may preclude the use of the bottom ash at the disposal site.

Truck Transport

The transport of ash by truck is normally restricted to dry or lightly wetted ash. Commonly used methods of truck transport are:

- Highway trucks
  - --Triaxial, dump truck, 25-ton capacity (22.7-metric ton capacity)
  - --Pneumatic trailers, 15-ton capacity (13.6-metric ton capacity)
  - --End dump trailer, 30-ton capacity (27.2-metric ton capacity)
- Off-road trucks
  - --Off-road dump truck, 35-ton capacity (31.7-metric ton capacity)
  - --Self-powered scraper, 30-ton capacity (27.2-metric ton capacity)

This list represents a cross section of available truck transport methods and commonly used sizes and types of equipment. Many other types and sizes of equipment are available.

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Truck transport has the advantage of utilizing an existing technology that is capable of quickly reacting to changes in operating conditions. If breakdowns occur, additional equipment can be rented; if the primary transportation route is made unusable, other routes are usually available. Truck transport places the ash at the point of active disposal operations and, therefore, does not require second handling. These advantages provide for flexible operation, and the ability to meet future changes. Disadvantages of truck transport are primarily labor and operating costs; its cost is directly related to these items. The reliability of truck transport is dependent on the truck drivers, the trucks, and the availability of fuel. Truck transport disadvantages also include high visiblity, increased traffic, and dust problems.

Rail Transport

The transport of dry ash by rail car is not common at present due to operational constraints, such as unloading facilities and scheduling. Rail transport is advantageous since rail routes made necessary by coal transport to power stations may already exist. The cost of new track construction specifically to the ash disposal area, however, would be included with ash transport costs. Applicable rail transport operation costs include fuel consumption on the return trip, additional track and bed maintenance, and the cost of dumping the ash on the return trip at the coal mine or disposal site. Train routes are usually not affected by outside influences and are essentially independent of weather. Disadvantages of rail transport include increased required on-site ash storage capacity, difficulties in unloading cars at disposal site, and double handling to place the ash in the disposal site.

Double handling of ash is required since railroad cars can only deposit ash at a central location or along a specific rail line. To place this ash in a disposal area requires that it be picked up, transported, and finally placed. Rail transport disadvantages also include dust problems, labor interruptions, and interference with mining operations.

Barge Transport

Barge transport of coal ash may be practical for a few cases, but it does not show the possibility of wide applicability. Barging will be limited to stations located on or very close to navigable waterways, stations which can consider ocean disposal, and/or stations requiring a long transport distance (greater than 100 miles, 161 kilometers). Barging theoretically can accommodate wet or dry ash wastes, and

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provide high system reliability at very low unit costs. However, the limited transportation routes and the special loading and unloading facilities make the overall economics unfavorable for all but a few selected cases. Barging alone will not get the waste to the disposal site, except for ocean disposal. Disadvantages include increased required on-site ash storage capacity, difficulties in unloading, and double handling to place the ash in the disposal site (2).

Pipeline Transport

The transport of ash by pipeline requires the slurrying of ash (typically ten percent solids by weight) and pumping it to an ash disposal pond. The pump design is consistent with standard pumping system design. The only specific requirement is that the minimum velocity be sufficient to maintain the ash in suspension. Conveying velocities range between 4.5 and 12.0 feet per second (1.4 and 3.7 meters Per second), depending on a number of factors such as particle size, material density, and pipeline configuration. After the pipeline system has been designed, the type of pipe can be selected. Pipe selection is based on various parameters, including ash properties. The types of pipe available for ash transport are:

- Steel,
- Cast iron,
- Hard iron alloy,
- Basalt lined steel,
- Ceramic lined fiberglass,
- Plastic (PVC, PCVC, ABS, etc.),
- Fiberglass.

The pipe selection requirements for a fly ash transport system are not as severe as for a bottom ash or combined transport system, since fly ash is less abrasive than bottom ash. Standard utility practice tends to favor either steel or cast iron pipe with mechanical joints. As the pipe wears, it is rotated so that the pipe is more evenly worn. A single pipe can be rotated three times prior to replacement. Other types of pipes are enjoying increased popularity. These include high quality abrasion resistant pipe, such as basalt lined steel pipe and ceramic lined fiberglass pipe. These pipes provide substantial increases in the life expectancy of the pipe, and thus may warrant their high initial capital cost. Fly ash may coat the inside of the pipe and in time will reduce its capacity. Because of this possibility, provisions for periodic cleaning of the lines must be provided. Examples of this

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are periodic pumping of bottom ash, designed access points for hydraulic and mechanical cleaners, and back-up lines and pumps.

An integral part of the pipeline transport system is the overflow water return system. Based on currently proposed regulatory requirements for a new point source, an ash pond discharge will be limited to a small concentration of suspended solids. The most expeditious method of compliance may be a water recycle system which would require a water return line from the ash pond to the plant and, if there is not sufficient head, a water-return pump. Since the suspended solids concentration in the recycled water would probably be low, other conventional pipeline materials, such as plastic and fiberglass pipe, could be used for the water-return pipeline.

The advantage of a pipeline ash transport system is that it is relatively independent of labor or energy problems. The primary disadvantage of a pipeline is continual maintenance, although this may be reduced by the use of abrasion resistant pipe.

Conveyor Transport

Conveyor transport includes both belt and pneumatic transport of ash. Although the design basis of these transport alternatives are not similar, they do share similarities in that they:

- Require a dedicated transport line,
- Have a high initial capital cost, and
- Require a storage silo or pile at the disposal area.

Belt Conveyor Transport. The transport of ash by belt conveyor requires that the ash be dry, although partial wetting may be used to reduce dusting. Conveyor systems consist of one or more conveyor flights, each made up of a continuous belt supported by rollers and powered by a central motor drive. Each flight is separated by a transfer station where the ash is transferred from one flight to another. The length of a conveyor flight is constrained by both the strength of the conveyor belt and required horsepower of the motor drive. Conveyor flights in excess of 10 miles (16 kilometers) have been constructed. Another restriction of conveyors is the geometry of the transport system. The maximum slope of the system is typically restricted to less than ten percent, and large curves or turns cannot be executed without a transfer station. The number of transfer stations should be minimized since both their capital and operation costs are quite high. A final requirement of ash conveyor systems is that fugitive emissions be minimized. This can be

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accomplished by either wetting the ash or enclosing the conveyor. Reduction of fugitive emissions by wetting could cause emission violations unless moisture control over the entire length of the conveyor is exercised. Therefore, an enclosed conveyor system would be preferred.

Advantages of a belt conveyor system include a lack of dependence on either labor or energy. Disadvantages include its high capital cost; plant disruption in a case of failure, unless a back-up system is available; and the requirement of double handling at the site to place the ash in the fill.

Pneumatic Conveyor Transport. Pneumatic ash transport requires that the ash be completely dry. Pneumatic ash transport consists of a pressurized pipeline system in which the ash is transported along a stream of air. The actual design of the transfer method may be either dense phase or dilute phase, referring to the concentration of ash particles within the air stream. Upon reaching the disposal area, the air velocity is reduced and the ash settles into a storage silo prior to placement in the landfill. The carrier air is exhausted through a baghouse with the removed ash redeposited into the silo. Design of this type of system is restricted by the ability of the carrier air to transport the ash. Specific transport distance capabilities are based on the type of phase transport, temperature of the air and/or ash, piping system resistance, and altitude. If long transfer distances are required, a transfer or booster station may be necessary.

Advantages of pneumatic transport include unattended operation, use of an existing technology relative to ash handling, and ability to conform to existing topography. Disadvantages include high capital cost and double handling of the ash at the disposal area.

COAL ASH DISPOSAL

Dry Ash Disposal

Dry disposal areas are commonly designed and constructed with methods similar to those used for the design and construction of earth fills. The EPRI Fly Ash Structural Fill Manual (3) contains detailed information concerning the testing of ash to determine its physical properties along with design considerations which are somewhat unique to ash. The major factors in the design of dry disposal areas are:

- Fill configuration and construction,
- Erosion and sediment control,

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- Surface and groundwater protection.

Fill Configuration and Construction. The overall slope stability of the site is influenced by its configuration and the manner in which it is constructed. Figure 5-1 shows a typical dry ash fill. The simpliest ash fill would be where all the ash was placed in a similar manner, regardless of any material zoning. The major configuration and construction features that influence slope stability are:

- Method of ash placement,
- Fill slopes,
- Exclusion of water from the fill.

In dry ash disposal, ash is commonly hauled to the active portion of the fill, dumped, spread, and possibly compacted. The degree of compaction of the ash will influence the overall stability of the fill, the permeability of the ash, and also the volume required for ash disposal. For example, compacted ash will have a higher in-place density, higher shear strength, lower volume, and lower permeability than an ash loosely dumped without compaction.

Depending upon the method of ash placement and degree of compaction, fill slopes are designed to ensure the stability of the disposal area. Normally ash fills will be designed with overall slopes of 3 or 4 horizontal to 1 vertical, and incorporate terraces at 15 to 25 foot vertical intervals; however, material strength may dictate greater or lesser slope ratios. Local terrace slopes may be as steep as 2 horizontal to 1 vertical. It should be noted that the length and steepness of local slopes can influence other site features, such as soil cover and vegetation used in erosion control measures.

Water should be excluded from the fill to minimize the formation of leachate and ensure the fill integrity. The primary means of excluding water are:

- Collection of groundwater with a layer of inert, permeable material placed beneath the fill. In some circumstances, the groundwater may require collection in a pipe underdrain network for discharge,
- Diversion of surface water away from the disposal area,
- Provision of positive drainage from the ash fill surface and provision of drainage systems to carry runoff away from the fill,
- Covering of the ash with a soil material capable of supporting vegetation and providing minimal infiltration.

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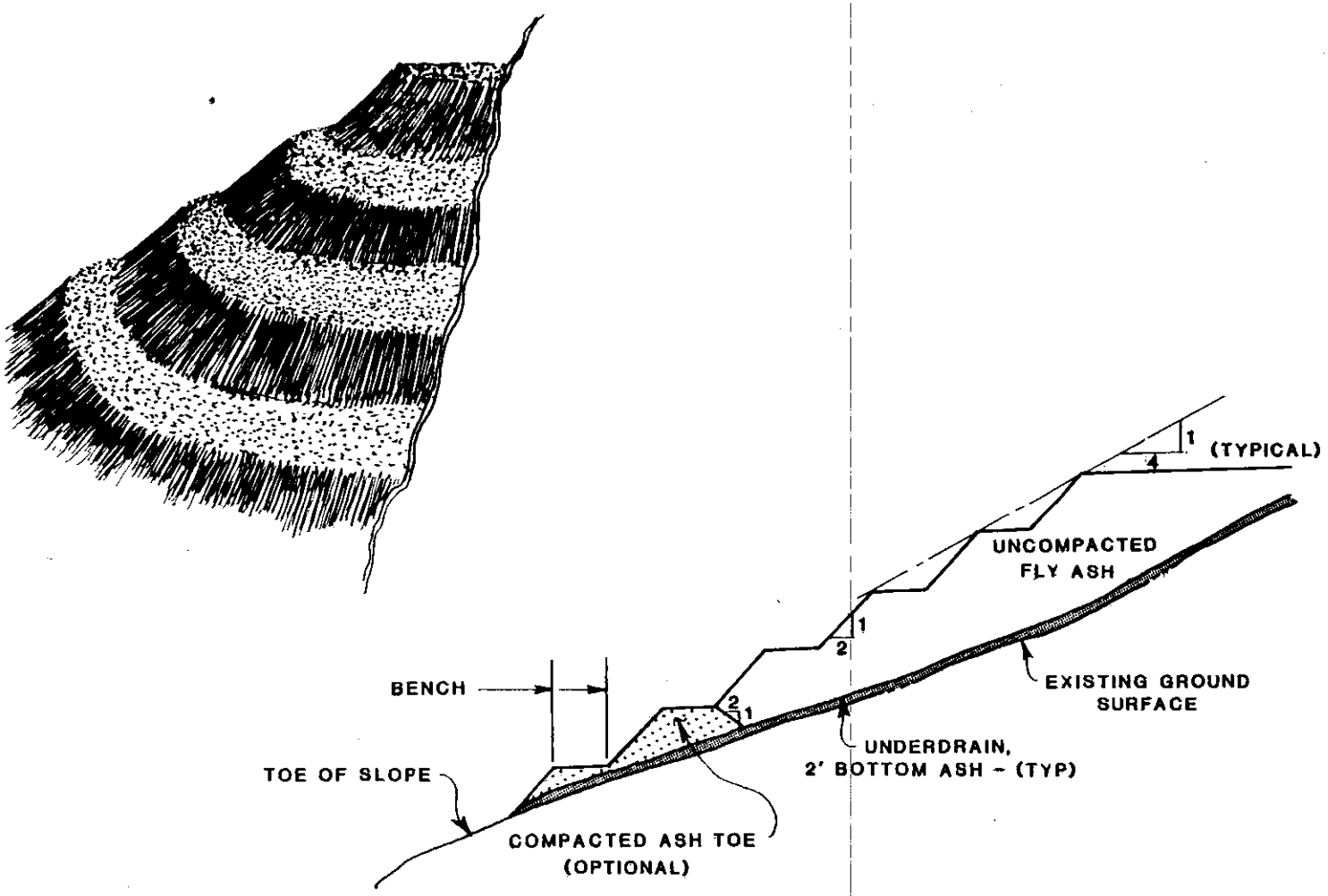

Figure 5-1. Cross-Section: Dry Ash Disposal Area

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Erosion and Sediment Control. In order to satisfy environmental regulations and to prevent erosion, it is necessary to incorporate measures to control erosion and subsequent sediment transport from the fill. These design features commonly include:

- Staged site development to minimize the area of ash exposed without soil and vegetal cover,
- Sedimentation pond to trap sediment carried by site runoff,
- Ditches for channeling and controlling the surface runoff on the disposal site,
- Manipulation of the slope, length, and gradient of disposal area to control runoff velocity and sediment transport potential,
- Berms at the foward edge of benches to keep runoff from flowing over the bench face,
- Sloped benches to direct runoff into collection ditches,
- Temporary sediment traps, such as straw bale barriers or sandbags, to trap sediment eroded from exposed ash or earth stockpiles,
- Soil cover and vegetation, if needed, on all exposed ash surfaces and soil stockpiles.

Surface and Groundwater Protection. Increasing concern about the pollution of surface and groundwaters has necessitated the use of water protection measures in the design of dry ash disposal areas. The use of these protection measures is determined by regulatory requirements, the type and permeability of soils underlying the site, and ash leachate characteristics. Common measures used to protect surface and groundwater include:

- A site liner, natural or synthetic,
- Surface water diversion ditches and pipes,
- A permeable layer of inert material beneath the site to collect leachate,
- Treatment of site leachate, if needed.

Wet Ash Disposal

The design of a wet ash disposal area incorporates the following major items:

- Sizing,
- Disposal area configuration,
- Embankment design,

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- Surface and groundwater protection,
- Required settling time.

In addition to these design features, consideration should be given to the post-closure requirements of a wet disposal area. If the disposal area is filled with ash and the power plant discharge is stopped, then the site is a landfill which should meet the design requirements previously discussed for dry disposal sites. If water continues to enter the site, then continuing maintenance of the embankment and discharge structures is required to ensure their integrity.

The sizing and configuration of a wet ash disposal area is discussed in Section 9 and will not be included here.

Embankment Design. The design of earth embankments is a detailed topic beyond the scope of this manual. Figure 5-2 has been included to illustrate some factors in such an embankment or levee. The height and type of embankment are influenced by the soil types and quantities available near the site along with the site topography and the required disposal volume.

Surface and Groundwater Protection. The protection of groundwater may entail the use of a site liner. This liner may be constructed of natural or synthetic materials, or it may make use of naturally occurring features, such as an aquiclude. Surface water protection is somewhat more complex to analyze. It is possible that effluent quality restrictions will preclude pond discharge to surface waters, and will require treatment or the use of a closed loop water recirculation system. If a closed loop water recirculation system is to be used, it will be necessary to undertake a water balance study to compare water entering the disposal area from sluicing operations, precipitation, and upland runoff with water leaving the area by evaporation and discharge. This type of study is necessary to determine the net amount of water returned to the plant and the need for upland runoff diversion ditches. The water quality must also be investigated to assure that a build-up of dissolved solids will not degrade the recirculation system.

Currently, several methods of handling sluice water discharges are available. These are:

- Filtration of the discharge to achieve zero suspended solids,
- Evaporation of the discharge,

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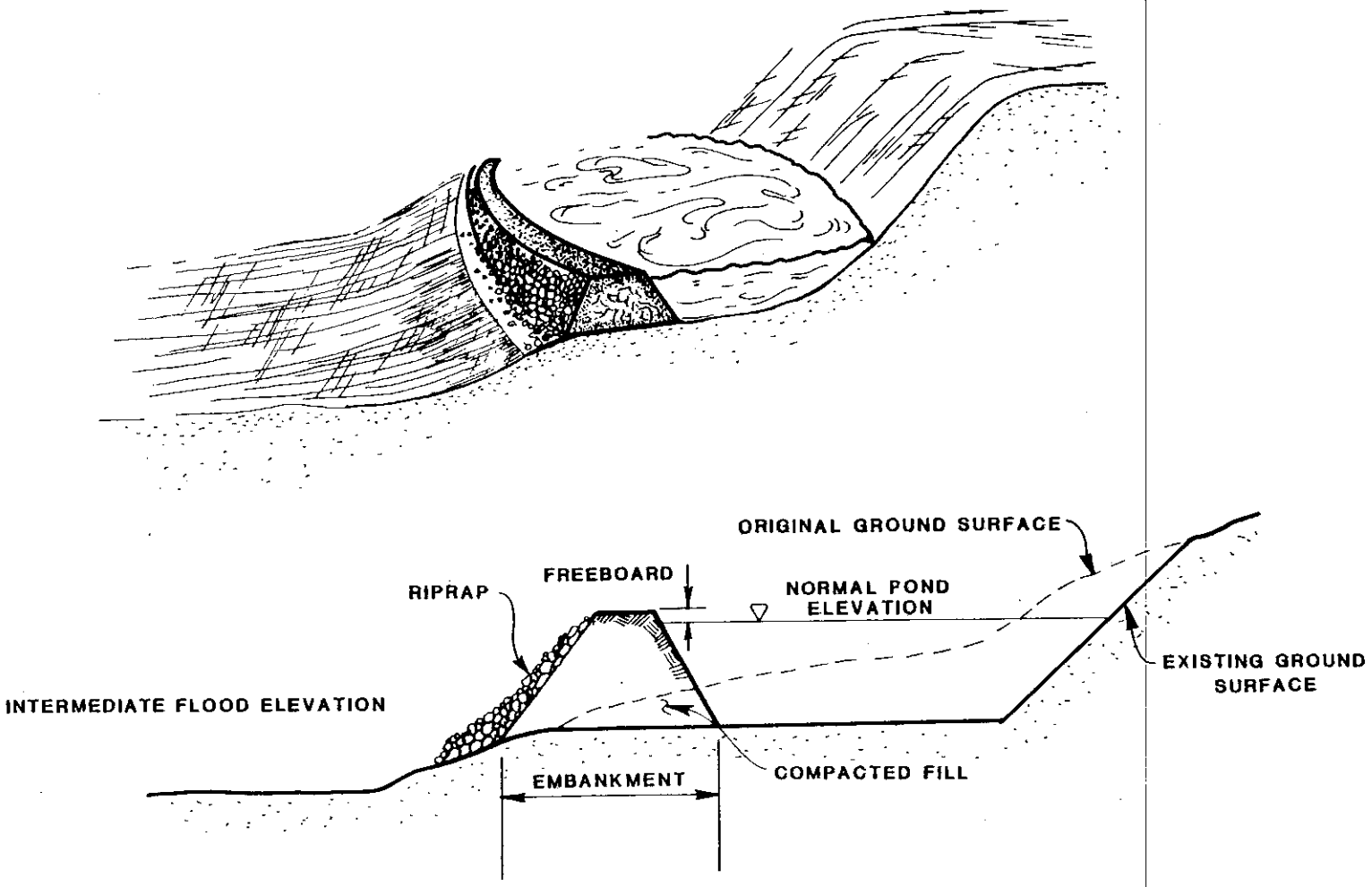

Figure 5-2. Typical Ash Pond Embankment Section

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- Operation of the system in a closed loop system in one or more of the following modes:

  --Operate until the dissolved solids exceed a set limit, then treat or evaporate the spent water,

  --Operate with frequent bleed-offs and water additions to maintain the system at a pre-determined level. Any bleed-off water would require treatment or evaporation,

  --Operate with constant acid addition (sulfuric, hydrochloric, etc.) to maintain a neutral pH,

  --Operate with a side stream diverted for advanced treatment (reverse osmosis, electro-dialysis, etc.) such that the system dissolved solids would be maintained at a pre-selected level.

Required Area for Settling. One of the primary functions of a wet disposal area is to provide sufficient detention time of the incoming ash slurry to allow the settling of ash particles. The settling of solids is theoretically related to the pond outflow rate, the surface area of the pond, and the critical settling velocity of the ash particles in the pond influent. This relationship can be stated as:

$$\text{Required Settling Area} = \frac{\text{Outflow Rate}}{\text{critical settling velocity of the smallest particle to be retained}}$$

Other design features, such as baffles or skimmers, may be required for cenosphere removal and to prevent short circuiting. It may also be necessary to incorporate underflow weirs, trash racks, or antivortex plates on discharge structures to prevent the outflow of particles and ensure the proper functioning of the discharge structure.

LINER INSTALLATION PROCEDURES

Installation of liners for coal ash disposal sites should follow well designed and detailed procedures. There should be adequate planning, use of good quality materials, and proper construction techniques. The design and installation of a liner can be divided into four steps:

1. Define facility function and geometry,

2. Select liner material,

3. Plan, design, and conduct suitable subgrade preparation procedures and proper liner installation procedures, and provide adequate seepage monitoring and collection provisions,

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4. Develop appropriate post installation operation and maintenance procedures.

This section reviews liner installation procedures. Additional detailed information is available in the EPRI report Disposal Area Liner Design RP 1457(4).

Liners are used primarily to prevent leachate from the coal ash from entering the groundwater. Liners should provide a permeability of less than 1 ft/year (10^{-7} cm/sec). By using a site liner it must not be assumed that total prevention of leachate ever entering the groundwater system is achieved. Its use reduces the rate of leachate migration relative to the unlined case, but does not eliminate it. The use of a dual liner system significantly reduces the rate as compared to the single liner case.

The degree of success of a liner installation is related to:

- Initial quality of the liner material,
- Compatability of the liner with the waste material,
- Suitability of liner construction.

No long range predictions as to the lifetime performance of a liner can be made at this time due to the lack of long term experience. However, various studies are ongoing which are attempting to answer this question.

Liner Categories

There are four liner types that are applicable to coal ash disposal operations. These include:

- Compacted clay liners,
- Admixture liners,
- Asphaltic liners,
- Polymeric membrane liners.

A more detailed description of these liners can be found in the EPRI FGD Sludge Disposal Manual CS-1515(1). A recent study (5) outlined procedures for the design and construction of two liner categories:

- Polymeric membrane liners,
- Bentonite (clay), asphalt, and cement liners.

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This section will describe installation procedures for both categories. Procedures that are common to both categories will be described first, followed by more detailed procedures for each category.

Approach

Liner installation can be divided into three categories:

- Subgrade preparation,
- Liner placement,
- Special design considerations.

Subgrade preparation will be the same, regardless of the liner type. Liner placement is specific to the type of liner used, and special design considerations are as required for each installation.

Subgrade Preparation. The disposal site must be prepared for liner placement. Subgrade preparation can be divided into six operations:

1. Cleaning, grubbing, and stripping,
2. Sterilization,
3. Excavation and filling,
4. Compaction,
5. Proof rolling,
6. Subdrainage and gas venting.

All the listed operations must be performed to insure an acceptable subgrade (6).

The first task is to clear off all tall grasses, trees, brush, fences, poles, stubs, rubbish, debris, and refuse. With plant removal, it is especially important that the entire root system is removed. To insure eradication of all plant life, the prepared subgrade should be treated with a reliable herbicide. The herbicide should be applied in a uniform manner over the entire site, including the top of the berms, disked into the soil at a minimum depth of 2" to 4", and the earth moistened. The magnitude of the excavation and filling will be determined by the scope of the project, and the results of the soils investigation. If the site is to receive the liner directly, the surface should be smooth, free from fractured rock, and no rocks should be over 1/4" in diameter. The next step is compaction of

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the disposal area. After compaction, the area should then be proof-rolled with a minimum 5-ton smooth-wheeled or pnuematic tire roller.

If leachate collection from the site is required, a highly pervious layer of soil or geotextile fabric is placed over the compacted soil, providing a path for the leachate to travel. Venting for the site must be provided if gas production beneath the site is expected or if a fluctuating water table is present immediately below the pond surface. This venting will allow the produced gas to be vented, and allow air forced upward, by a rising water table, to be vented.

Liner Placement. Subsequent to subgrade preparation, the liner itself is installed. As previously mentioned, each liner type has a specific installation procedure. The basic procedure described will be for polymeric membrane liners. A series of photographs depicting this procedure are included in Appendix A. Installation procedures specific to the other liner category will follow.

Liner installation can be divided into six steps (7):

1. Factory preparation,
2. Placement at the site (panel placement),
3. Securing the liner (anchoring),
4. Seaming liner sections,
5. Seaming around penetrations (inlet pipes, vents, etc.),
6. Soil covering (optional).

To insure that the installed liner will perform as designed, a strict quality control program must be enforced in all phases. The materials used and the workmanship involved must be of high quality. The liner to be installed will be prepared for shipping from the factory. At the site, proper storage of liner materials should be provided. It is important that the liner material be covered, whether by placement in a building or under a protective cover. This must be done to prevent possible degradation due to sunlight or heat buildup. The type of storage is a function of liner type, anticipated weather, storage time, and ambient temperatures.

The first step in the actual installation of the liner is to place liner panels in position for installation. The panel is then unfolded and pulled into position. The panel, once positioned, is then anchored by being secured into a trench on top of the embankment. The next panel is placed in position and, like the first panel,

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pulled into position. The first two panels are joined together by a seam crew. At the same time, the third panel is positioned and pulled into place.

There are a variety of field seaming techniques which may be utilized. These techniques may include:

- Two part epoxy adhesives,
- Gum tape,
- Tongue-and-groove splice,
- Contact adhesive,
- Bodied solvent adhesives,
- Pure solvents,
- Hot air,
- Hot melt.

The first four represent the most common seaming techniques for membrane type liners (8). More difficult is the seaming around protrusions through the liner. These protrusions could include inlet and outlet pipes, vents for gas relief, column supports for pipes, etc. These protrusions must be kept to a very minimum; however, for those that do exist it is necessary that a good seal be achieved around them. A common method for insuring a good seal is the use of a boot, which is constructed to fit over the protrusion and seal to the liner.

The last phase of liner placement is the use of a soil cover over the liner to protect the liner from the harmful effects of ultraviolet radiation and heat. This is not necessary for all liner materials. However, the soil cover also acts as a stabilizing agent, holding down the liner beneath. A problem arises in the placement of the soil covering: the effect of heavy equipment on liner integrity is not clear at this time. It may cause the liner to have a shortened life. There are methods to abate potential liner damage from the usage of heavy equipment. Examples are:

- Limit the absolute weight of equipment that is allowed on the liner,
- Use bulbous tired or tracked vehicles with relatively low contact pressures,
- Vary the entrance/exit locations for the heavy equipment onto the liners.

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The second category of liner--asphalt, admixture, or clay--can be applied in a similar manner. This type also requires the same subgrade preparation as described previously in this section.

Asphalt concrete liners can be placed by conventional paving machines. A compacted thickness of two inches may be sufficient, except for areas of heavy truck usage. In addition, this type of liner requires side slopes no steeper than two horizontal to one vertical (9).

Admixture liners are composed of soil, cement (coal ash may replace some cement), and water. Installation of this liner involves placing the admixture in a compacted layer of sufficient thickness to insure a permeability of less than 1 foot/year (10^{-7}cm/sec). Quality control is imperative to prevent curing cracks from occurring, which can drastically increase liner permeability.

Installation of clay liners is performed in a manner similar to that of admixture type liners. Clay is spread and compacted in six inch layers until the necessary thickness is obtained. This must be done with the clay in a dry state. A soil cover is recommended for a clay liner.

Special Design Considerations. There are certain options which may be necessary for the disposal area, depending upon local topography or regulations. These can include:

- Monitoring,
- Control of surface runoff,
- Dual liners,
- Special subgrade preparation,
- Provision for future expansion.

Monitoring wells may be required to identify the presence of a leak in the disposal area. Surface water control is important for two reasons: 1) increase the useful life of the facility, and 2) insure the integrity of the disposal area. Dual liners provide additional security against leachate migration from the waste disposal area. Special subgrade preparation may be necessary if there is a damaged or irregular subgrade. Provision for future expansion will allow for economical expansion of the facility, if required.

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The most important feature of any liner installation procedure is quality. The materials used, and especially the workmanship must be of high quality to insure a leak proof liner system. There should be a Quality Control inspector at each site. A well developed plan for inspection, developed prior to liner installation, should be followed to insure liner integrity.

Liner Cost

The installed cost of the liner is more important than the material cost of the liner alone. Liner costs should be calculated on a total cost basis, including maintenance costs. The cost of a liner is included in the disposal cost, discussed in Section 9. A thorough review of liner costs is provided in the EPRI FGD Sludge Disposal Manual CS-1515 (2).

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Section 6

CASE STUDIES

INTRODUCTION

During the course of collecting data for this manual, twenty-seven coal-fired generating stations, which are believed to represent most of the variations in ash disposal methodologies in the United States, were visited. The alternative methodologies are shown in Figure 6-1. This section is not intended to provide design guidance, but is merely a compendium of concepts that the utilities visited have used in the past. Each generating station and ash disposal system was different, but common comparative features were noted and are summarized in Table 6-1. These include:

- plant size and location,
- boiler type,
- average coal consumption,
- average ash content in coal,
- ash disposal method.

As stated above, variations of ash disposal practice were observed. These differences in basic wet or dry disposal systems are the result of specific problems encountered by utilities. The selection of a particular ash disposal method and/or the location of the disposal areas at a given plant is a function of a given utility's experience with a disposal method and its economic trade-offs, common practice of a region, topographic and property constraints, and any unusual contractual requirements. For example, many northeastern utilities truck their dry ash to compact it in a disposal area due to a lack of available disposal sites and high property acquisition costs. Table 6-2 is a breakdown of the variations observed.

From the sites visited, two wet and two dry sites were selected for an in-depth discussion of their ash disposal systems. Three of the sites are in the major coal burning regions of the country, and the other is in an area which may become a major coal burning region. The plants were selected because they represent the general practice for larger, more modern plants in their portions of the country.

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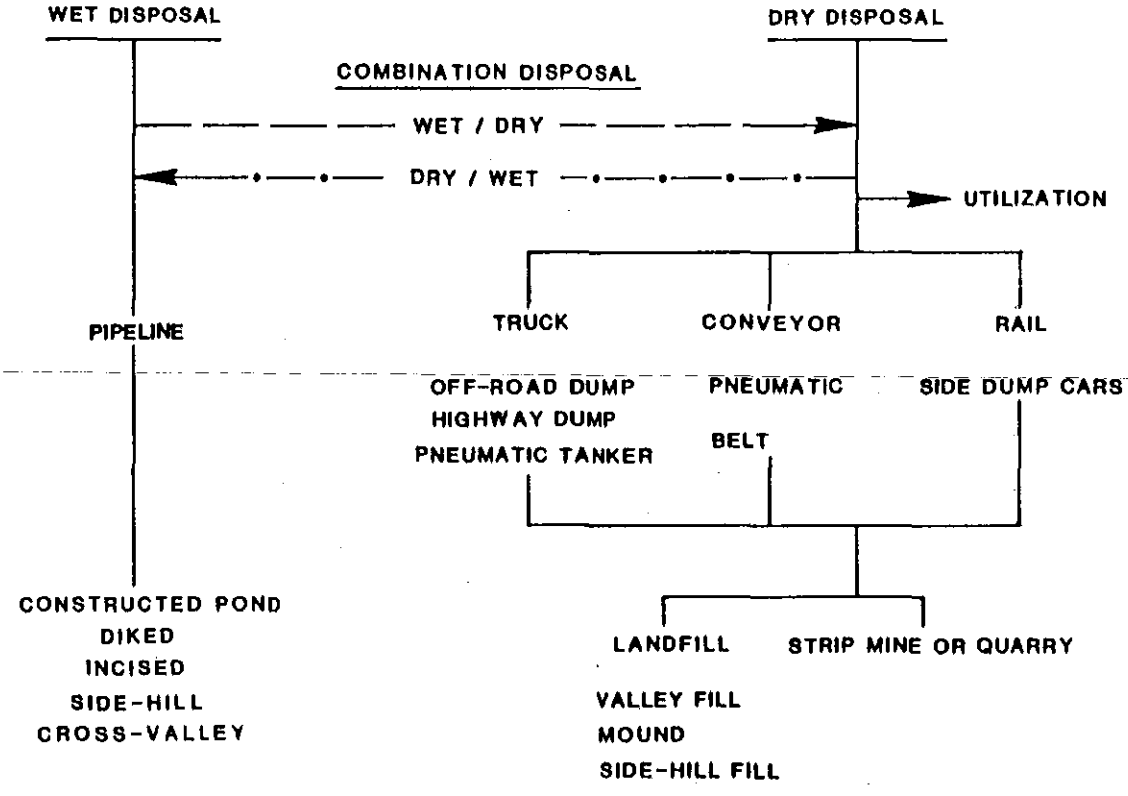

Figure 6-1. Ash Disposal Methodologies

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Table 6-1
SUMMARY OF POWER PLANT DATA

[1] CLIMATES OF THE STATES, N.O.A.A. VOL. 1&2, 1974

PLANT NAME	OWNER / OPERATOR	LOCATION		TOPOGRAPHY	POP. DENSITY	GENERATING CAPACITY			BOILER DATA		AIR CLEANING EQUIP.			REFUSE QUANTITIES		
		TOWN /& OR COUNTY	STATE			NO. UNITS	UNIT SIZE (MW)	TOT. CAP. (MW)	TYPE	SUPPLIER	TYPE	SUPPLIER	RATED EFF.	FLY ASH (TPD)	BOTTOM ASH (TPD)	PYRITIC REFUSE (TPD)
ALLEN	DUKE PWR.	BELMONT, GASTON CO.	N.C.	ROLLING	MODERATE	2 2 1	150 165	1155	D.B.	C-E	EP	R-C J-W	99.5	526	175	N/A
GIBSON	PUBLIC SERVICE OF INDIANA	MT. CARMEL, WABASH CO.	ILL.	FLAT	LOW	4	650	2600	D.B.	F-W	EP	UNIT J-W 1&2 B-E 3&4	99 99	[2100]	[530]	N/A
KEYSTONE STATION	PENNA. ELECTRIC CO.	ELDERTON, ARMSTRONG CO.	PA.	ROLLING	LOW	2	840	1680	D.B.	C-E	EP	R-C	99	2800	560	45-50
SAN JUAN	PUBLIC SERVICE OF NEW MEXICO	FARMINGTON SAN JUAN CO.	N.M.	FLAT	LOW	2	350	700	W.B.	F-W	EP	J-W	99	1500	300	N/A
BULL RUN	TVA	CLINTON, ANDERSON CO.	TN.	ROLLING	LOW	1	950	950	W.B.	C-E	EP	A-S	99	1360	340	N/A
LABADIE	UNION ELECTRIC CO.	LABADIE, FRANKLIN CO.	MO.	FLAT	LOW	4	600	2400	D.B.	C-E	EP	R-C	99.5	1216	405	N/A
RUSH ISLAND	UNION ELECTRIC CO.	RUSH TOWER, JEFFERSON CO.	MO.	FLAT	LOW	2	600	1200	D.B.	C-E	EP	L-C	99.6	890	300	N/A
BRUNNER ISLAND POWER PLANT	PENNA. POWER & LIGHT	YORK HAVEN, YORK CO.	PA.	FLAT	MODERATE	1 1 1	344 397 744	1485	W.B.	C-E	EP	UNIT R-C 1&2 J-W 3	99- 99.5 99.5	1100	370	60
SUNBURY POWER STATION	PENNA. POWER & LIGHT	SUNBURY, NORTHUM-BERLAND CO.	PA.	ROLLING	LOW	2 1 1	75 94 128	372	D.B.	F-W	BH EP EP	UNIT J-W 1&2 B-E 3 R-C 4	99.8 99.5 99.5	550	180	N/A
KINGSTON STEAM PLANT	TVA	KINGSTON, ROANE CO.	TN.	ROLLING	LOW	4 5	175 200	1700	D.B.	N/A	MC EP	B-E A-S R-C & AA-F	99.6	2000- 2700	360	N/A
PLANT JACK McDONOUGH	GEORGIA POWER CO.	SMYRNA, COBB CO.	GA.	ROLLING	MODERATE	2	245	490	W.B.	N/A	EP	B-E	99+	[304]	[76]	N/A
MONTROSE STATION	KANSAS CITY POWER & LIGHT	CLINTON, HENRY CO.	MO.	FLAT	LOW	3	170	510	D.B.	C-E	EP	R-C	99.5	855	173	140
NAUGHTON POWER PLANT	UTAH POWER & LIGHT	KEMMERER, LINCOLN CO	WY.	FLAT	LOW	1 1 1	150 220 330	700	W.B.	C-E	EP	B-E R-C	99+	[612]	[153]	N/A
CLIFTY CREEK POWER PLANT	IN.-KY ELECTRIC CORP.	MADISON, JEFFERSON CO.	IND.	FLAT	LOW	N/A	N/A	1284	N/A	N/A	EP	N/A	N/A	814	665	N/A
MARSHALL STATION	DUKE POWER CO.	TERRELL	N.C.	ROLLING	LOW	4	N/A	2025	D.B.	C-E	MC & EP	AEROTECH B-E R-C	99+	552	186	N/A
NAVAJO GENERATING STATION	SALT RIVER PROJECT	PAGE, COCONINO CO.	ARIZ.	FLAT	LOW	3	805	2415	W.B.	C-E	EP	J-W	99.5+	1920- 2400	480- 960	N/A
FRONT STREET STATION	PENNA. ELECTRIC CO.	ERIE, ERIE CO.	PA.	FLAT	MODERATE	4	N/A	110	D.B. D.B.	C-E ZURN IND.	EP	R-C	99+	120	30	1
WAUKEGAN STATION	COMMON-WEALTH EDISON CO.	WAUKEGAN, LAKE CO.	ILL.	GENTLY SLOPING	LOW	1 1 1	110 378 373	861	C D.B. D.B.	B-W C-E C-E	EP EP EP	R-C KOPPERS P.C. WALTER	98	500	100	N/A
ALLEN S. KING PLANT	NORTHERN STATES POWER CO.	OAK PARK HEIGHTS, WASH. CO.	MINN.	N/A	N/A	1	581	581	C	B-W	EP	R-C	99	160	160	N/A
POWERTON GENERATING STATION	COMMON-WEALTH EDISON CO.	PEKIN, TAZEWELL CO.	ILL.	GENTLY SLOPING	LOW	2	900	1800	C	B-W	EP	R-C	99.5	500	685	N/A
COAL CREEK	COOPERATIVE POWER ASSOC.	UNDER-WOOD, McLEAN CO.	ND.	FLAT	LOW	2	550	1100	DB	C-E	EP	W-F	99.5	1512	376	N/A
CENTRALIA	PACIFIC POWER & LIGHT CO.	CENTRALIA LEWIS CO.	WA.	ROLLING	LOW	2	665	1330	N/A	C-E	EP	KOPPERS L-C	99.9	1320	880	N/A
BIG BROWN	TEXAS UTILITIES	FAIRFIELD FREESTONE CO.	TX.	FLAT	LOW	2	515	1150	DB	C-E	EP	R-C	N/A	2047	512	N/A
LELAND OLDS	BASIN ELECTRIC	STANTON MERCER CO.	ND.	FLAT	LOW	1 1	216 440	656	N/A	B-W	EP	R-C J-W	99.9	700	350	N/A
HUNTER	UTAH POWER & LIGHT	CASTLE DALE	UT.	FLAT	LOW	2	410	820	DB	C-E	EP	B-E	99.6	734	184	N/A
CHEROKEE	PUBLIC SERVICE CO. OF COLORADO	DENVER DENVER CO.	CO.	FLAT	MEDIUM	4	108 100 150 350	708	DB	GE	EP MC BH PS	SEVERAL	97	325	140	N/A
JIM BRIDGER	PACIFIC POWER & LIGHT CO.	ROCK SPRINGS WY SWEET-WATER CO.	WY.	FLAT	LOW	4	510	2040	WB	C-E	EP	FLAKT	N/A	1920	480	N/A

R RAIL
T TRUCK
D,B DRY BOTTOM
C-E COMBUSTION ENGINEERING
EP ELECTROSTATIC PRECIPITATOR
L-C LODGE-COTTRELL
PS PARTICULATE SCRUBBERS

P PIPE
D DRY
W,B, WET BOTTOM
AA-F AMERICAN AIR FILTER
A-S AMERICAN STANDARD
B-E BUELL-ENVIRONTECH
R-C RESEARCH COTTRELL

W WET
MC MECHANICAL COLLECTOR
C CYCLONE
BH BAG HOUSE
( ) DATA FROM VERSAR REPORT
[ ] DATA CALCULATED BY GAI

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Table 6-1
(Continued)

[1] CLIMATES OF THE STATES, N.O.A.A. VOL. 1&2, 1974.

PLANT NAME	OWNER OPERATOR	COAL INFORMATION					DISPOSAL SYSTEM					CLIMATE[1]		COMMENTS
		QUANTITY BURNED (TPD)	ORIGIN	ASH CONTENT %	SULFUR CONTENT %	HEAT VALUE (BTU x 10^3/lb)	TYPE	TRANS. SYSTEM	DISPOSAL AREA: DIST. FROM PLANT (MI.)	DISPOSAL AREA: SIZE (AC.)	DISPOSAL AREA: CAPACITY (TONSx10)	AV. ANNUAL PRECIP. (INCHES)	AV. ANNUAL TEMP. (°F)	
ALLEN	DUKE PWR.	6100	W.KY.	12	1.5	12	W	P	0.25	130	5.6	46	61	
GIBSON	PUBLIC SERVICE OF INDIANA	23000	IND. ILL. KY.	6-15	1-4	10-11	W	P	0.25	225 60 210 20	N/A N/A N/A N/A	43	57	
KEYSTONE STATION	PENNA. ELECTRIC CO.	15000	PA.	22	2	11.6-11.7	D	T	2	83	5.6	41	51	MOST OF B.A. & A PORTION OF F.A. IS SOLD .
SAN JUAN	PUBLIC SERVICE OF NEW MEXICO	9000	N.M.	20	0.8	9.2-9.5	D	T	2	N/A	15.4	10	60	PLANT RECOVERS ELEMENTAL SULFUR & SULFURIC ACID.
BULL RUN	TVA	7500-8000	KY.-TN.	16.8	1.0	11.1	W	P	1	200	16.2	52	58	
LABADIE	UNION ELECTRIC CO.	15137	S. ILL.	10.7	2.5	10.8	W	P	0.25	150	10.0	36	58	B.A. UTILIZED BY STATE HIGHWAY DEPT.
RUSH ISLAND	UNION ELECTRIC CO.	8800	VAR.	13.4	1.0	10.5	W	P	0.25	96.4	9.2	37	56	
BRUNNER ISLAND POWER PLANT	PENNA. POWER & LIGHT	12500 MAX.	PA.	14.4	2.2	12.2	W	P	0.25	35 95	1.5 3.5	41	53	
SUNBURY POWER STATION	PENNA. POWER & LIGHT	4100 ANTHRACITE COKE & BIT.	PA.	17.9	2.0A&C 2.2 B	9.9 12.1	W	P	1.25	45 50	1.2	41	51	B.A. IS RECOVERED & SOLD.
KINGSTON STEAM PLANT	TVA	12000-16000	KY.-TN.	16.0	2.21	11.5	W	P	1	248	[6.5]	52	58	B.A. IS RECLAIMED & USED LOCALLY. PORTION OF F.A. IS SOLD FOR USE IN CONCRETE. CENO-SPHERES ARE COLLECTED & SOLD
PLANT JACK McDONOUGH	GEORGIA POWER CO.	3800	KY.-TN.	10	(1.8)	12.0	W/D	P	.25	2-3 50-75 75-100	N/A	47	61	35% DRY F.A. SOLD FOR CONCRETE. DISPOSAL SITE CONTAINS 3 ACTIVE & 1 ABANDONED PONDS.
MONTROSE STATION	KANSAS CITY POWER & LIGHT	5000 (AV.) 7000(MAX.)	LOCAL	24-26	6	9.6	D	R	5	N/A	N/A	39	56	28% OF F.A. IS SOLD.
NAUGHTON POWER PLANT	UTAH POWER & LIGHT	9000	WY.	6-9	0.4-0.7	9.3	W	P	0.25	26 36	N/A	9	38	SUB-BITUMINOUS APPROX. 45,000 TONS OF F.A. WAS SOLD IN 1978.
CLIFTY CREEK POWER PLANT	IN-KY ELECTRIC CORP.	11000	IND.&KY	12-16	(4.0)	N/A	W	P	N/A	N/A	N/A	44	57	55 F.A./45 B.A. PORTION OF B.A. IS SOLD. NEW EP PRECIPITATORS-1979.
MARSHALL STATION	DUKE POWER CO.	10000	KY. & TENN.	13.5	(1.2)	11.8	W	P	1	268	6.7	47	60	MOST OF F.A. IS MARKETED
NAVAJO GENERATING STATION	SALT RIVER PROJECT	24000	BLACK MESA	10		11.0	D	T	2	102	[22.8]	< 7	57	SUB-BITUMINOUS MOST OF THE F.A. IS CURRENTLY MARKETED.
FRONT STREET STATION	PENNA. ELECTRIC CO.	1000	PA.	15	<1.5	N/A	D	T	7	41.8	0.316	38	49	
WAUKEGAN STATION	COMMON-WEALTH EDISON CO.	5000	WEST-ERN	10-12	0.39-0.55	9.3-9.8	D	T	7.5	37	1.5	33	48	LOW SULFUR SOLD MOST OF B.A. & B.S.
ALLEN S. KING PLANT	NORTHERN STATES POWER CO.	5000	MONT. & ILL.	9.5 AVG.	(1.2)	8.9	D	T	N/A	N/A	2.5	26	42	ALSO UTILIZES PETROLEUM COKE
POWERTON GENERATING STATION	COMMON-WEALTH EDISON CO.	12000	WEST-ERN	10	0.24-0.59	9.3-9.8	D	T	0.5	38 10	1.5 0.5	35	51	PRIOR TO JULY 1979, ILLINOIS COAL BURNED SOME F.A. IS SOLD FOR USE IN BITUMINOUS PAVEMENTS.
COAL CREEK	COOPERATIVE POWER ASSOC.	21000 BOTH UNITS	ND.	9	.4-.6	5.8-6.8	D/W	T/P	3	N/A 410	N/A	17	41	WET DISPOSAL FOR BOTTOM ASH; DRY MINE DISPOSAL FOR FLY ASH.
CENTRALIA	PACIFIC POWER & LIGHT CO.	19000	WA.	17	.75	8.0	D	T	1	N/A	N/A	47	51	
BIG BROWN	TEXAS UTILITIES	19200	TX.	15	0.6	6.8	D/W	T/P	6	125	N/A	31	67	WET DISPOSAL FOR BOTTOM ASH; DRY MINE DISPOSAL FOR FLY ASH.
LELAND OLDS	BASIN ELECTRIC	12000 MAX.	ND.	10	.6	6.0 - 7.0	W	P	.5	160	N/A	17	41	
HUNTER	UTAH POWER & LIGHT	6800 BITUMINOUS	UT.	13.5	.52	N/A	D	T	2.5	180	N/A	14	45	
CHEROKEE	PUBLIC SERVICE CO. OF COLORADO	6000	CO.	9	.4-.5	10.0-11.0	D	T	1	23	N/A	16	50	
JIM BRIDGER	PACIFIC POWER & LIGHT CO.	24000 MAX.	WY.	10	0.6	9.5	D	T	7	N/A	N/A	9	43	

R RAIL
T TRUCK
D.B DRY BOTTOM
C-E COMBUSTION ENGINEERING
EP ELECTROSTATIC PRECIPITATOR
L-C LODGE-COTTRELL
PS PARTICULATE SCRUBBERS

P PIPE
D DRY
W.B. WET BOTTOM
AA-F AMERICAN AIR FILTER
A-S AMERICAN STANDARD
B-E BUELL-ENVIRONTECH
R-C RESEARCH COTTRELL

W WET
MC MECHANICAL COLLECTOR
C CYCLONE
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( ) DATA FROM VERSAR REPORT
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Table 6-2

CASE STUDIES ON SPECIFIC ASPECTS OF COAL ASH DISPOSAL

Process	Power Plant
A. Wet Disposal	
1. Operation Alternatives	
a. Once thru ash slurry systems	Bull Run, Allen, Leland Olds
b. Once thru ash slurry systems w/effluent treatment	
o Carbon Dioxide	Labadie, Rush Island
o Acid	Brunner Island
o Lime	Sunbury
c. Partial sluice water recycle system	Kingston, Jack McDonough
d. Total recirculation	
o Bottom ash slurry water only	Montrose, San Juan, Navajo, Big Brown
o Total water recirculation	Gibson
e. Series operation pond systems	Naughton, Gibson
2. Ash Movement and Control	
a. Floating ash slurry discharge line	Clifty Creek
b. Dredging	Marshall
c. Dragline	Kingston
d. Segregation of bottom and fly ash	Labadie, Rush Island
3. Embankment Types	
a. Embankment/excavation	Rush Island, Labadie
b. Cross valley	Marshall
c. Side hill	McDonough
B. Dry Disposal	
1. Canyon or Valley Fill	Navajo
2. Open Area Fill	Keystone, Hunter
3. Strip Mine	San Juan, Montrose, Big Brown, Coal Creek, Jim Bridger, Centralia
4. Disturbed Area Restoration	Front Street, Cherokee
5. Fixation	Waukegan
C. Environmental Considerations	
1. Monitoring	
a. Ash pond discharge	Allen
b. Groundwater monitoring	King, San Juan
2. Revegetation	
a. Wet	Allen
b. Dry	
o Eastern	Keystone, Powerton
o Western	Navajo, San Juan
3. Constructed Site Liner	Powerton, Front Street, Cherokee

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Appendix B contains brief descriptions of the other generating stations visited. These are included to illustrate the broad range of current practices in the two primary disposal methods which vary from those observed at the four sites described in this section, and to serve as a possible reference for utilities with similar problems. The geographic location of all twenty-seven plants is shown on Figure 6-2.

Data on monitoring systems is presented only where it varies from that required under National Pollutant Discharge Elimination System (NPDES) requirements.

IN-DEPTH DISCUSSIONS

The power plants selected for in-depth discussion are:

Wet Ash Disposal:

Allen Station - Duke Power Company

Gibson Station - Public Service Company of Indiana

Dry Ash Disposal:

Keystone Station - Pennsylvania Electric Company

San Juan Plant - Public Service Company of New Mexico

The Allen and Gibson Stations are located in the South Atlantic and East North Central portions of the country, respectively, where wet ash disposal is predominant. Keystone Station, located in the Middle Atlantic region, and San Juan Station, located in the Mountain region, are both situated in areas where dry ash disposal is predominant.

Allen Station

Allen Station, as shown in Figure 6-3, is a 1100 MW coal-fired power plant owned by Duke Power Company and located near Charlotte, North Carolina. The area is located in rolling terrain and has a moderate population density. At normal operating capacity the power plant consumes 6,100 tons (5,530 metric tons) of bituminous coal per day. There are five units, Units 1 and 2 are 150 MW each, Units 3 and 4 are 265 MW each, and Unit 5 is 275 MW. Units 1 and 2 were brought on-line in 1957 and have tangentially-fired boilers. Units 3, 4, and 5 were brought on line in 1959, 1960, and 1961, respectively. These units have two boilers per unit. All boilers are Combustion Engineering, dry bottom type and operate General Electric turbines. The boilers are fueled primarily by Western Kentucky Coal with less than 1.5 percent sulfur, an average of 12 percent ash content, and an average heat value of 12,000

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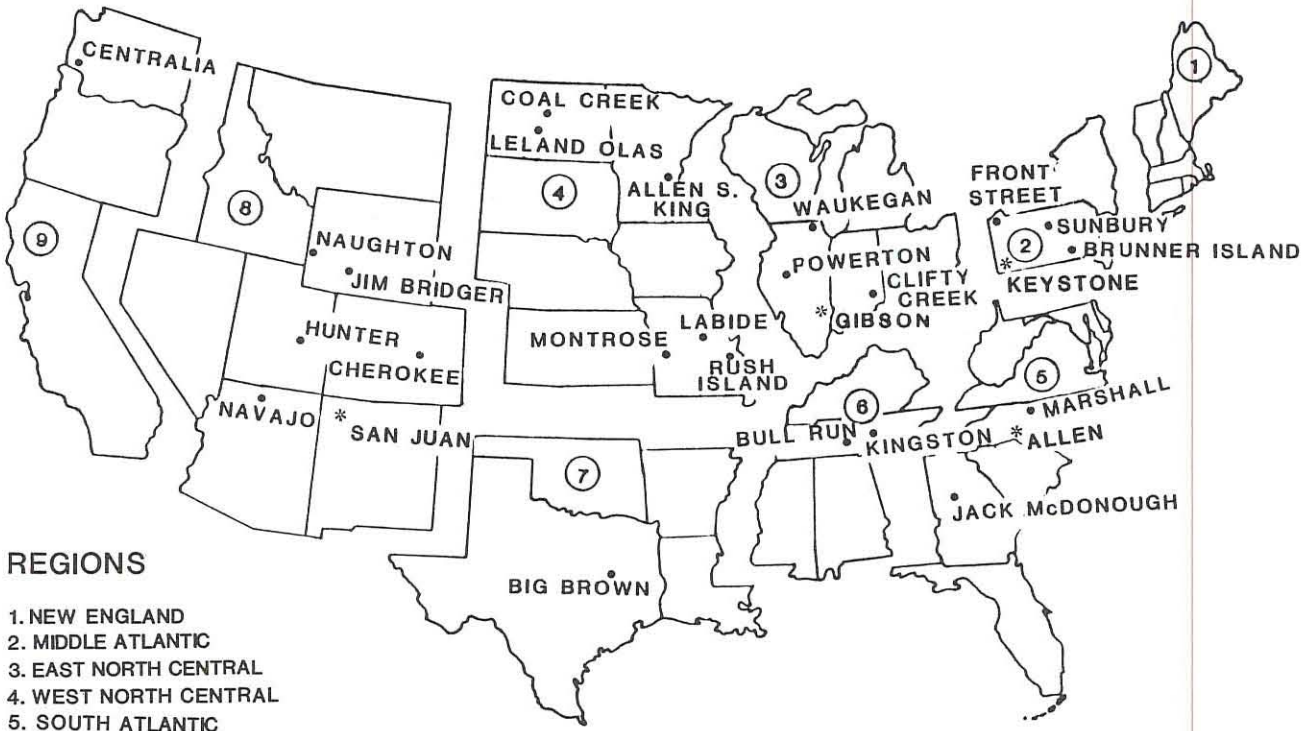

REGIONS

1. NEW ENGLAND
2. MIDDLE ATLANTIC
3. EAST NORTH CENTRAL
4. WEST NORTH CENTRAL
5. SOUTH ATLANTIC
6. EAST SOUTH CENTRAL
7. WEST SOUTH CENTRAL
8. MOUNTAIN
9. PACIFIC – PLUS ALASKA & HAWAII

Figure 6-2. Location of Sites

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Figure 6-3. Allen Station

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Btu/lb (27,890 kj/kg). The coal is normally delivered to the plant via unit trains. Additional coal is obtained through the spot market and delivered by train at single car rates.

Allen Station has a unique water arrangement due to its proximity to both the Catawba and South Fork Rivers. Water is withdrawn from the Catawba River for once through cooling and is then discharged via a canal to the South Fork River. Some of this intake water is diverted for other uses, such as ash slurry water, and is ultimately discharged to ash ponds. The three-mile long discharge canal supports a substantial population of striped bass, crappie, carp, catfish, sunfish, and bream, commonly referred to as bluegill.

Units 1 and 2 boiler exhaust gases are routed through mechanical collectors followed by Research-Cottrell electrostatic precipitators (99+ percent overall efficiency). Fly ash from Units 3, 4, and 5 is collected by Research-Cottrell hot side precipitators followed by Joy-Western cold side precipitators. This system provides 99+ percent collection efficiency. The exhaust from these particulate removal systems exits through five 250 ft (76 m) high stacks.

Fly ash is transported dry, via a vacuum transfer system, to an ash sluicing area. Here, the fly ash is combined with the quenched bottom ash and pyritic refuse and sluiced to the ash disposal ponds by a jet propulsion pump. This type of arrangement is utilized to minimize the abrasive effects of bottom ash on the pumps. The slurry lines are cast iron, mechanical joint pipe which is rotated approximately every three years and provides 9 to 10 years of service. Alternatively, fly ash can be handled dry for sale. Average daily productions of fly ash and bottom ash is 526 tons (478 metric tons) per day and 175 tons (159 metric tons) per day, respectively.

The ash disposal area, shown on Figure 6-4, is comprised of active and abandoned sites. The original ponds, which include the two west coves, 20 to 30 acres (8.09 to 12.1 ha) and the east cove, 50 acres (20.24 ha), provided the initial ash disposal capacity. These ponds were approximately 25 to 30 ft (7.6 to 9.1 m) deep and provided approximately 3,630,000 yds (2,776,950 m^3) of ash storage.

The east and west coves, presently filled to capacity, are being used for revegetation research. In the west cove, Duke Power Company is studying the effects on revegetation created by varying the depth of soil cover on fly ash. Table 6-3 shows the details of the revegetation study. Figure 6-4 indicates revegetation

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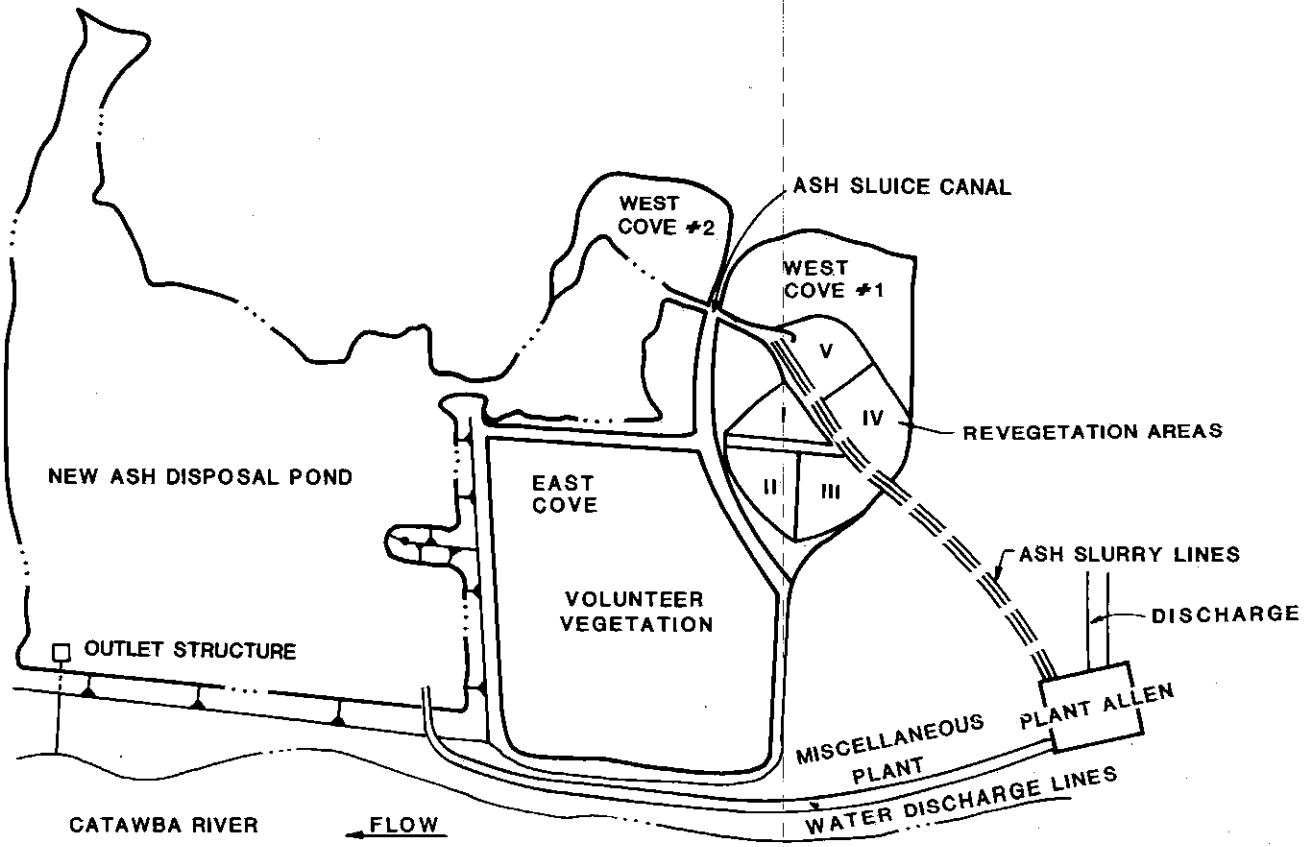

Figure 6-4. Allen Station Ash Disposal System

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areas. Although depth of soil cover varys appreciably, no noticeable variations in the density of vegetation have been noted to date, as can be seen in Figure 6-5.

Table 6-3

Allen Station Revegetation Areas

Area	Depth of Soil Cover
I	3 in (7.6 cm) not disked
II	6 in (15.2 cm) not disked
III	12 in (30.5 cm)
IV	6 in (15.2 cm)
V	6 in (15.2 cm)

By comparison, the east cove has not been covered or revegetated. However, a substantial cover of natural vegetation was present on the above water areas of the pond (see Figure 6-6). Duke Power is maintaining the water level in the east cove to minimize fugitive dust emissions. It also plans to study the vegetative cover and terrestrial species which have begun to populate the pond.

The new ash disposal pond, completed in 1975, is a 130-acre (52.61 ha) pond constructed in a previous backwater embayment in the Catawba River (see Figure 6-7). The pond is impounded by an earthen embankment which has a maximum height of 70 ft (21.3 m). It has a current storage volume of 1,200,000 yds (918,000 m^3) which is sufficient for 3 years of disposal. Silty clay was excavated from the pond area to provide the material for the pond embankment. The dike will eventually be raised to 90 ft (27.4 m) to increase disposal volume.

Present ash pond operation consists of pumping the ash slurry to the western cove and allowing it to flow through a canal to the new pond. The supernatant is discharged to the Catawba River. In addition to the ash slurry water, all other plant water discharges, except the cooling water, are piped directly to the ash disposal pond. These discharges include the ammoniacal bromate and hydrochloric acid utilized in boiler cleaning operations. Studies conducted by Duke Power indicate that the ash disposal pond is effective in treating these wastes and that the resultant discharge does not violate their NPDES permit limitations which include arsenic, selenium and other heavy metals.

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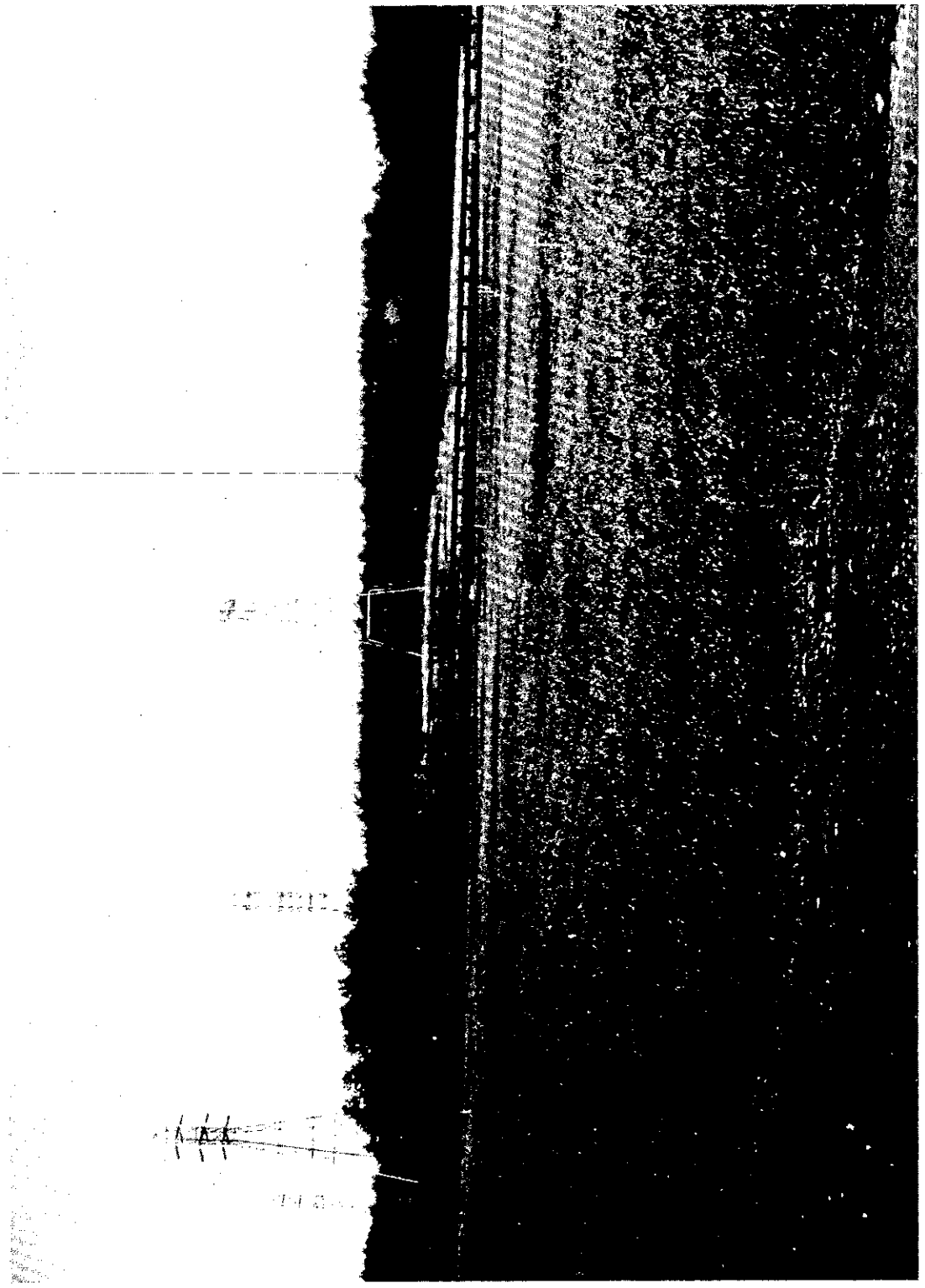

Figure 6-5. Revegetated Pond Areas at Allen Station

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Figure 6-6. Volunteer Vegetation on Ash Pond at Allen Station

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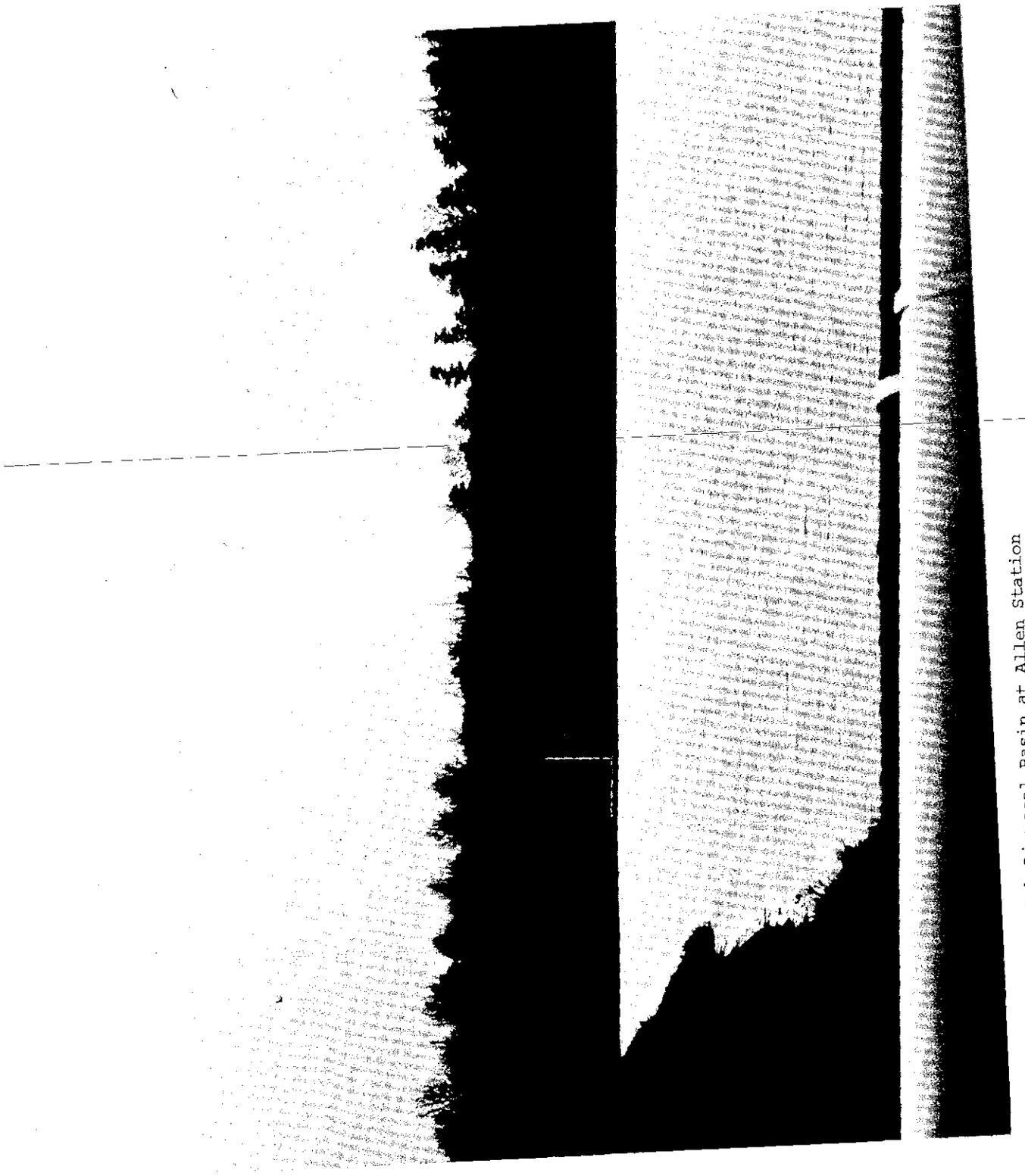

Figure 6-7. Current Ash Disposal Basin at Allen Station

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In addition, Duke is presently studying ash basin leachates and monitoring groundwaters in the vicinity of these basins. Because of the natural clay deposits in this area, both the old and new ponds are underlain by relatively impermeable soils similar to constructed clay liners. Thirteen monitoring wells have been placed within and around these ponds and samples are analyzed on a monthly basis. The results of this study will provide both short-term (new pond) and long-term (old ponds) in situ metal migration data which may improve and broaden practice in disposal pond utilization.

Gibson Station

Gibson Station, shown in Figure 6-8, is a 2600 MW coal fired power plant owned by Public Service Company of Indiana and located on the Wabash River near Mt. Carmel, Illinois. The station is located in flat terrain with low population density. The power plant now has four 650 MW units. A fifth unit is presently under construction. Southern Illinois bituminous coal, with an ash content ranging from 8 to 15 percent, sulfur content ranging from 1 to 4 percent, and heating value of from 10,000 to 11,000 Btu/lb (23,240 to 25,560 kj/kg), is burned at a maximum rate of 23,000 tons (20,860 metric tons) per day. It is supplied to the plant either by unit trains or trucks. Daily coal deliveries consist of approximately two to three unit trains and 400 to 500 truck loads.

Gibson Station utilizes Foster Wheeler, pulverized coal, dry bottom boilers which produce 4,588,000 lb (2,081,000 kg) of steam per hour. The combustion exhaust gases are passed through cold side electrostatic precipitators which provide 99+ percent fly ash removal efficiency. The plant has two 500 ft (152 m) stacks; a third stack will be added for Unit 5. Plant cooling water is obtained from a closed recirculation system which uses a 3,000-acre (12.14 ha), approximately 15 ft (4.6 m) deep, impoundment for storage and cooling. Although the cooling system is classified as closed, make-up water from the Wabash River is required to maintain the lake level. During the summer months more than 56,000 gpm (3,528 l/s) is pumped into the cooling lake to maintain the water level. The cooling water lake has been developed by the utility for recreation; however, water skiing and swimming are not permitted. Shad are the dominant species in the lake, and because of their number cause problems at the plant water intake during certain periods of the year. Presently, it has been proposed to solve this problem by stocking the lake with bass which feed on shad.

Fly ash is collected dry and transported via a vacuum system to a slurry area. There it is combined with the sluiced bottom ash and pyritic refuse and pumped to

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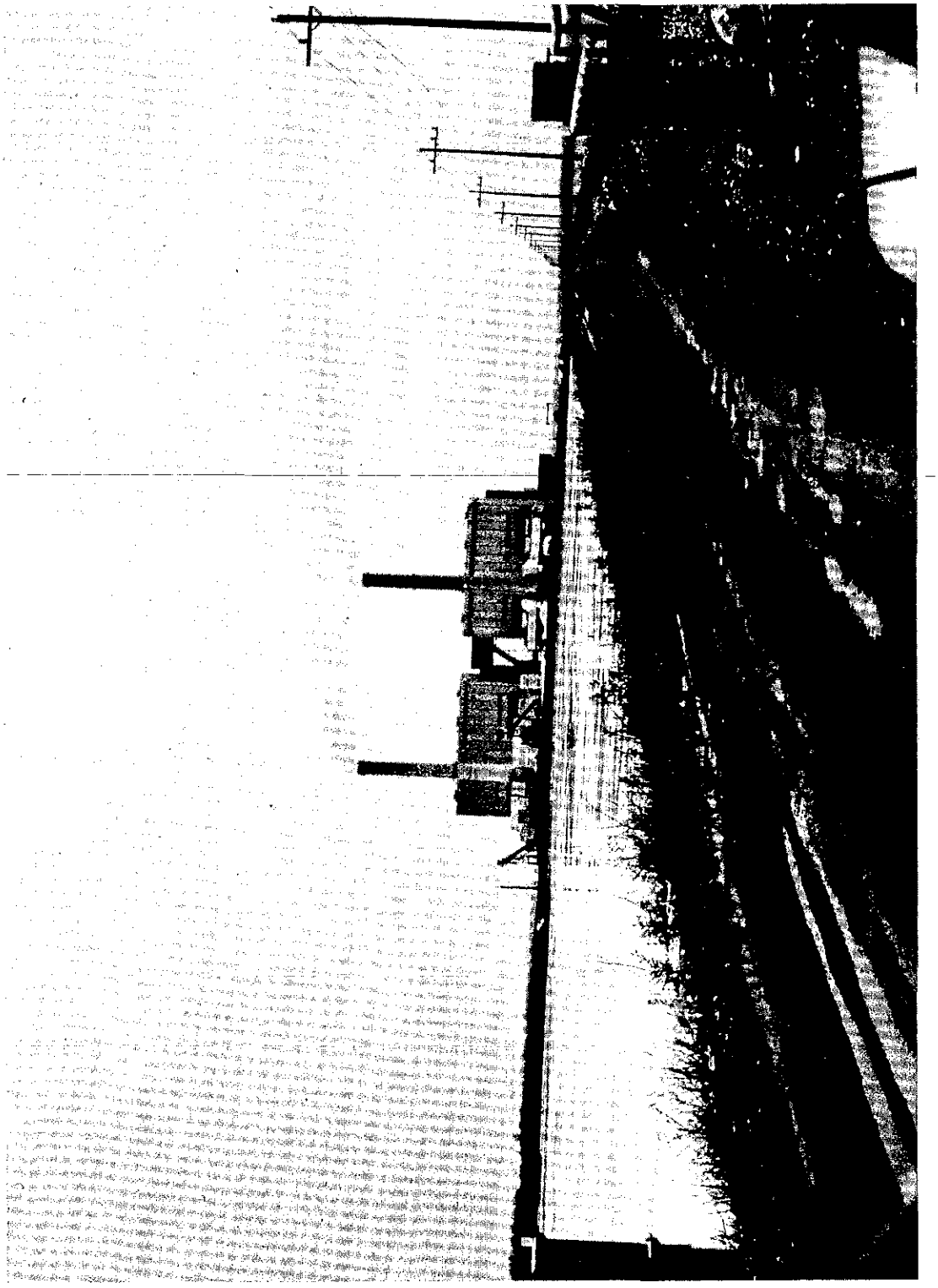

Figure 6-8. Gibson Station

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disposal areas by 1,250 hp, 3,720 gpm (932.5 kw, 234 l/sec) pumps. Average daily production of fly ash and bottom ash are 2,800 tons (2,500 metric tons) and 700 tons (630 metric tons) respectively. The ash ponds are shown in Figure 6-9. In addition to slurried ash, the ponds receive coal pile drainage, treated sanitary wastes, and other plant water. As the water reaches a predetermined level in the ponds, discharge pumps are turned on to transfer water to the main cooling lake. Units 1 and 2 have a pair of ponds, 210 acres and 20 acres (84.9 and 8.1 ha). Units 3 and 4 also have a pair of disposal ponds, 225 acres and 60 acres (91.0 and 24.3 ha). Ash disposal plans for Unit 5 are not presently known.

The ash ponds operate in series. The first pond provides primary particle removal and the second pond provides final settling and skimming. Presently, operation of the first pond for Units 1 and 2 ash is hampered by the rapid settling of the bottom ash near the point of slurry discharge. Due to this rapid settling, the bottom ash forms a delta and subsequently retards the movement of the ash slurry. To provide for the unimpeded movement of the ash slurry, this bottom ash is removed by either dragline or other coal pile handling equipment, and is placed on nearby ash deposits or the pond embankment (see Figure 6-10).

A similar problem has been avoided in the Units 3 and 4 ash ponds since the slurry pipe extends approximately 1,000 ft (305 m) into the first ash pond. The bottom ash delta formed at the pipe outlet does not adversely affect the flow of the ash slurry.

Pond embankments are either rip-rapped (interior levees) or seeded (exterior levees). Natural vegetation occurring in rip-rap areas (including grasses and trees) is discouraged by periodic spraying of herbicides. This is done to prevent water movement along tree roots, which could cause leaching or structural (soil piping) problems. Soil borings in the ash disposal and cooling pond area prior to construction indicate the presence of 5 to 6 ft (1.5 to 1.8 m) of gray or brown silty or sandy clay overlying various sand layers. Since the pond areas were excavated to provide plant fill material, the pond area is underlain by the sandy, permeable layer and is prone to seepage. To minimize the percolation through the sand, a clay liner was placed over pond interiors.

Keystone Station

Keystone Station, as shown in Figure 6-11, is a 1680 MW mine-mouth coal-fired power plant operated by the Pennsylvania Electric Company and located in rolling, lightly populated country near Elderton, Pennsylvania. The plant consists of two 840 MW

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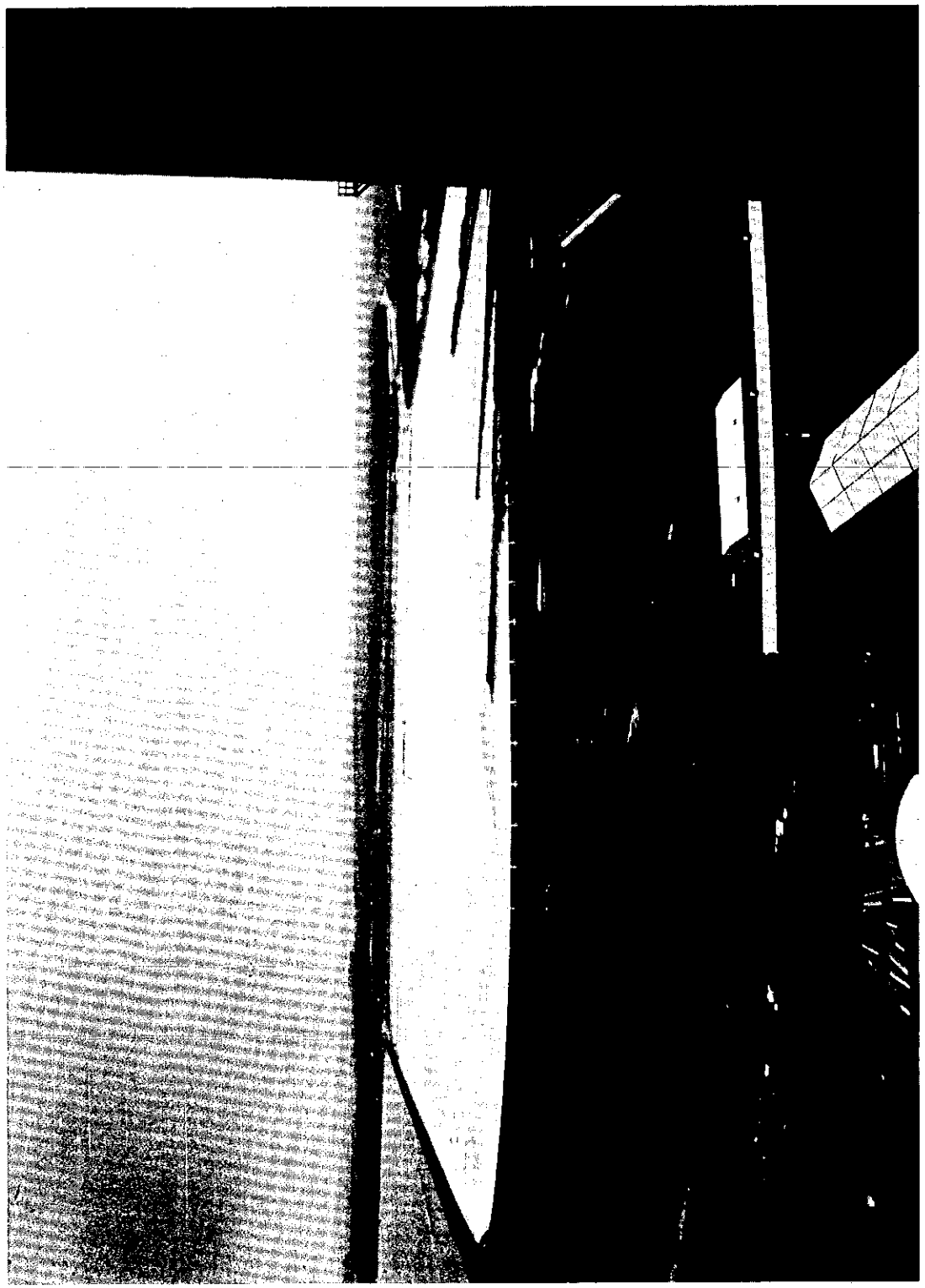

Figure 6-9. Gibson Station Ash Pond

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Figure 6-10. Removal of Ash Deposits Near Slurry Discharge, Gibson Station

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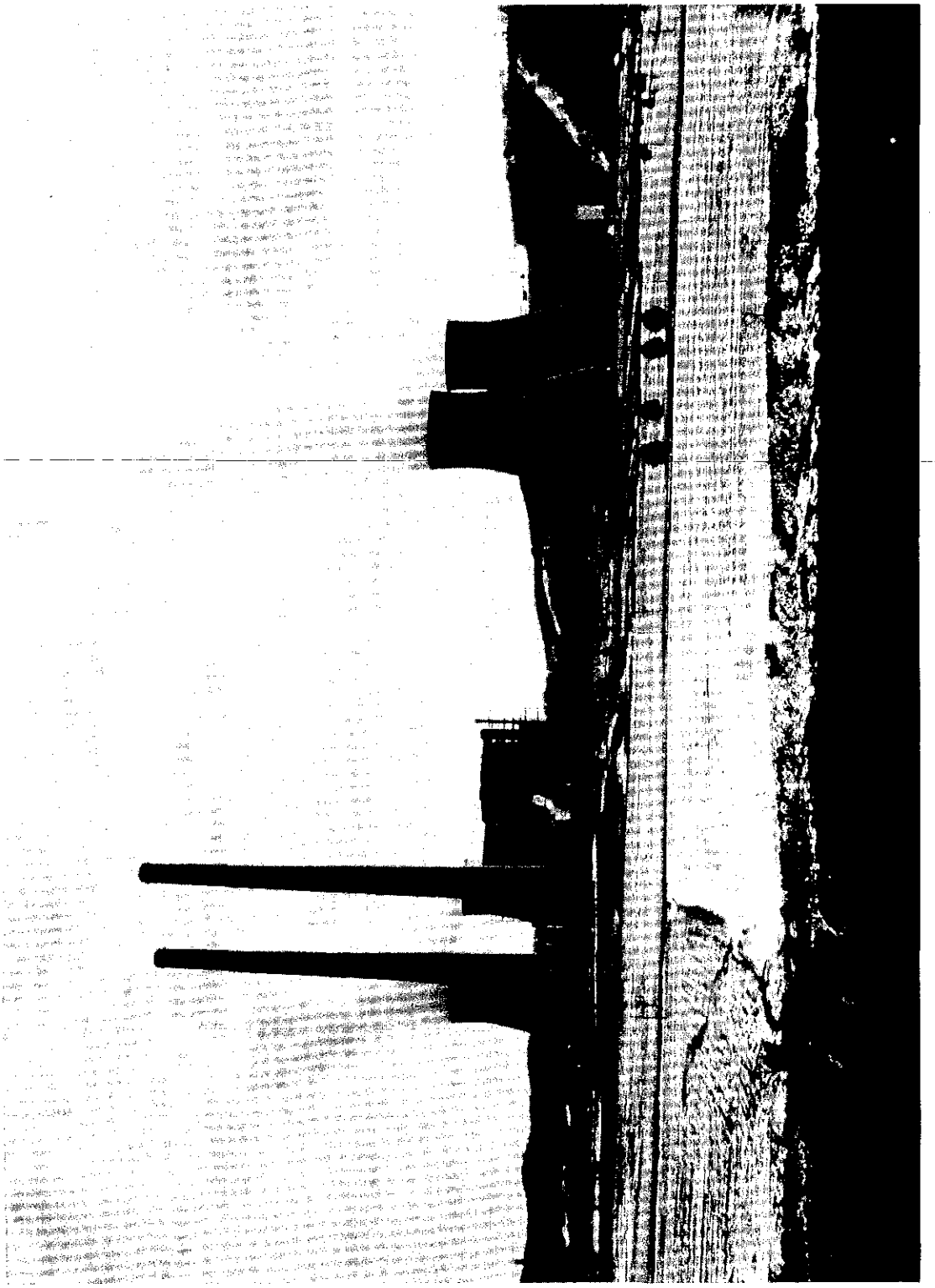

Figure 6-11. Keystone Station

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units which were brought on-line in 1967 and 1968. These units consume approximately 15,000 tons (13,600 metric tons) per day of western Pennsylvania bituminous coal. Until recently, the plant had been burning bituminous coal with an ash content of 18 to 19 percent and containing approximately 2 percent sulfur. The average heating value of this coal was 11,600 to 11,700 Btu/lb (27,000 to 27,200 kj/kg). However, due to variations within the coal seam, coal currently being used is of somewhat poorer quality having a 22 percent ash content and an energy content of only 11,300 to 11,400 Btu/lb (26,300 to 26,500 kj/kg). Exhaust from the boilers is passed through Research-Cottrell electrostatic precipitators rated at 99+ percent efficiency which utilize ammonia fly ash conditioning. The gases are then exhausted through two 800 ft (244 m) stacks.

Bottom ash is sluiced to dewatering bins. There is also a bottom ash pond for emergency backup. Approximately 25 percent of the bottom ash is sold and the remainder is placed in the disposal areas. Fly ash is collected dry from the precipitator hopper and transferred via a vacuum system to storage silos. The fly ash is either marketed (in a dry state) or mixed with water to reduce fugitive dust emissions and trucked to the disposal area (see Figure 6-12).

The disposal area is permitted by the state of Pennsylvania as a solid waste disposal facility, and is located in an area previously strip mined. Initial site capacity was 5,590,000 tons (5,070,000 metric tons) of ash when disposal operations began in 1967. However, as of January 1, 1979, only 5 years of ash disposal capacity remained. This has required an investigation into a new ash disposal area. Fortunately, the power station is located in a rather rural area and the original power station property has adequate area for a valley fill ash disposal area.

The current disposal area is operated by placing an 80 ft wide compacted fly ash embankment around the perimeter of the site to the height of the proposed fill. Ash embankment side slopes are approximately 2.5 horizontal to 1 vertical with benches 40 ft (12 m) wide at 20 ft (6 m) vertical intervals. Maximum height of the embankment will exceed 100 ft (30 m). When a side slope is constructed, it is then covered with 6 in (15 cm) of soil material stripped from the surrounding area, hydro-seeded (Crown Vetch and Kentucky 31 Fescue) and mulched (see Figure 6-13). Ash placement proceeds within the confines of this barrier. The embankment provides both structural support and aesthetic enhancement to the site since disposal operations are hidden from view.

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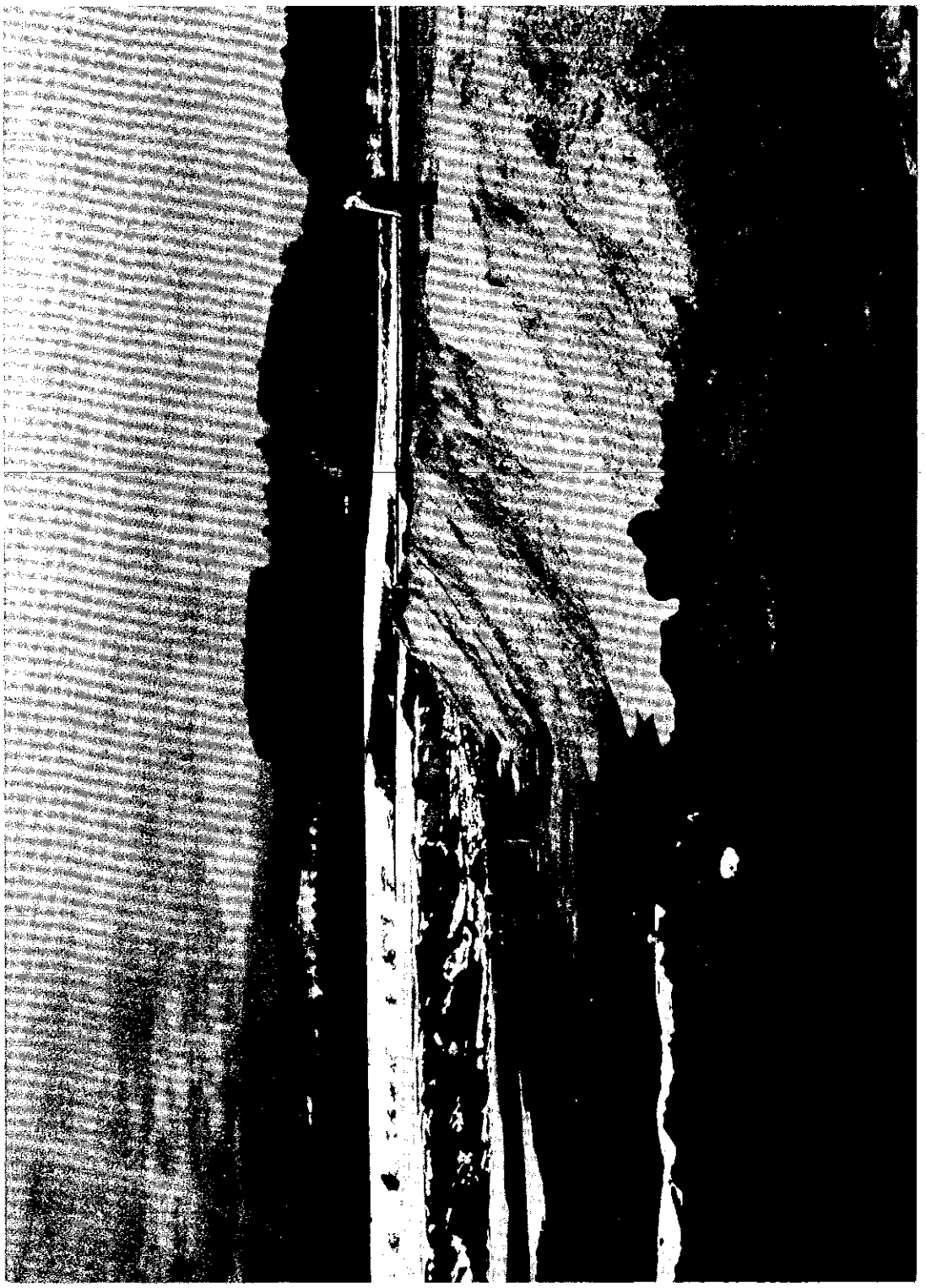

Figure 6-12. Keystone Ash Disposal Area

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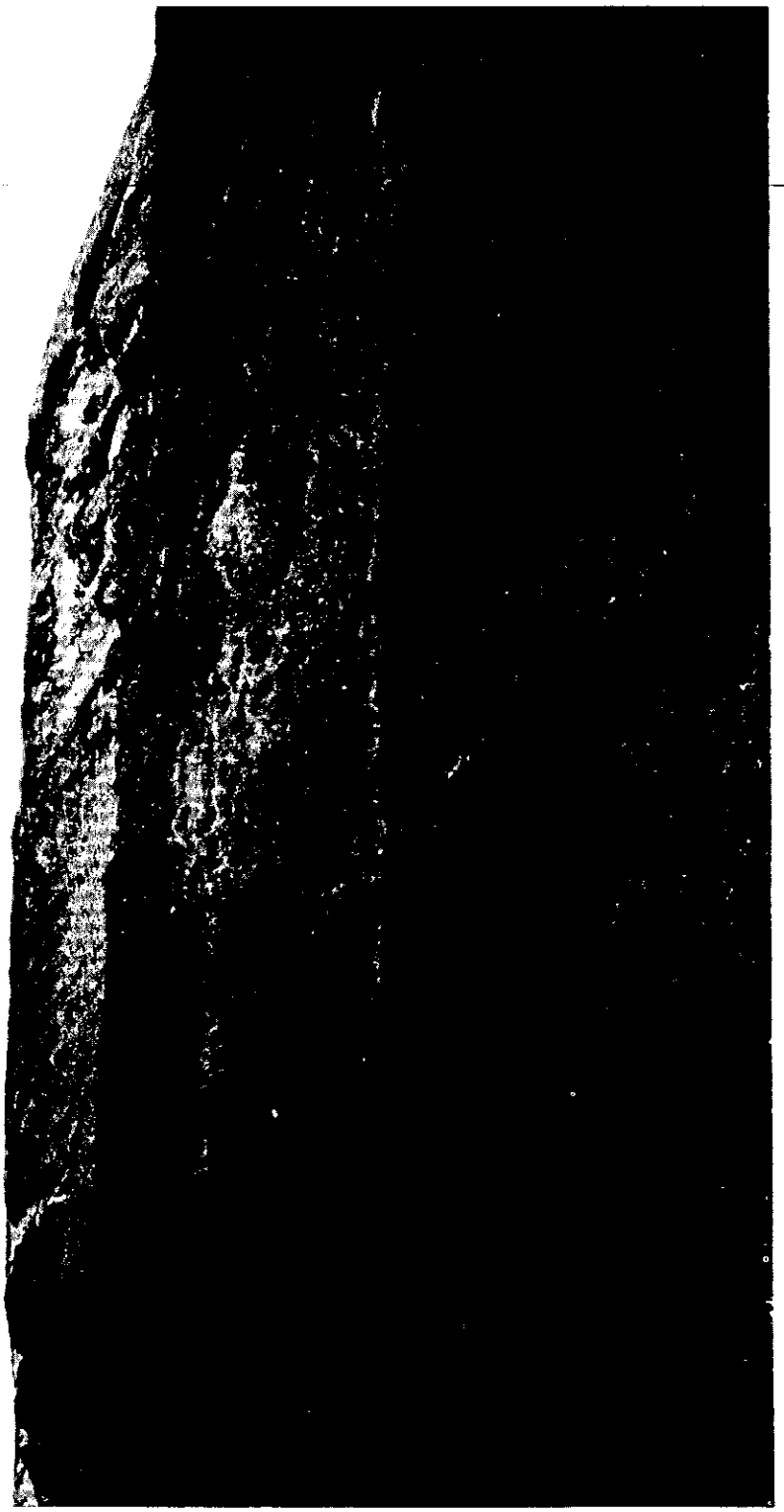

Figure 6-13. Ash Embankment, Keystone Station

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Ash in the interior of the disposal area is end dumped (see Figure 6-14). Fly ash will be spread in two-foot layers and mechanically compacted. This serves to densify the embankment, reduce the rate or amount of water infiltration due to decreased ash permeability, and increase the disposal capacity of the site. Surface and subsurface discharge from the site is monitored monthly at a surface monitoring point below the ash area after combination with other plant water, and currently complies with NPDES requirements.

San Juan Plant

San Juan Power Plant, as shown in Figure 6-15, is a 700 MW coal-fired power plant located in flat country of low population density near Farmington, New Mexico, and is owned by Public Service Company of New Mexico and Tucson Electric Power Company. The power plant consumes approximately 9,000 tons (8,100 metric tons) per day of coal. The San Juan Plant has two 350 MW units, which were brought on-line in 1973 and 1976. These units are Foster-Wheeler wet-bottom boilers. A 550 MW unit was brought on-line in 1980 and an additional 550 MW unit is under construction, with a 1982 scheduled completion date. These units are Babcock and Wilcox wet-bottom boilers. Subbutuminous coal is supplied by the San Juan Mine, which is adjacent to the power plant. This coal has an average ash content of approximately 20 percent, a sulfur content of approximately 0.8 percent, and an average heating value of 9,250 to 9,500 Btu/lb (21,500 to 22,100 kj/kg).

Plant water is obtained from the San Juan River. Units 1 and 2 condenser water is cooled by wet cooling towers. During the permitting of Units 3 and 4, sufficient water rights could not be obtained to satisfy the required cooling capacity during all seasons. Therefore these two units will use a combination wet/dry cooling tower system. A storage lake has been created to maintain water reserves during dry months and to supply irrigation water used in mine reclamation.

Fly ash is removed from the plant exhaust by Joy-Western hot side electrostatic precipitators which provide 99+ percent particulate removal efficiency, and is then transported to storage silos by a pressurized ash handling system. The transfer from the precipitator hoppers, which are under a slight vacuum, to the pressure system is accomplished by a proprietary air-lock system. After particulate removal, the exhaust gases are routed through a SO_2 scrubber and absorber system. The absorber solution is then treated in a regenerative SO_2 removal system whose end product is elemental sulfur or sulfuric acid. The end products are collected and sold.

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Figure 6-14. Ash Placement, Keystone Station

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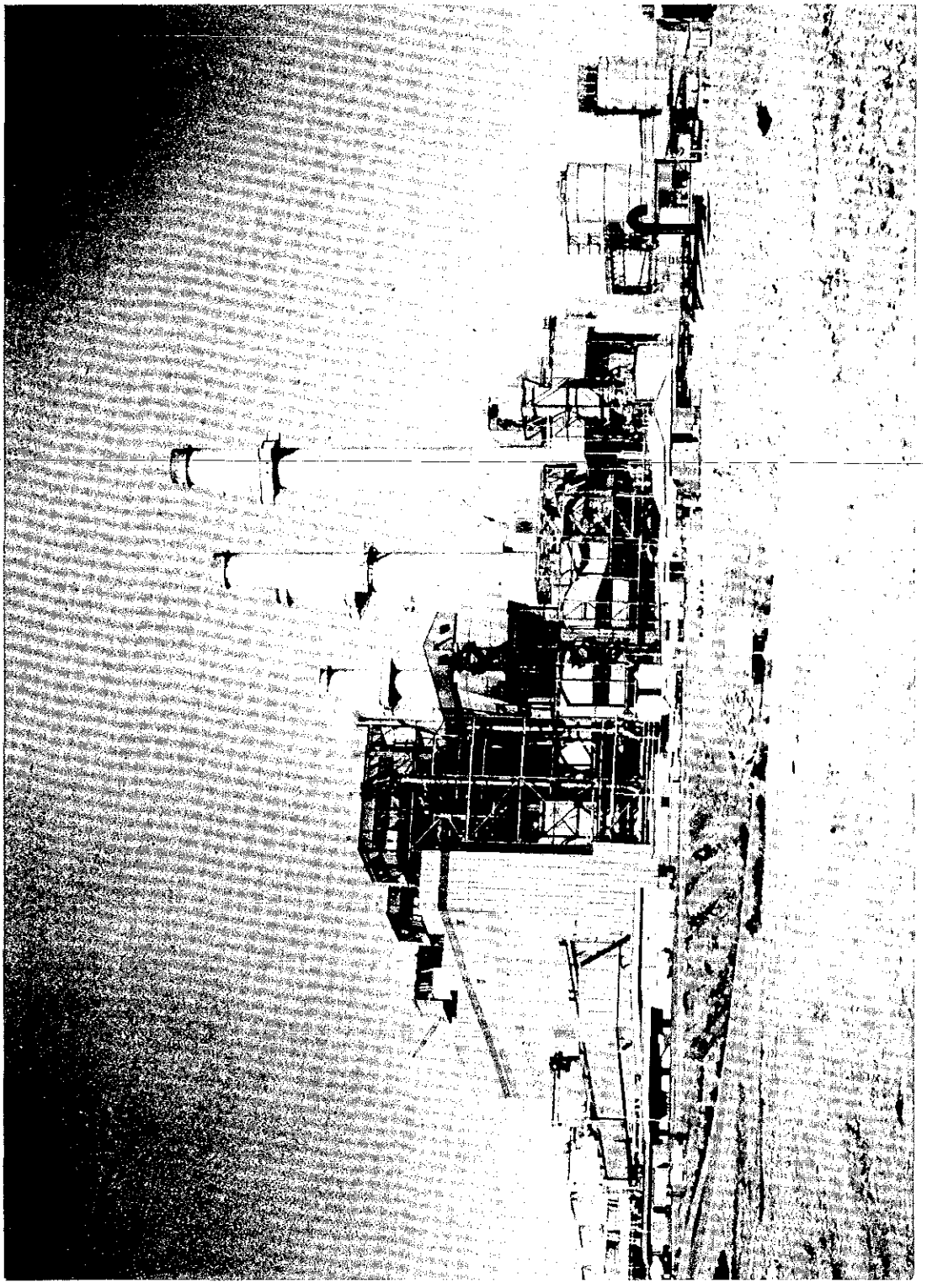

Figure 6-15. San Juan Power Plant

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Bottom ash is quenched and sluiced together with the pyritic refuse to dewatering bins, shown in Figure 6-16, prior to transport to the disposal area. Supernatant from ash dewatering is clarified and returned to the ash surge tank, completing a closed loop water system in bottom ash handling.

Approximately 1500 tons (1363 metric tons) and 300 tons (272 metric tons) of fly ash and bottom ash, respectively, are produced per day. Prior to loading, fly ash is passed through dustless unloaders where it is moistened with water (5-6 percent moisture content). Fly ash and dewatered bottom ash are then loaded into 60-ton (54 metric ton) open-end, off-road, dump trucks for transport to disposal areas (see Figure 6-17). The disposal scheme essentially entails the placement of ash in strip mine pits of the San Juan Mine. If the mine is operating, ash is end dumped into open pits prior to replacement of overburden. This procedure creates an ash seam, approximately 4 ft (1.2 m) thick, at the same elevation as the coal seam (see Figure 6-18). Alternately, if the mine is not operating or emergency disposal is required, pit areas are completely filled with ash. This is accomplished by end dumping with subsequent equipment spreading and compaction as shown in Figure 6-19. Ash is placed in 3- to 6-ft (0.9- to 1.8 m) lifts until alternate areas are filled to within 5 ft (1.5m) of the ground surface. Normal operation procedures require that at least one pit be left open for this purpose. Water trucks are used on access roads and open disposal areas to control dust.

Western Coal Company, a subsidary of the Public Service Company of New Mexico and Tucson Electric Company, leases mineral rights, obtains mining permits, and reclaims mining areas. Utah International Mining Corporation does the actual mining, and coal and ash hauling. Large drag lines with a capacity of 55 and 62 yds (42 and 47 m^3) are used to remove overburden and expose the coal seam. After blasting, a smaller shovel loads the coal into 120 ton (109 metric ton) bottom dump trucks for transport to the coal preparation plant. Coal seam thickness is approximately 16 ft (4.9 m). Overburden thickness varies from 0 to 200 ft (0 to 61 m).

Site restoration consists of filling the strip pit with overburden material and placing stockpiled topsoil on the surface in one 8 in (20.3 cm) layer, or about the normal thickness of topsoil in this area, and then revegetating. However, due to the unfavorable climate, specific revegetation practices have been devised to mitigate erosion and establish a well diversified, permanent vegetative cover. This area of New Mexico receives an annual precipitation of 6 to 8 in (15.2 to 20.3 cm). Much of this accumulates as snow which is subject to significant evaporative losses. In the summer season, the low relative humidity coupled with 100°F

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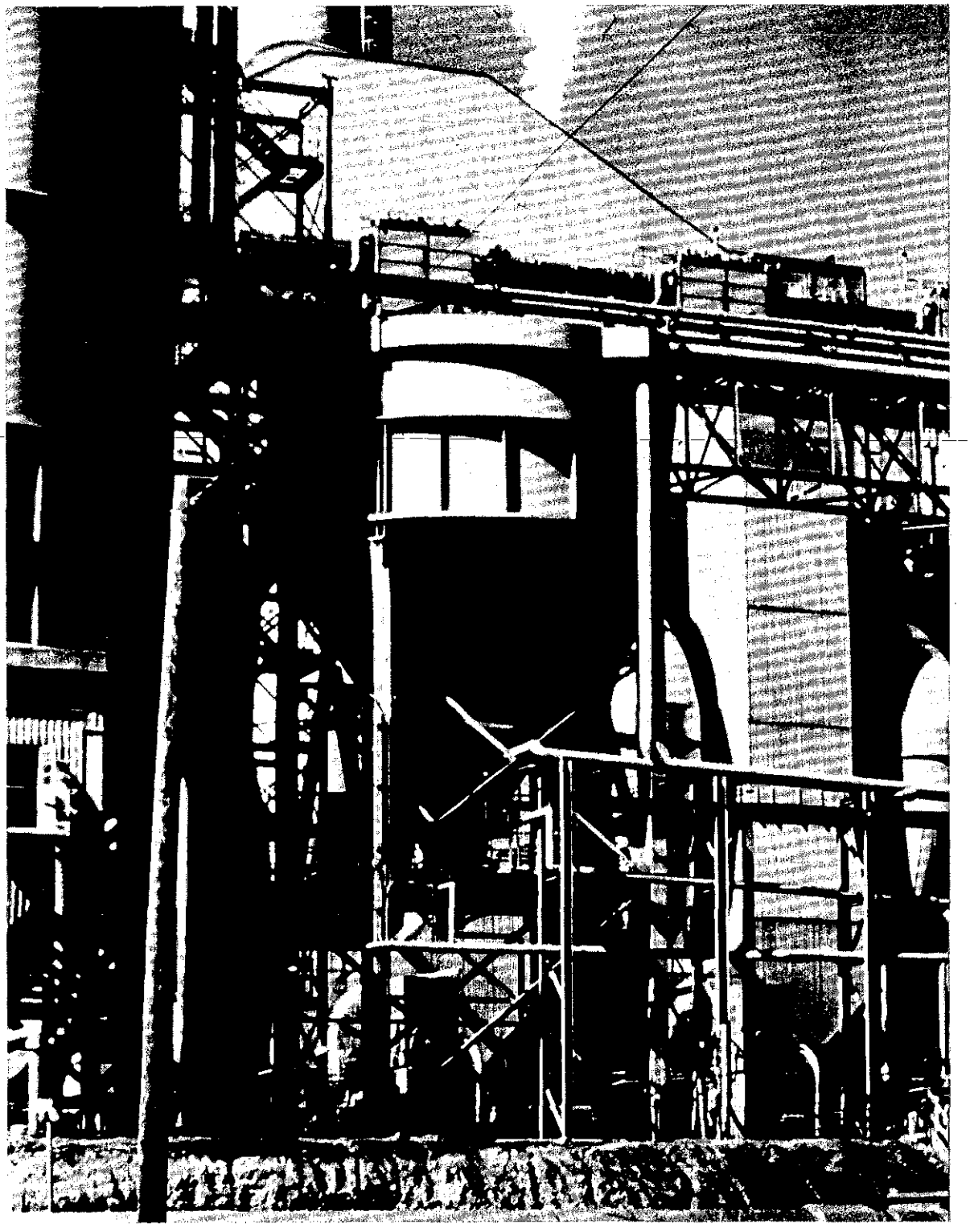

Figure 6-16. Bottom Ash Dewatering Bins, San Juan Power Plant

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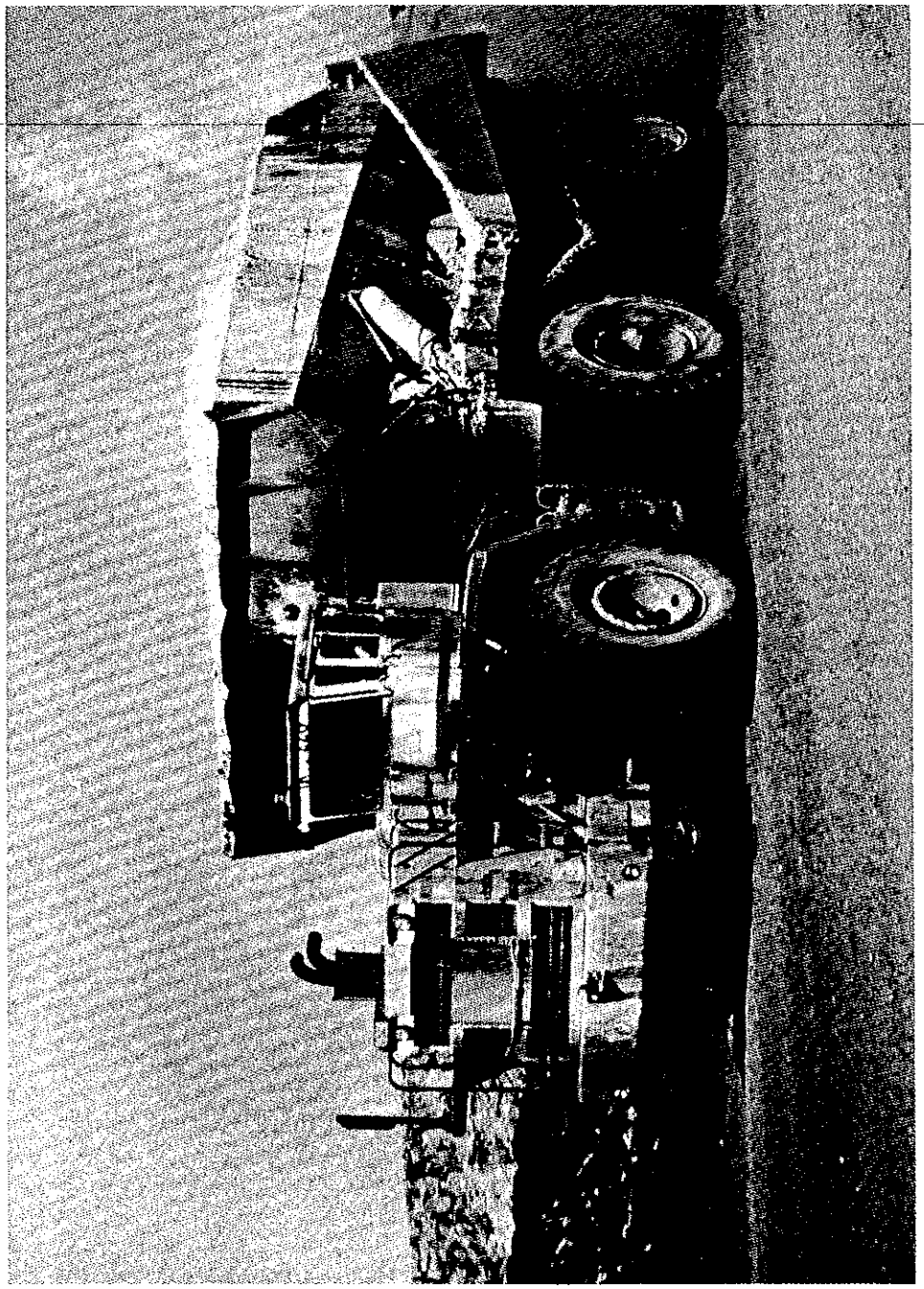

Figure 6-17. Ash Truck, San Juan Power Plant

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Figure 6-18. Ash in Strip Mine Pit, San Juan

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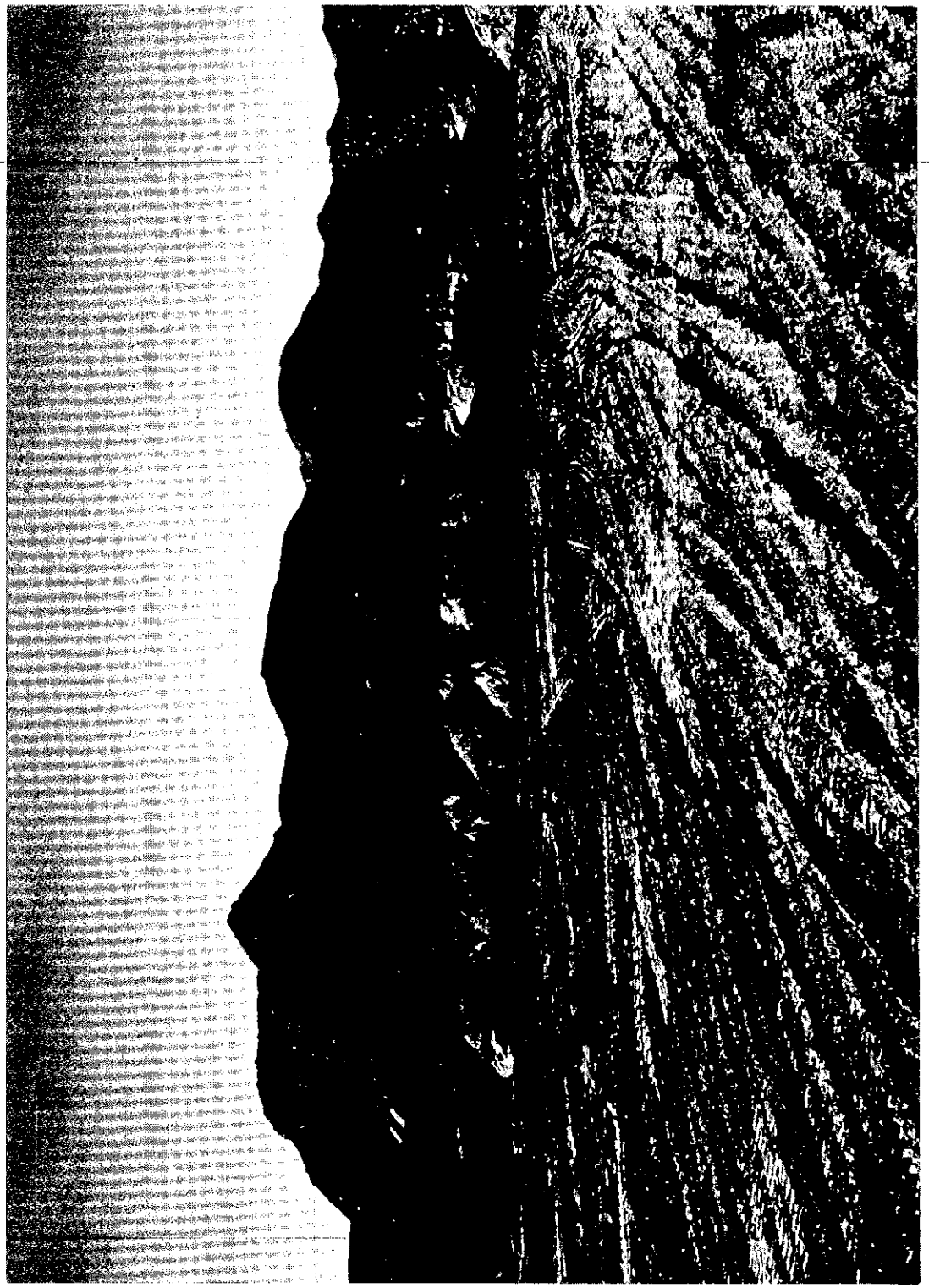

Figure 6-19. Secondary Ash Disposal Area, San Juan Power Plant

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(30°C) daytime temperatures causes evaporation rates to exceed 0.5 in (1.3 cm) of water per day.

The topsoil which is available at the San Juan mine for reclamation reseeding is less alkaline than most in the area, falling in the pH range of 7.5 to 8.0 and is chemically well suited for plant growth. Unfortunately, these soils also have a predominantly sandy texture which results in a low water holding capacity in an already moisture deficient environment.

Native plant species are used for revegetation, since these plants are already adapted to this growing environment. Species now being used include Indian rice-grasses, fourwing saltbush, shadscale, alkali sacaton, sand dropseed, winterfat, galleta, western wheatgrass, and streambank wheatgrass. Irrigation water is pumped from the storage lake and sprayed on revegetated areas during the first two years after a particular area has been seeded (see Figure 6-20). In the first year, 16 in (40.6 cm) of water is applied. Two inches (5.1 cm) is applied immediately after seeding and 0.5 in (1.3 cm) is applied every other day thereafter through emergence (usually 8 to 10 days). The remainder is applied as needed. During the second year, only 8 in (20.3 cm) is applied.

This reduced amount of water represents an attempt to "harden" vegetation in preparation for an existence the following year supported solely by natural precipitation. Fertilizer is applied to some revegetated areas; however, little difference is noted in the fertilized and "control" areas. Water harvesting, consisting of parallel tapered areas to optimize water infiltration as shown in Figure 6-21, is also being investigated.

The area affected by both the strip mine and power plant is presently being monitored for changes in the groundwater system. This monitoring program was put into effect to assess the impact of surface mining on the groundwater system. However, it will also indirectly assess the impact of ash disposal. Nine monitoring wells, similar to that shown in Figure 6-22, have been located around the area to monitor alluvial groundwater and the aquifer below the coal seam. Wells are sampled and analyzed on a quarterly basis for the constituents shown in Table 6-4.

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Figure 6-20. Reclaimed Area, San Juan

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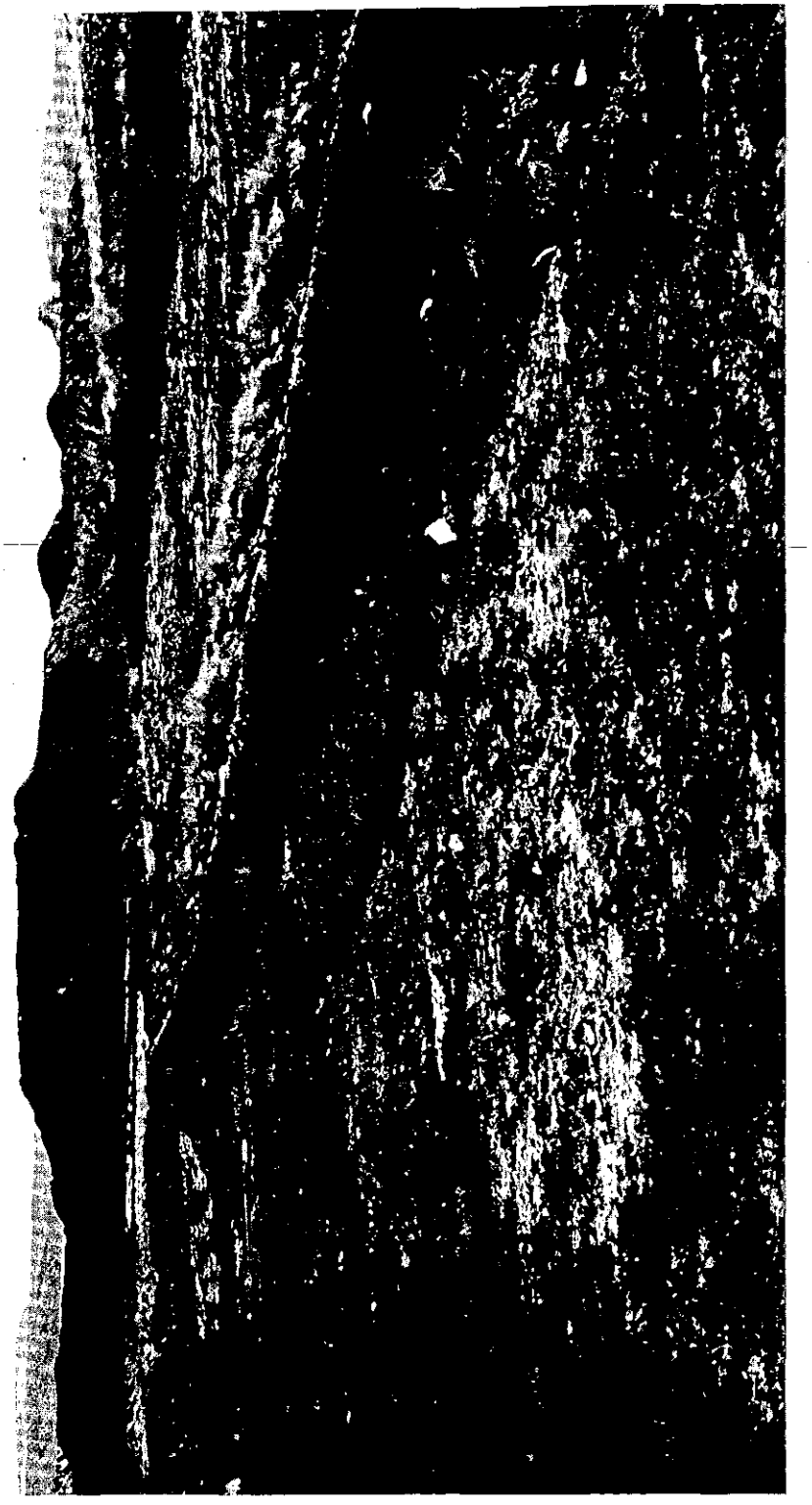

Figure 6-21. Water Harvesting, San Juan

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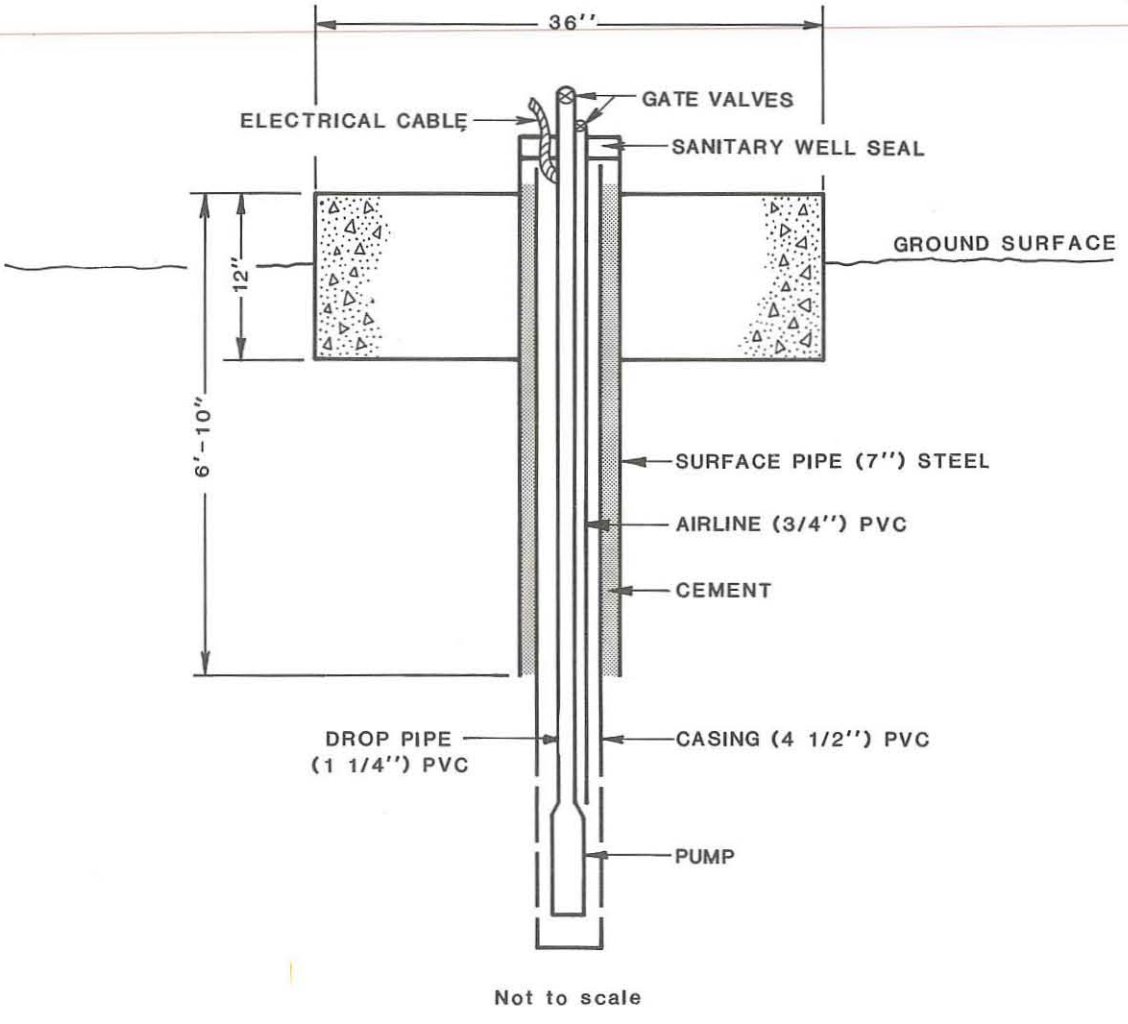

Figure 6-22. Monitoring Well Cross Section

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Table 6-4

GROUNDWATER QUALITY PARAMETERS
SAN JUAN POWER PLANT
FARMINGTON, NM

pH	Manganese*
Specific Conductance	Mercury*
Aluminum*	Molybdenum*
Arsenic*	Nickel*
Barium*	Nitrate
Boron	Nitrite
Cadmium*	Nitrogen, Total
Calcium	Phenols*
Chloride	Phosphate
Chromium	Potassium
Cobalt*	Radium-226, 228*
Copper	Selenium*
Cyanide*	Silver*
Fluoride	Sodium
Gross Alpha	Sulfate
Gross Beta	Total Dissolved Solids
Hydrogen Sulfide	Total Organic Carbon
Iron	Uranium*
Lead*	Vanadium*
Magnesium	Zinc

*Measured annually; all other parameters measured quarterly.

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Section 7

MONITORING

INTRODUCTION

Water quality monitoring of utility solid waste disposal sites is increasingly being required by many regulatory agencies. These requirements are based on the potential for ash disposal to adversely affect the water quality in the vicinity of the disposal site. Monitoring programs are designed to detect pollutants emanating from the disposal area, and assess their impact on the water quality of the area.

The monitoring of a coal ash disposal site may consist of surface water, groundwater, and leachate monitoring. A surface water or groundwater monitoring system allows for the detection of contaminants once they have entered the water system. Leachate monitoring provides the opportunity to detect possible contamination prior to entering the groundwater system.

The method of sampling and frequency plus the number of monitoring points is a function of the specific disposal site. In some cases, the selection of the monitoring system will be made by a regulatory agency. Site specific and ash specific data may or may not be used in their selection process. The typical minimum number and location of water quality monitoring points are as follows:

- Surface water - ash pond discharge or subsurface drain outlet, sedimentation pond outlet, and upstream surface flow, if present.
- Groundwater - upgradient, downgradient.

If these monitoring points are determined and placed in operation at a reasonable interval prior to the start of construction, valuable background data can be obtained that may be used in the design and operation of the disposal area or in evaluation of the monitoring data.

Water quality monitoring has been studied and reviewed in the literature. Many references have become the standard in the field due to their excellent coverage of the material and/or to their widespread use by regulatory agencies. These references are listed in a bibliography at the end of the section. Table 7-1 is a

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brief listing of some regulatory and professional organizations dealing with pollution monitoring. Although neither the bibliography nor Table 7-1 is a complete listing, they do include some of the fundamental texts, references and organizations concerned with monitoring. In addition, there are many environmental information services, journals, and organizations that deal with the area of pollution monitoring.

REGULATORY REQUIREMENTS

Monitoring requirements may result from federal, state, or local regulations. State and local monitoring requirements are variable and changing rapidly. Some states' requirements were reviewed in Section 4 and will not be discussed herein. However, the federal requirements which will have the greatest impact on the design and operation of ash disposal areas will be reviewed.

The two principal federal laws pertaining to water quality monitoring are the Resource Conservation and Recovery Act (RCRA) of 1976 and the Clean Water Act (CWA) of 1977 (through the National Pollutant Discharge Elimination System (NPDES). Table 4-1 of this manual lists other federal regulations that could also affect the monitoring requirements of an ash disposal area.

Table 7-1

ORGANIZATIONS INVOLVED WITH POLLUTION MONITORING

Regulatory

U. S. Environmental Protection Agency (USEPA)
U. S. Geological Survey (USGS)
U. S. Bureau of Mines (USBM)
Various State Environmental and Natural Resource Departments and Agencies

Professional

American Water Works Association (AWWA)
Water Pollution Control Federation (WPCF)
American Society for Testing and Materials (ASTM)
Environmental Protection Service (EPS) (CANADA)
World Health Organization (WHO)
American Society of Civil Engineers (ASCE)
American Society of Agricultural Engineers (ASAE)
Soil Science Society of America (SSSA)

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Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) of 1976 (Public Law 94-580, October 21, 1976) provides for specific controls over solid waste disposal. On March 26, 1979, guidelines for the disposal of non-hazardous wastes were published. Regulations were published by the Environmental Protection Agency (EPA) on May 19, 1980, to govern the determination and disposal of hazardous wastes. Section 4 of this manual reviews in some detail the requirements of RCRA.

Currently, fly ash and bottom ash are excluded from the EPA's list of hazardous wastes (45 FR 33120, Section 261.4, May 19, 1980). Therefore, utility ash is governed by the RCRA Subtitle D - State or Regional Solid Waste Plans. The specific regulations pertaining to surface water and groundwater can be found in the Code of Federal Regulations (40CRF 257.3-3,4).

In the RCRA regulations, surface water discharges from a disposal facility are subject to the requirements of the Clean Water Act and will be described later. Groundwater pollution, on the other hand, is regulated by RCRA, which basically states that, "A facility or practice shall not contaminate an underground drinking water source beyond the solid waste boundary...". The regulation does not specifically state that the groundwater must be monitored. However, it is difficult to prove non-contamination without monitoring, and the burden of proof is placed on the industry. State regulations for non-hazardous coal ash will be developed in accordance with the proposed RCRA Subtitle A, Section 1008 guidelines which encourage monitoring.

The EPA suggested groundwater monitoring procedures (1) for utility wastes require a minimum of four monitoring wells, one upgradient and three downgradient. One of the downgradient wells should be located adjacent to the site and all of the wells are required to be located within site property lines. In addition, these monitoring wells are to be located at depths where groundwater pollution is likely to occur.

Sampling of the monitoring wells should begin at least three months prior to the commencement of disposal, with sampling on a monthly basis continuing for a period of one year. These analyses provide background water quality required to determine the impact the solid waste disposal site has on the groundwater.

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After this first year of monitoring, the sampling period is dependent on the groundwater flow rate. The periodicity of sampling after the first year as recommended by the EPA is as follows:

- Groundwater flow rate less than 25 meters/year (82 ft/year) - annual sampling, comprehensive analysis.
- Groundwater flow rate 25 to 50 meters/year (82 to 164 ft/year) - semi-annual sampling, one comprehensive analysis, one minimum analysis.
- Groundwater flow rate greater than 50 meters/year (164 ft/year) - quarterly sampling, one comprehensive analysis, three minimum analyses.

Groundwater flow rates are quite variable even on the local level. Therefore, they should be measured rather than estimated. The procedures for measuring groundwater flow rates are well documented in the literature (2, 3, 4). Groundwater flows are a function of porosity, permeability, and hydraulic gradient, and vary from a few meters per year to tens of meters per day.

Other factors that could influence monitoring frequency are:

- Complaints from near-by residents,
- Abnormal rainfall,
- Another possible pollution source,
- An unusual operational occurrence.

Upon completion of the initial 12-month comprehensive analysis program, the groundwater background data base is established. To determine the extent of effect of the ash disposal area, subsequent groundwater analyses are compared to the background data base levels. The regulations specify that the disposal area has significantly affected the groundwater if subsequent analyses indicate levels that exceed the background level's 95 percent confidence level as statistically determined by the Student's t, single-tailed test.

The samples obtained from the groundwater monitoring system during the first year of operation should be given a comprehensive analysis similar to that shown in Table 7-2. After the background conditions are established during the first year, those characteristics not common to that specific ash can be eliminated from the comprehensive analysis required in subsequent years. If more than annual sampling is required in subsequent years because of the groundwater flow rate, the

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Table 7-2

GROUNDWATER MONITORING ANALYSIS PARAMETERS

Comprehensive Analysis:

Specific conductivity	Toxaphane*
pH	2,4-D*
Chloride	2,4,5-TP Silvex*
Total dissolved solids	Copper
Dissolved organic carbon*	Foaming Agents
Arsenic	Hydrogen Sulfide
Barium	Iron
Cadmium	Manganese
Chromium (VI)	Sulfate
Fluoride	Zinc
Lead	Color
Mercury	Corrosivity
Nitrate (as N)	Odor
Selenium	Beryllium
Silver	Nickel
Endrin*	Cyanide
Lindane*	Phenolic Compounds*
Methoxychlor*	Organic Constituents (by GC Scan)*
	Alkalinity

Other parameters possible in coal ash:

Aluminum	Boron
Cobalt	Magnesium
Molybdenum	Phosphorus
Potassium	Silicon
Sodium	Strontium
Sulfur	Titanium

Minimum Analysis:

Specific conductivity
pH
Chloride
Total dissolved solids
Dissolved organic carbon
Principal hazardous constituents found in the ash

*Probably not necessary for coal ash.

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additional samples are only subject to a minimum analysis, shown in Table 7-2.

Clean Water Act

The RCRA regulations stipulate for both hazardous and non-hazardous wastes, that site runoff is to be considered a point source discharge and is subject to the requirements of the Clean Water Act (40 CFR 257.3-3). If the ash disposal area involves a point surface water discharge (e. g. surface runoff, leachate collection system, springs, etc.), a National Pollutant Discharge Elimination System (NPDES) permit will be required. This permit program was originally established by the Federal Water Pollution Control Act Amendments of 1972, and was continued under the Clean Water Act of 1977. Usually a state's water quality agency administers the NPDES permit program. Permitting under the NPDES system currently suggests that a leachate analysis be made of the ash, a water balance about the disposal area be calculated, and an estimate be made as to the average daily discharge from the site. Current discharge criteria are as follows:

- pH between 6 and 9.
- Suspended solids (average monthly discharge)

  --less than 30 mg/l for ponded sites, and

  --less than 50 mg/l for dry sites.

However, depending on the size and quality of the receiving stream, these discharge requirements can be made more stringent to preclude degradation of existing stream quality.

Under the present permitting process, applications for permits are filed with the appropriate authority (federal or state); draft permits and fact sheets are then prepared by the authority and made available for comment. The draft permit and fact sheets set the effluent limits and determine the degree, if any, of treatment and monitoring requirements for the permitted discharge. The fact sheets are intended to explain in detail how and why the agency arrived at specific permit conditions. After comments have been received and analyzed, any necessary changes are made by the permitting authority and the final permit is issued. All permittees are required to monitor and analyze discharges in accordance with the permit document. The monitoring results are usually reported on a monthly basis and the analyses are conducted for those pollutants which effluent guidelines were set in the permit.

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If a particular state has not assumed authority for NPDES permitting, the Regional EPA Office administers the program. The EPA may require an Environmental Impact Statement if they consider the discharge to cause possible significant deterioration. The normal permitting process requires six months to one year, assuming that there are no requirements for appeals, hearings, or an Environmental Impact Statement.

SURFACE WATER MONITORING

Surface water monitoring may consist of monitoring a discharge pipe, small intermittent stream, or larger water body. To describe the processes that are operating within the aquatic system of interest, a series of samples is required. In general, a single grab sample is not adequate to describe an aquatic system since it is unknown whether a normal, high or low situation exists at the time the sample is secured. Therefore, the majority of monitoring programs will entail the gathering of water samples over a specific period of time and at a specific location. Sampling plans should be carefully developed with the aid of an experienced hydrologist. These sampling plans should include the following:

- a baseline data set which characterizes the effluent with a greater detail, precision, and accuracy than the data to be obtained from the monitoring program under design,
- the variation of the baseline data with time,
- an estimate of the statistical distribution of the baseline data,
- the number of samples to estimate the mean as a function of the monitoring program under design, and
- an estimate of the desired precision of the monitoring program under design (5).

After gathering the samples, they must be handled carefully (so that the constituents of interest do not change or degrade), analyzed at an approved laboratory, and subsequently reviewed and compared to current standards. The result of this procedure will be either the approval to discharge, or the design of a treatment process such that the discharge will be acceptable under current standards.

Sampling Points

Sample collection consists of obtaining the sample, any on-site preparation or analysis which may be required, and subsequent storage and shipment. The actual collection of the sample may be manual or automatic. The sample may be single or composite, and the sampling method either grab or periodic. Whatever the mode of

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collection, the primary purpose of a single sample is to describe the water body at that moment in time. A set of samples, in turn, will describe the fluctuations of that water body over a period of time.

The number and location of sample collection points are based on two criteria:

- Sufficient collection points to monitor the effluent and its effects; and
- As few collection points as possible to minimize the cost.

The location of an effluent discharge is normally an obvious monitoring point. Any disposal site, wet or dry, will have a discharge point(s). In general, dry disposal sites will be monitored either at the subsurface drain discharge(s) or at the sedimentation pond discharge, or both. Wet disposal sites are normally monitored only at the pond outlet.

In addition, sampling points in the receiving stream may be required both above and below the site. These sampling points provide information as to the receiving stream water quality and the effects of the discharge on that stream. The selection of monitoring points within the receiving stream and method and timing of sampling should be analyzed carefully.

Monitoring points are easier to locate for large streams and rivers due to the assimilation and buffering capacity of the water. However, for smaller streams, the ability of the water to assimilate the discharge is decreased. An additional sampling complication is that smaller streams may undergo large daily variations in both their inorganic and organic composition due to physical and biological influences. Thus, the selection of sampling time is of great importance as is the maintenance of that time during subsequent sampling. This can be seen in the comparison of a large river, the Allegheny, located in western Pennsylvania and south central New York State (average flow = 19,100 CFS or 535 m^3/sec), to a small stream, the Deep River in North Carolina (average flow = 118 CFS or 3.3 m^3/sec). The variation in dissolved oxygen in the Allegheny River varies only a few ppm on any given day. However, the Deep River can vary from zero dissolved oxygen to a supersaturated state of dissolved oxygen in one day, all due to biological factors. In addition, the concentration of both inorganic and organic constituents in the water can also vary due to the alternating oxidizing-reducing conditions. Sampling points should also consider mixing zones, plume effects, and other points of discharge within the river, as well as seasonal variations in flow. If one is not

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careful in the selection of monitoring points and times, one could confuse the effects of a natural process for pollution. Thus, monitoring points and times must be selected much more carefully for smaller streams.

Sample Collection

After selecting the number and location of the monitoring points, the type of sample and method for obtaining it must be determined. Depending on the type of process (i.e., wet or dry disposal), receiving stream, and regulatory agency, the collection method and periodicity will vary. Sample collection methods include either manual or automatic methods. Manual methods are normally used at monitoring points where samples are taken at greater than daily intervals. This type of sampling is typical for wet ash disposal areas since the discharge rate from these processes is usually quite consistent. This method consists of manually collecting the sample in a suitable container, preserving and/or analyzing the sample as required, and transporting it to a laboratory for further analysis.

Although quite simple in nature, sampling is probably the single greatest source of error in environmental monitoring. Sampling errors occur since a small sample is being collected whose constituents are being used to determine the concentrations in the entire water body. Thus, obtaining a representative sample is of utmost importance. There is, however, no clear cut method to obtain a representative sample. In general, obtaining the sample from the main flow stream will provide data on the majority of the water; however, it does ignore backwater considerations. To obtain a sample from the main flow stream is sometimes difficult, although various samplers have been marketed to aid in this activity. Once the area to be sampled has been reached, by shore, bridge, boat, etc., then the actual collection of the sample may commence. First, the sample jar should be of the proper type and should be either new or cleaned in accordance with the methods described in Standard Methods (6). These cleanings should be followed by at least three complete rinsings with distilled water and, in case of trace metals, should be followed by a rinse with distilled-deionized water. To obtain the sample, the sample container should be rinsed two or three times with the water being sampled and then filled to the brim. This must be done with a minimum of turbulence as to minimize either the entrainment or loss of gases. Upon filling the sample container, the required preservative (discussed later in this section) may be added, and the bottle quickly capped. An alternative procedure is to rinse the bottle with the water to be sampled, add the required preservative, and then fill the bottle to the brim. The bottle may then be capped. If the sampling procedure is to be done automatically,

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the samples are obtained and preserved within the automatic sampler. The samples may then be removed at predetermined intervals for analysis.

The type of sample obtained may be either grab or composite. Grab samples are those samples that are obtained and then analyzed. A composite sample is one where small samples are obtained at specified time intervals or intervals of equal volume of flow and combined. This combined sample is then analyzed and reported. For example, hourly samples could be combined in a single composite sample whose chemical composition would represent the daily average chemical composition.

The method of obtaining grab samples may be of two types: single or periodic. Grab sampling is obtaining and analyzing a single sample. This is typical of water monitoring at an ash disposal site. Periodic sampling requires obtaining single samples at specific intervals and is aimed at describing the waterbody or discharge as a time-related function.

GROUNDWATER MONITORING

Groundwater monitoring is the surveillance of groundwater for pollutant movement or changes. This is accomplished by providing access to the groundwater via a monitoring well. Although similar in nature to surface water monitoring, groundwater monitoring entails major differences. These are due to the variations in groundwater movement versus surface water movement, and to the differences in the method of sampling.

The location of the groundwater monitoring points is not as well defined as that of surface water monitoring points, since groundwater does not travel in well defined paths. In fact, it is not uncommon to find the groundwater flow direction to be contrary to the surface contours. The rate of groundwater movement under natural conditions is quite slow when compared to surface waters. Therefore, it does not require sampling as frequently as surface water. The EPA-recommended sampling frequency based on estimated groundwater flow rates was presented earlier in this section.

Groundwater Monitoring Wells

The location and depth of a groundwater monitoring well(s) is the single most important aspect of a groundwater monitoring program. The successful placement of a well can provide a wealth of information, whereas an incorrectly placed well may be of little or no use. Placement should be determined with the aid of an exper-

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ienced geohydrologist. To accurately determine the proper location of a groundwater monitoring well requires a knowledge of site subsurface conditions. These data can be obtained in many ways. These include:

- A site subsurface investigation,
- Background data from the power plant design/construction process
- Published data available through:

  --Bureau of Mines

  --Soil Conservation Service

  --Geologic Survey

  --State Environmental and Natural Resource Agencies

  --local universities

  --professional journals

In general, only an on-site subsurface investigation will provide the detail necessary to locate the monitoring wells; however, this investigation should include a survey of the power plant design/construction data and previously published data. The cost of a preliminary subsurface investigation is quite variable as to geographical area, general site geology, site area, depth to rock, background information, etc. A general range of costs would be from $5,000 to $30,000 per site and would include a review of existing subsurface data, test pits, a series of borings with at least two deep borings of approximately 100 feet (30 meters), a site topographic map or aerial photograph locating the borings, a geological cross-section(s), and a brief report including the boring and test pit logs. Upon completion of this investigation, sufficient information is available to determine the general direction and flow rate of the primary and secondary aquifers.

Geohydrologic Considerations. The specifics in determining the direction of groundwater flow are quite complex; however, the general procedure is somewhat straightforward. By reviewing water-related data such as streams, springs, marshy areas, groundwater depth (in the borings), etc., the groundwater level may be estimated. This groundwater surface is defined as that level at which the water is at one atmosphere of pressure. This level is described by the groundwater level in a well which is exposed to one atmosphere of pressure. It should be noted that this does not include any water that has risen in the soil/rock matrix due to capillary rise. This water, known as the capillary fringe, partially fills or saturates the material above the groundwater level. If sufficient data exist,

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groundwater level contours can also be estimated. This groundwater level data then indicates the direction of groundwater flow, but does not indicate the specific aquifers in which it is transported.

Groundwater flow is primarily in either porous or semi-porous soil layers, rock strata, or at the interfaces between rock strata (1). The rate of groundwater flow through the aquifer is a function of the driving force or head operating on the water and the permeability of the aquifer. The permeability of the aquifer is defined as the rate at which water can flow through the soil or rock under a hydraulic gradient of one. Aquifer permeability can be determined by on-site pressure tests, pumping tests, estimates based on previous experiences with similar soil or rock types, or laboratory permeability tests conducted on samples obtained from the borings. However, one must be cautious with utilizing permeability data obtained in the lab, due to other factors affecting in-place permeability.

Soil permeability is influenced by the soil grain size distribution, and other factors including soil density, porosity, and homogeneity. Horizontal and vertical permeability may vary by an order of magnitude or more due to non-homogeneity and stratification.

Rock permeability is a function of rock porosity, or the volume of voids per unit volume of rock, the degree of fracture (joints and bedding planes within the rock), and interface effects between rock strata and adjoining material. Rock porosity can vary from extremely porous karst limestone with large solution cavities to a semi-porous sandstone to a relatively nonporous shale or claystone. Although the rock porosity, and as a result the permeability, will be highest in the limestone and lowest in the claystone, rock fracture and interface effects can alter these dramatically. A relatively impervious shale can provide for the relatively unimpeded flow of water if in a fractured state. Thus, rock permeability data should be used with caution in analyzing aquifer systems. In aquifers of fracture and solution porosity, it is possible that monitoring wells might not intersect the leachate plume. If possible, in-place permeability tests should be conducted with the exploratory drilling program to provide specific in-place permeability data which is invaluable in future analysis and design of an ash disposal area.

By comparing the in-place permeabilities of the soil layer's rock strata, the primary and secondary aquifers may be determined, and the primary flow direction in these aquifers estimated. It should be noted that many groundwater systems consist of only one aquifer which may include one or more adjacent rock strata. By comparison

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other groundwater systems may include three or more aquifers, although these systems would be relatively uncommon.

Well Location. Figure 7-1 shows an example of groundwater contours superimposed upon a dry ash disposal area. The small arrows indicate the general direction of groundwater flow, whereas the large arrow indicates the estimated direction of travel for the ash disposal site leachate. Figure 7-2 shows the layout of the groundwater monitoring points for the site. Monitoring Points U-1 and D-1 are the minimum number of monitoring points necessary to pick up both upgradient and downgradient samples. The upgradient samples will provide a background sample whereas the downgradient sample will provide a sample that exhibits the effects of the ash disposal area on the groundwater system.

As suggested by EPA, additional monitoring wells may be desirable or required, such as wells D-2 and D-3. Although not obvious in plan view, the additional monitoring wells are to provide additional pollutant plume coverage and provide groundwater data on specific aquifers. Figure 7-3 indicates a geological section taken through wells U-1 and D-1 with the other wells projected onto the section. On this site, the extra wells have been used to specifically sample the primary and secondary aquifers whereas the primary wells sample the combined groundwater system.

Although adequate for a dry disposal site or a lined wet disposal site, this type of groundwater monitoring system would not be sufficient for an unlined wet disposal area, due to the alteration in the groundwater surface contours by the water percolating from the wet disposal area. Figure 7-4 illustrates this situation; a mound in the groundwater table. The solid lines are the groundwater level contours, influenced by the pond, and the dashed lines indicate pre-pond or undisturbed groundwater level contours. As can be seen, the wet disposal area drastically affects the groundwater system. The small arrows indicate the general direction of groundwater flow as affected by the pond. In this situation there is now no single primary direction of travel for the ash leachate. As indicated by the three large arrows, the leachate would spread out in a general westerly direction.

Figure 7-5 shows the location of the monitoring wells required to monitor the groundwater beneath the site previously described by Figure 7-4. The upgradient wells, U-1 and U-2, are placed to sample the background water. Although these wells could be combined in some cases, the extent of the entering groundwater in this example dictates two wells. Background data obtained prior to the disposal site operation would provide significant information concerning upgradient leachate

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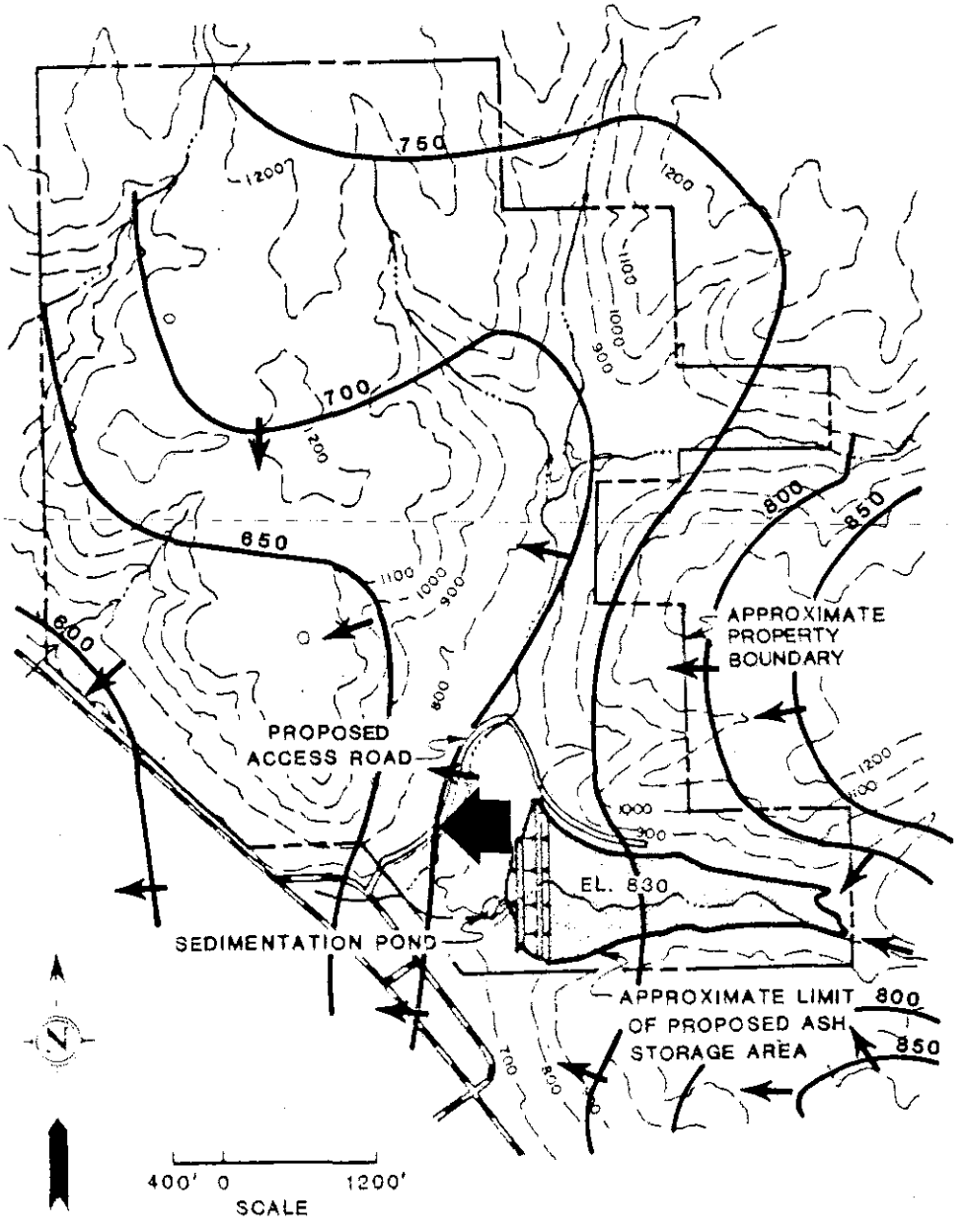

Figure 7-1. Groundwater contours supperimposed upon a dry ash disposal area. Small arrows indicate general groundwater flow directions. Large arrow indicates the estimated direction of travel for the ash site leachate.

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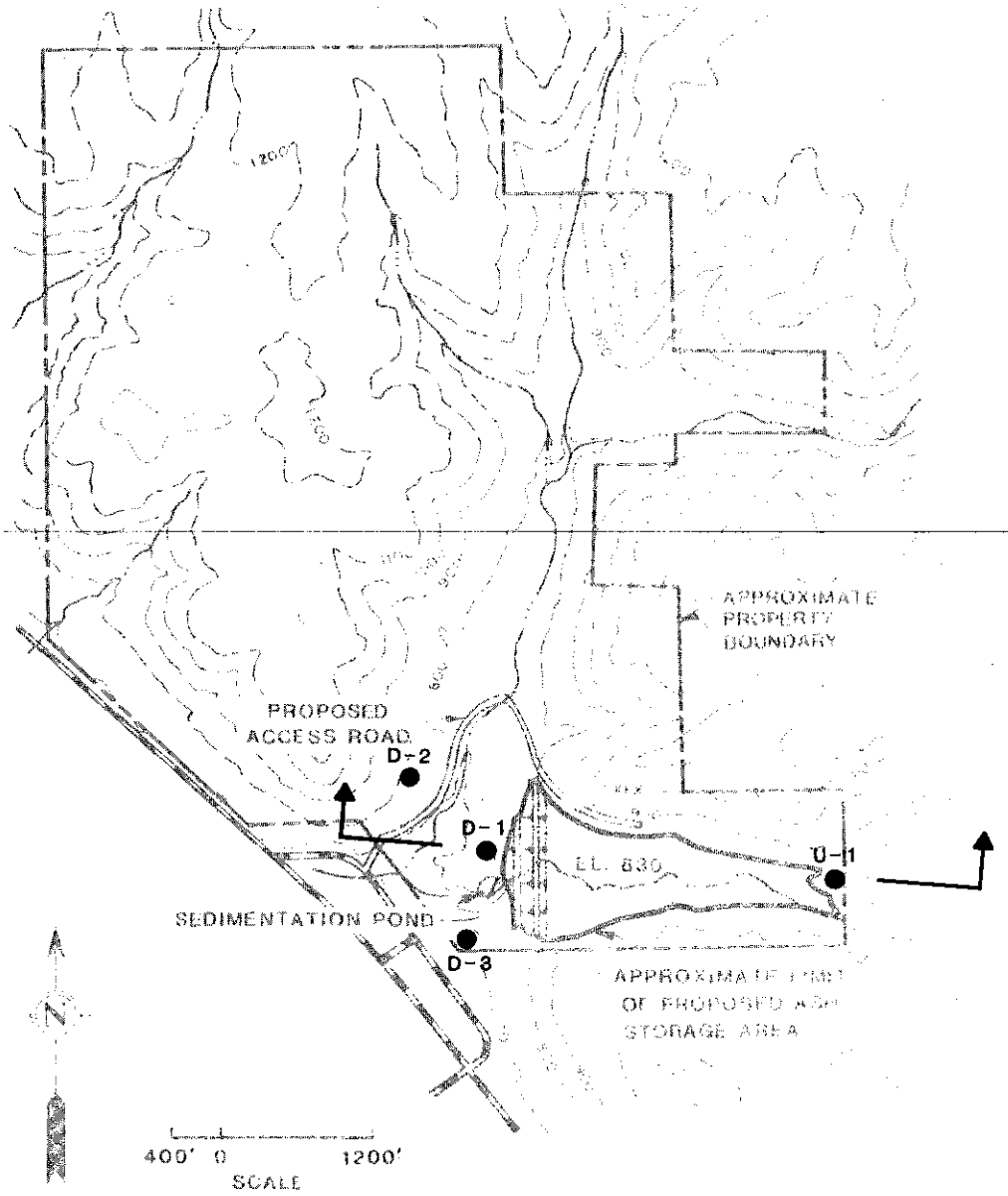

Figure 7-2. Groundwater Monitoring Points for a Dry Disposal Site.

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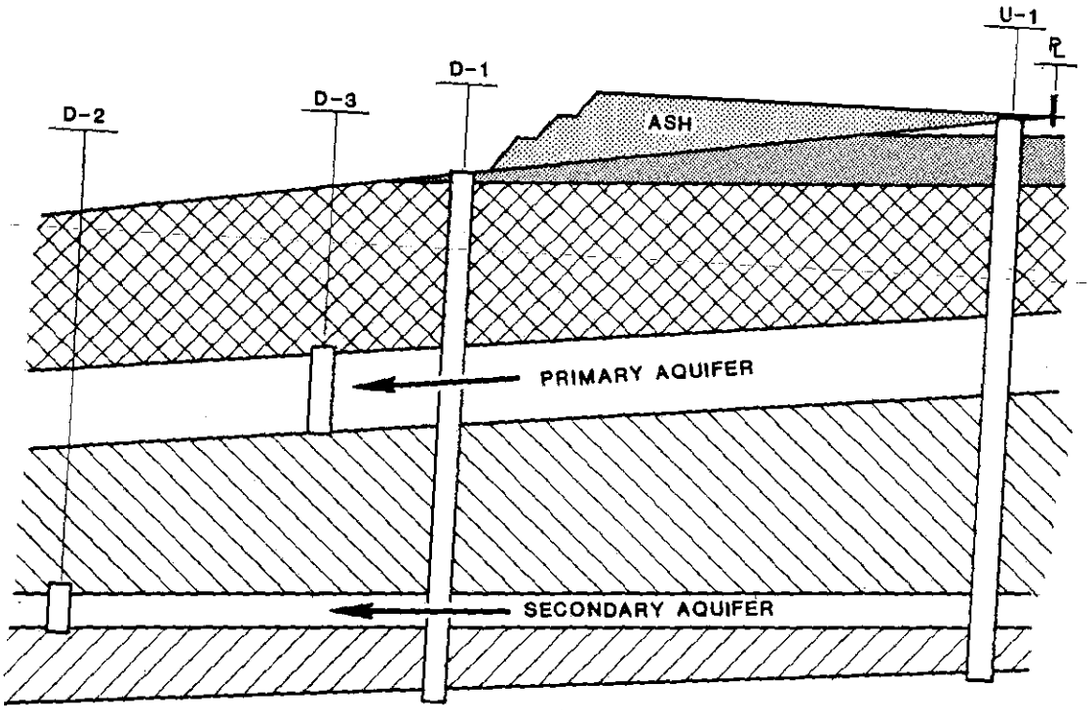

Figure 7-3. Geologic Cross-Section of Disposal Area

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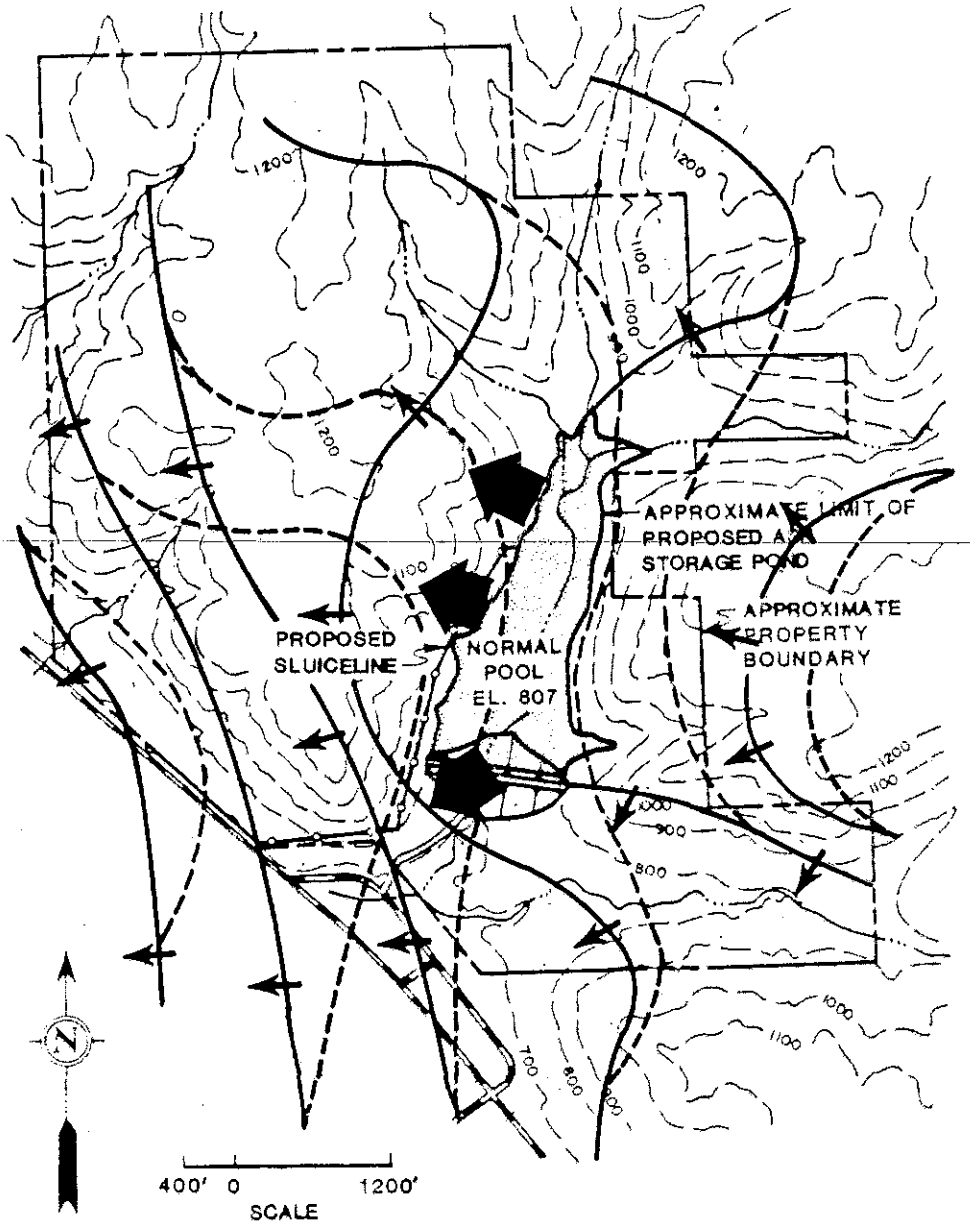

Figure 7-4. Effect of Wet Disposal Area on Groundwater System. Small arrows indicate groundwater flow directions. Large arrows indicate direction of travel for ash disposal leachate.

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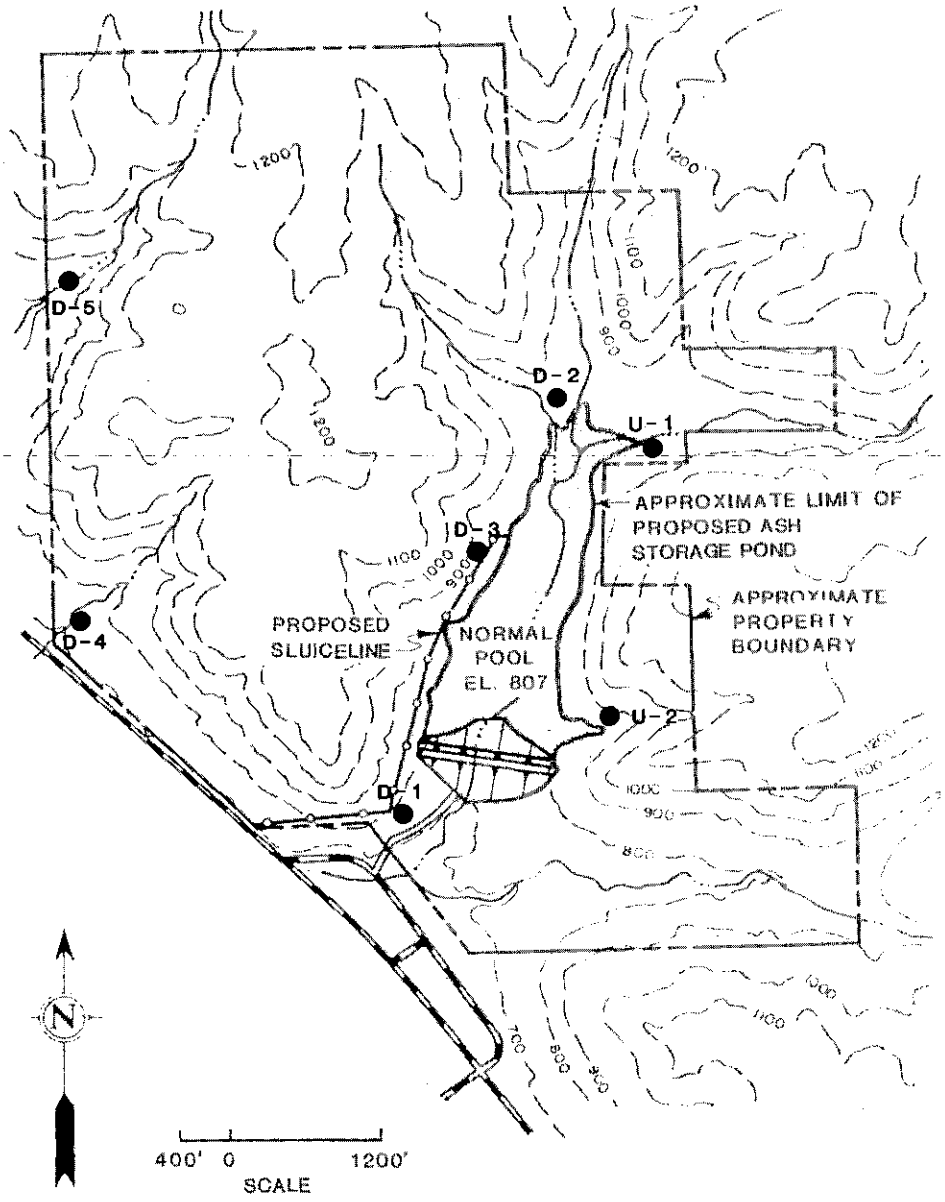

Figure 7-5. Groundwater Monitoring Points for a West Coal Ash Disposal

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movement.

Downgradient wells D-1, D-2, and D-3 are placed to monitor the near effects of the ash leachate. These wells are designed to provide an early warning system if some groundwater parameter would reach too high a level. Wells D-4 and D-5 are designed as backup wells. If wells D-1 through D-3 should miss the pollutant plume, due to preferential travel, poor well installation, etc., then wells D-4 and D-5 would intercept this water prior to its movement onto other property. The decision of whether or not to install backup monitoring wells is based on both the quantity and quality of leachate expected. Other influencing factors may be the proximity of water supply wells or environmentally sensitive areas to the disposal site.

Design and Installation. The purpose of a groundwater monitoring well is to provide access to the groundwater for sampling. However, the installation of a monitoring well must be done with care since:

- A representative sample of the groundwater is desired, therefore the monitoring well materials should be relatively inert,
- The installation of the well could be the cause of surface infiltration into the system, thus a source of contamination.

The inability to accurately predict groundwater levels prior to drilling requires experienced personnel to supervise the drilling and to record the samples for future analysis and testing.

Figure 7-6 indicates a cross section of two monitoring wells; one designed to sample the combined groundwater, and one designed to intercept a specific aquifer. As can be seen, the materials recommended for use are relatively inert while at the same time provide an economical installation.

The danger of surface contamination is very real in the use of monitoring wells (1). Referring to Figure 7-6, it can be seen that without the presence of the concrete cap, surface water would be free to penetrate the well. However, even with the concrete cap there is still some possibility of contamination due to the soil-concrete cap interface. Therefore, the installation of the monitoring well should be accomplished with adequate surface drainage considerations.

The installation of a monitoring well is normally performed by a private drilling contractor. The method of constructing each monitoring well will vary as to the

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soil or rock encountered but can be summarized as follows (1):

- A hole is drilled to the size and depth required. Although a specific size monitoring well may be called for, this hole must be drilled oversized to permit pipe installation. In addition, in certain soils such as sand, the sides of the hole tend to cave in and a casing is required. One final consideration is the amount of rock drilling required. The drilling of rock is much different than soil drilling and, therefore, requires special equipment. These above factors all combine to determine the cost of drilling.

- After the hole has been drilled, and cased as required, the monitoring well pipe is inserted into the hole. At this point, the determination of an open or closed bottom monitoring well must be made. A closed bottom well is usually preferred to prevent well cuttings from infiltrating through the bottom.

- With the pipe in place the annular fill material, either pea gravel or grout, is placed. If grout is being used, the driller must be careful to control its placement.

- Upon filling the annular space with the proper material, the concrete cap and the top cap should be installed. The top cap is made commonly of steel pipe. It should be installed with a padlock to prevent vandalism.

- Finally, the well should be flushed. During the drilling and backfilling sequences, water or a water-clay mixture is used as a lubricant. This process may result in foreign materials being either enmeshed in the existing soil matrix or trapped at the bottom of the well. Thus, the well must be flushed to remove these materials. If the amount of groundwater is insufficient to flush the well, the hole should be drilled by rotary air methods. Using this method, the well may be flushed using a compressed air-vacuum system.

Sample Collection

The collection of representative samples from a groundwater monitoring well is one of the more difficult water sampling problems. Not only are the practical difficulties greater than in a surface water situation, but there is also more potential for sample contamination. Three possible sources of contamination in groundwater sampling are: the well casing material, entrained atmospheric gases and their subsequent chemical reactions, and the stratification of contaminants due to well water stagnation.

To avoid sample contamination it is important that a sample of the actual groundwater, i.e., not the water initially in the well, be obtained. This is accomplished by either bailing or pumping the well to remove the initial water. It is recommended that at least one, and preferably three to five volumes of water be flushed from

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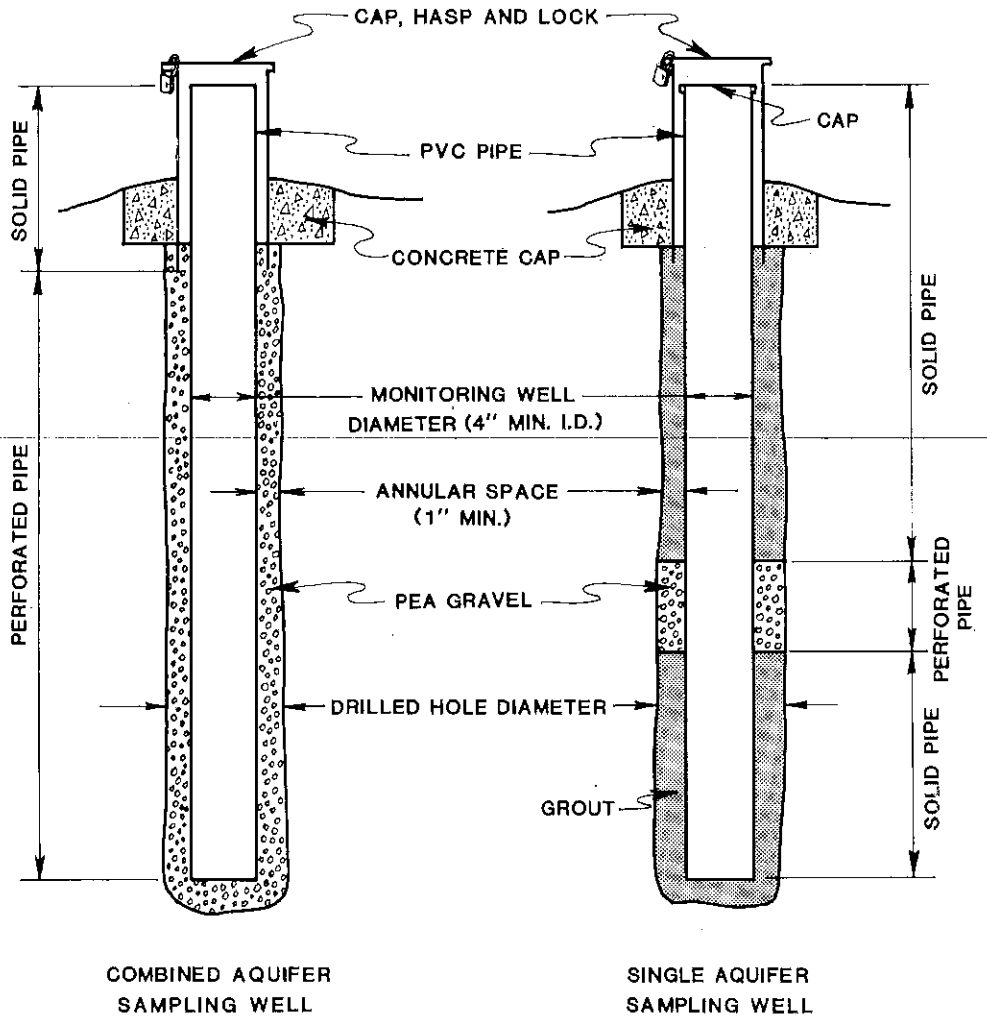

Figure 7-6. Monitoring Well Cross-Section for Single and Sampling of Aquifers.

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the well. This flushing not only clears the well of standing water but also clears the sampling equipment of water from previously sampled wells. Excessive flushing, however, may cause stratification of the leachate concentrations resulting in a decrease or an increase of contaminant concentration from what is representative. Dryer wells should be flushed only once and allowed to refill.

The most expedient and acceptable method of sampling is pumping, since it removes all the sediment in the bottom of the well and provides a positive mechanism for well water removal. For this method, either an aboveground or in-well pump is utilized to remove the initial well water and subsequent samples. The type of pump and method of sampling must be chosen with care to avoid the entrainment of atmospheric gases in the sample.

Various types of pumps have been produced that are suitable for sampling monitoring wells and are available through scientific supply companys. Above ground pumps can be used for lifts of up to 25 or 30 feet (7.6 or 9.1 meters). They may either be electric or manually operated. The units basically consist of a suction hose, pump, and discharge hose. The electric units can be operated with standard 12 volt dc, 110 volt ac, or attached to a vehicle electrical system. For pumping heads greater than 30 feet, in-well pumps must be used. Truck mounted submersible pumps are capable of lifting well water from as much as 300 feet (90 meters) at 7-14 gpm (.4-.9 l/s). These pumps will fit into a casing as small as 4-1/2 inches (11.5 cm) inside diameter (ID). Portable submersible pumps are also available and are capable of pumping up to 175 psi (12.3 kg/cm^2), which is equatable to approximately 400 feet (120 meters) of water, at flow rates up to 0.17 gpm (630 ml/min.). These portable pumps will fit into a casing as small as 3 inches (7.6 cm) ID.

One advantage of using aboveground pumps, either electric or manual, is the monitoring well diameter required. The suction hoses on these pumps are usually less than one inch (2.5 centimeters) in diameter and, therefore, require only a two-inch (5 centimeter) ID well. In-well pumps have the disadvantage of requiring larger well diameters. Some pumps are available that fit into a three or four-inch (7.5 or 10 centimeter) well as mentioned before; however, six-inch or eight-inch (15 centimeter or 20 centimeter) wells are normally required. This larger diameter increases the cost of the monitoring well, but for deeper wells, in-well pumps are the only alternative. Although more expensive, the larger diameter wells do provide added sampling capabilities. They can accommodate samplers which are capable of obtaining samples at specific depths with minimal interference.

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Another consideration in choosing a monitoring well diameter besides the type of pump is the possibility of in-well analysis. Depending on the information required, certain tests may be conducted via probes inserted into the well itself. These tests include pH, temperature, conductivity, dissolved oxygen and other chemical parameters. This capability allows testing on a depth basis which could provide leachate movement information.

Bailing of a groundwater monitoring well can be a tedious operation. However, when done properly, it can provide a reliable groundwater sample. Bailing consists of using a bailer, which is any weighted container, inserting it into a well, lowering it, and obtaining a water sample. Kemmerer or Van Dorn samplers are examples of bailers. The problems associated with bailing include the inability to adequately clean the monitoring well, the suspension of deposited sediment during sampling, and the inability to obtain large samples. To provide a single large water sample a series of small samples must be obtained. A recent development in bailer design has permitted the use of a mechanized bailer apparatus. This apparatus, while not negating the deficiencies of the process, does provide a more manageable sample collection system.

Another method of groundwater sampling is the use of a bubbler sampler (1). As shown in Figure 7-7, the sampler consists of two tubes and a chamber. The sampler is operated by inserting the assembly into a bore hole. The smaller tube is then pressurized by a small compressed gas canister. When the buoyant pressure in the chamber exceeds the weight of water in the larger tube, the water in the larger tube is conveyed to the surface by the gas bubble. This procedure is operated until either the well is cleaned or a sufficient sample has been obtained.

The actual process of obtaining the sample is similar to the sampling of surface waters. Once the well has been flushed of its standing water, the recommended sampling procedure is as follows: insert the inlet line (or in-well pump) to a depth just below the water surface and, if possible, pump the groundwater at the recovery rate of the well. When a relatively steady state has been attained, and the water is flowing free of air bubbles, sampling may begin. The sampling bottles should be prepared as described earlier in this section under surface water monitoring. The bottles should be filled quickly to the brim and immediately preserved with as little turbulence as possible. Contact between the sample and the air should be minimized. This is necessary because of the possibility that the groundwater constituents may be in a reduced state and that the entrainment of oxygen may oxidize these constituents and subsequently provide erroneous values when analyzed.

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LEACHATE MONITORING

The purpose of leachate monitoring is to intercept any contaminants migrating from the disposal site before they encounter and contaminate the groundwater or surface waters (1). Leachate concentration is likely to change as the plume proceeds through the underlying substrate. This is due to:

- Soil attenuation and dissolution,
- Ion exchange capacity of the soil,
- Dispersion,
- Depletion of contaminant source after closure of the site,
- Solubility differences because of changes in pH.

Each leachate contaminant behaves differently with respect to each of the above properties. For example, heavy metals are prone to attenuation while chloride does not attenuate or exchange at all. This property of chloride makes it ideal for measuring plume dispersion and leachate depletion.

The advantage of leachate monitoring is that, if successful, it allows early detection of leachate problems prior to contamination of groundwater or surface water. Early detection can minimize the cost and extent of any remedial measures required. Under the proposed RCRA regulations for hazardous solid wastes, leachate monitoring would be required. This requirement does not include ash disposal sites as currently drafted. For those sites where leachate monitoring might possibly be required, sampling frequency and analysis are similar to those for groundwater monitoring systems.

Various alternatives, as shown in Figure 7-8, exist for leachate monitoring. The simplest procedure is to sample the outflow from leachate collection systems. Leachate collection systems may include granular blankets above or below liners which drain to sumps or underdrain systems beneath landfills. Sampling procedures are similar to surface or groundwater sampling, as appropriate. The purpose of monitoring leachate in this situation is not so much to detect a threat to the groundwater, but to provide an input to a leachate treatment process.

When leachate collection systems are not included in the disposal site design, leachate sampling is generally accomplished via pressure-vacuum lysimeters, as shown in Figure 7-8. They are installed specifically for leachate monitoring (1). This specialized lysimeter is designed to draw water from the zone of aeration (the

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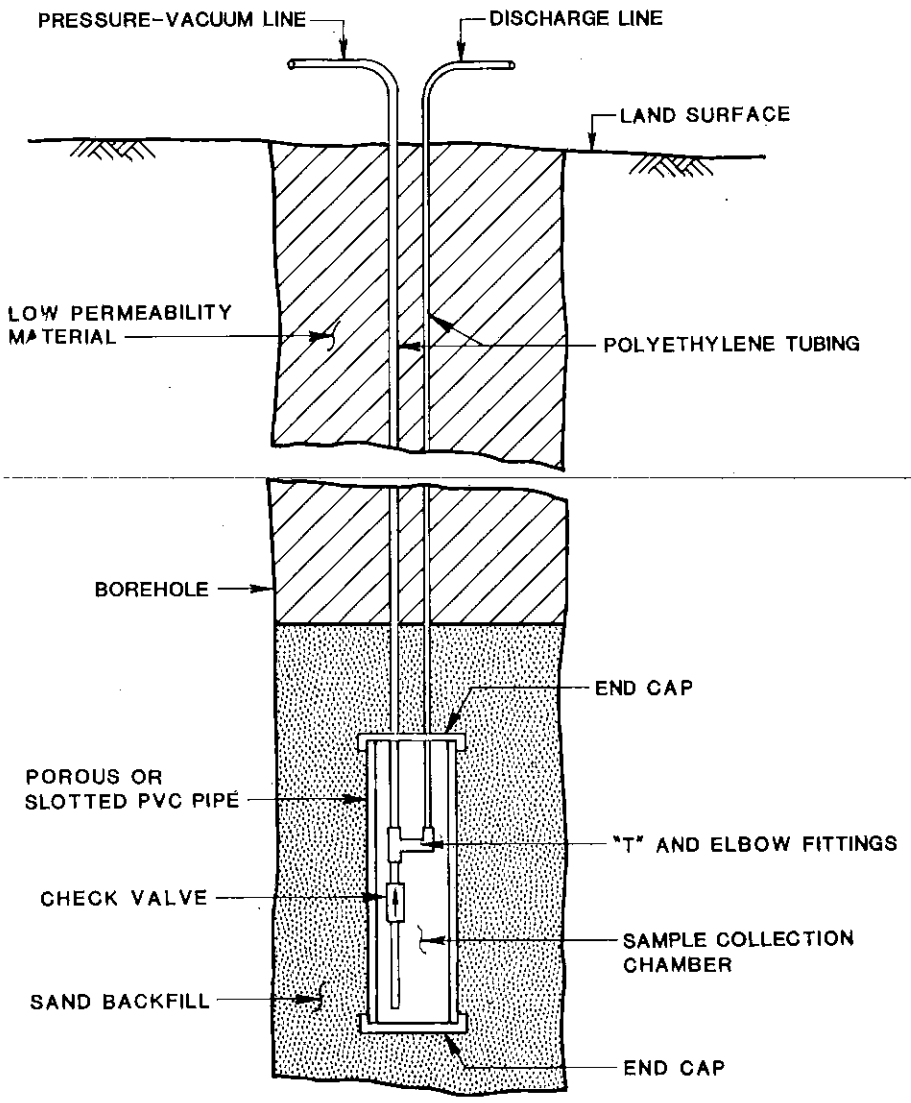

Figure 7-7. Schematic of a Bubbler Sampler

Source: U. S. Environmental Protection Agency. Procedures for Groundwater Monitoring at Solid Waste Disposal Facilities. Cincinnati, OH: Solid Waste Information, USEPA, 1977. EPA/530/SW-611.

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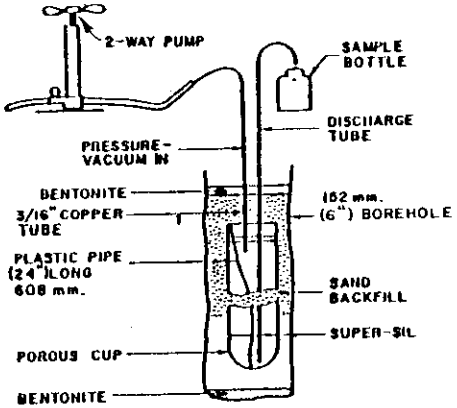
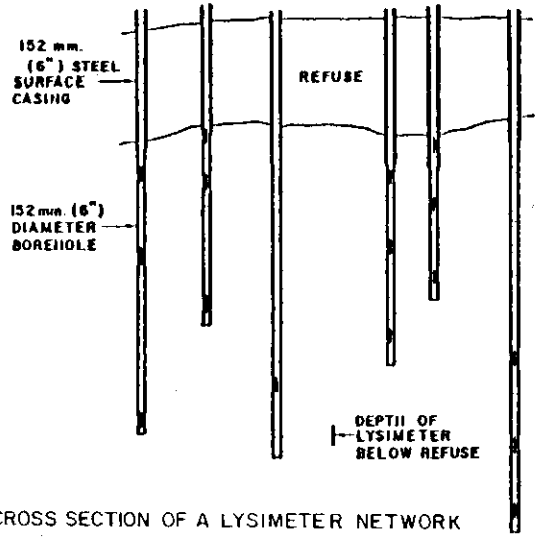
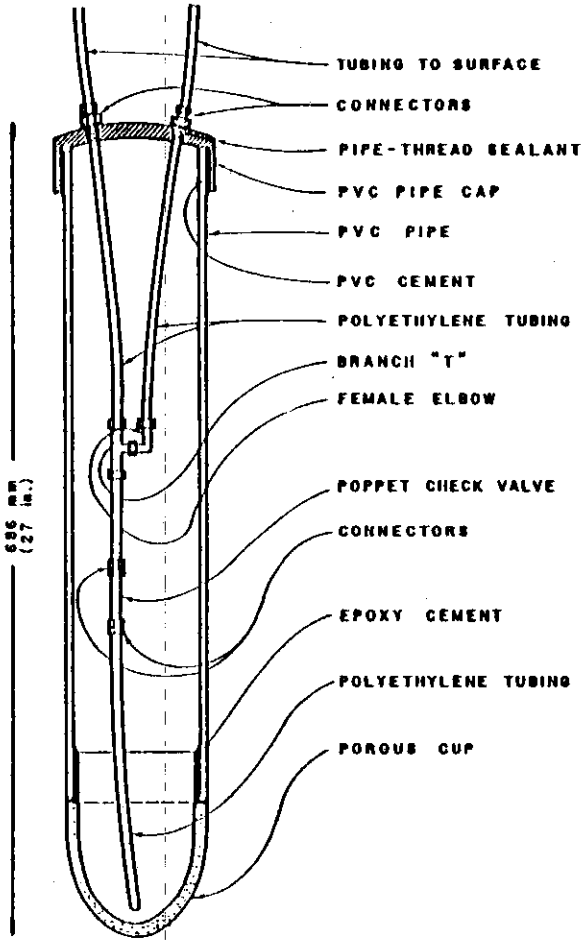


CROSS SECTION OF A TYPICAL PRESSURE-VACUUM LYSIMETER INSTALLATION



CROSS SECTION OF A LYSIMETER NETWORK



MODIFIED PRESSURE-VACUUM LYSIMETER INSTALLATION

Figure 7-8. Leachate Monitoring Alternatives.

Source: Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities, EPA/530/SW-611.

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unsaturated soil above the groundwater table). It is relatively inexpensive and quite reliable. The lysimeter consists of a sealed, vertical chamber installed in the ground with a porous cup at the bottom. Through the cap are two tubes leading to the surface. The pressure-vacuum tube terminates just inside the lysimeter cap. The sample tube extends to a point just above the low point of the porous cup. The process is started by applying a vacuum to the pressure-vacuum tube while sealing the sample tube and leachate water is drawn into the chamber through the porous cup. The water sample may then be forced to the surface by applying pressure to the vacuum tube and unsealing the sample tube.

The major problem in leachate monitoring by pressure-vacuum lysimeters is that samples need to be taken from the natural soil matrix directly beneath the fill. The EPA advises against locating monitoring wells within the bounds of the waste material because of vertical conduits that might form between the well casing and the soil matrix. The same logic would be true for lysimeters, although to a lesser extent, because they do not usually extend all the way into the water table. Other problems are that sampler failure is irreparable, the sample volumes are small, depth is usually limited to less than 33 feet, and the porous cup may contaminate or clog the sample.

An alternate approach sometimes used with existing disposal sites is soil coring (1). In this procedure, soil samples from the aeration zone are obtained through test borings and retained for the laboratory analysis. This is probably the best way to measure leachate attenuation and the vertical distribution of leachate concentrations by separating the core into several sections. In situ conditions can be maintained with proper handling. The process has several drawbacks, however, of which the foremost is the scarcity of commercial laboratories to perform the analyses. Also, this process is not standardized for leachate monitoring because the soil water is extracted from the soil rather than leached. Again, there is the potential problem of creating unnatural vertical channels through the soil. Finally, the use of soil sampling for leachate monitoring is normally not employed on a continuing basis because of cost.

The state-of-the-art in aeration zone sampling is not adequate to handle coal ash leachate without disturbing the permeability properties of the underlying substrate. In some cases, the decision to monitor leachate will be precluded by the use of liners for leachate collection. In other cases, leachate will not be monitored simply because it is not required. In the remaining cases, the decision to monitor may be based upon the practicality of the situation, and whether it is possible to

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obtain valid leachate samples at a reasonable cost.

SAMPLE PARAMETERS

Prior to obtaining any sample, one must determine the parameters which are of interest. These parameters may be dictated by regulatory requirement or permit requirements, or may be utilized to control specific process parameters, i.e., an acid feed to control pH. Parameter selection must be done prior to obtaining the sample since the method of preservation and size of sample must be selected to be commensurate with the parameters of interest. In many cases, two or more samples may be required due to the various preservation techniques required. If only one sample is used for several parameters, some loss of accuracy may occur. In that case, the analysis and method of preservation should be noted such that any subsequent analysis of the data will not be biased.

Water associated with ash leachates can contain a myriad of chemical constituents whose presence or effect can be analyzed as either general characteristics or metal concentrations. Federal analysis requirements listed in Table 7-2 are specifically related to the RCRA regulations. Other federal, state, and local requirements may dictate other analyses.

Although the parameters in Table 7-2 are those water parameters which apply to ash in general, the analysis of a given sample may or may not include all of the parameters. A general procedure for determining which elements should be analyzed is as follows:

- On the initial leachate studies or background samples, all applicable analyses should be performed. This analysis level would include all of the general characteristics and the metals of interest as described in Table 7-2, plus any other parameters that may be required by specific regulations (federal, state, or local).

- Upon obtaining the leachate and background groundwater data, the non-applicable analyses may be excluded from the analysis schedule. The non-applicable analyses are those that are either approximately equal to or much less than the background water quality or if the concentration is much less than (approximately 1/10) either standards or accepted safe levels. However, in no case should the general characteristic analysis be deleted. Also any parameters required by regulatory agencies cannot be deleted.

- Subsequent analyses should then be based on this reduced set of parameters.

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The above general procedure may be altered by either regulations and/or site specific criteria. However, it does provide some mechanism to reduce the amount of analysis required without sacrificing accuracy of the monitoring process.

Of particular interest in Table 7-2 is specific conductivity because of the positive correlation between conductivity and total dissolved solids. This correlation would be even more evident in coal ash leachate due to the high metals content and low organic (non-polar) content. An upward shift in groundwater conductivity would indicate an increase in total dissolved solids, which, in turn, would indicate the probable arrival of a leachate plume. Monitoring for conductivity is quite inexpensive because of the low cost of the equipment, the capability of in-well measurement, and the low level of skill required by the field operator. Therefore, conductivity monitoring can be used as a frequent spot check for leachate movement and a shift in conductivity would serve as a basis for prioritizing subsequent sampling. In addition, quality control is enhanced.

SAMPLE PRESERVATION

After selecting the location of the monitoring points, method of sampling, and chemical parameters to be analyzed, the next consideration is the selection of the preservatives necessary to maintain the chemical parameters in their sampled state. This is necessary due to the possible reactions of the chemical parameter with other chemicals in the sample. One example would be the analysis of hydrogen sulfide (H_2S). Upon obtaining the water sample, oxygen will be entrained in the water and react with hydrogen sulfide to produce oxidized species (H_2SO_3, H_2SO_4) or a family of other sulfate species. By undergoing this reaction, the amount of H_2S that will be determined in the sample at the laboratory will be less than the amount of H_2S in the original sample. To preclude this possibility, a preservative (zinc acetate) is added to the sample to maintain the sulfide as a sulfide. Unfortunately, the addition of the zinc acetate will preclude the use of that sample for the analysis of zinc in the sample and will, therefore, require a second sample which would be maintained by another preservative. Thus, the selection of chemical parameters must be made prior to sampling since the number of samples and the preservation techniques involved are based on the subsequent analysis.

Various preservation techniques are utilized for water and wastewater analysis. A listing of all currently used techniques are beyond the scope of this manual; however, the EPA-preferred methods are listed in Table 7-3 along with their general chemical action and application (1).

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Table 7-3 relates the method of preservation to the primary constituents normally analyzed for in environmental samples. The initial consideration involving sample preservation is the selection of the size and type of sample container.

Table 7-3

PRESERVATION METHODS

Preservative	Action	Applicable to
Mercuric Chloride ($HgCl_2$)	Bacterial Inhibitor	Nitrogen, Phosphorus
Nitric Acid (HNO_3)	Prevents Metal Precipitation	Metals
Sulfuric Acid (H_2SO_4)	Bacterial Inhibitor	Organic Samples (COD, Oil and grease, organic carbon, organic Nitrogen, organic phosphorus)
	Salt formation with organic bases	Ammonia, Amines
Sodium Hydroxide (NaOH)	Salt formation with volatile compounds	Cyanides, organic acids
Refrigeration	Bacterial Inhibitor and retards chemical reaction rates	Acidity, alkalinity, organic constituents, (BOD, color, odor, Phosphorus, Nitrogen, Carbon, etc.) and biological organisms

Although not specifically a preservation technique, the sample container should not affect the sample. Plastic or glass sample bottles are generally preferred. By knowing the chemical parameters of interest and by utilizing Table 7-4, the number and types of sample bottles may be determined. In addition, the table also includes the sample size, as determined by EPA, so that the sample bottle size may also be determined for each preservative.

After obtaining the water sample, the sample must be analyzed on site as required and the remainder preserved for future analysis. If the water sample is not

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Table 7-4

RECOMMENDATION FOR SAMPLING AND PRESERVATION OF SAMPLES ACCORDING TO MEASUREMENT

Measurement	Vol. Req., ml ASTM	Vol. Req., ml EPA	Container	Preservative	Recommended Maximum Holding Time(6)
Acidity	100	100	P, G(2)	Cool, 4°C	24 hours
Alkalinity	100	100	P, G	Cool, 4°C	24 hours
Arsenic		100	P, G	HNO_3 to pH<2	6 months
BOD		1000	P, G	Cool, 4°C	6 hours(3)
Bacteria Iron	500	--			
Sulfur, Reducing	100	--			
Bicarbonate (HCO_3)	100- 200				
Bromide	100	100	P, G	Cool, 4°C	24 hours
Carbon Dioxide	200	--			
Carbonate ($CO_3^=$)	100- 200	--			
COD	50- 100	50	P, G	H_2SO_4 to pH<2	7 days
Chloride	25- 100	50	P, G	None required	7 days
Chlorine		200			
Chlorine Res.	2000-4000	50	P, G	Determine on site	No holding
Color	100- 500	50	P, G	Cool, 4°C	24 hours
Cyanides	25- 100	500	P, G	Cool, 4°C NaOH to pH 12	24 hours
Detergents	100- 200	--			
Dissolved Oxygen					
Probe	500- 1000	300	G only	Det. on site	No holding
Winkler	500- 1000	300	G only	Fix on site	4-8 hours
Fluoride	200	300	P, G	Cool, 4°C	7 days
Hardness	50- 100	100	P, G	Cool, 4°C HNO_3 to pH<2	7 days
Hydrazine	50- 100	--			
Hydrogen (H_2)	1000	--			
Hydroxide (OH^-)	50- 100	--			
Iodide	100	100	P, G	Cool, 4°C	24 hours
MBAS		250	P, G	Cool, 4°C	24 hours
Metals					
Dissolved		200	P, G	Filter on site HNO_3 to pH<2	6 months
Suspended				Filter on site	6 months
Total	100- 1000	100		HNO_3 to pH<2	6 months
(except):					
Copper	200- 4000	--			
Lead	100- 4000				
Mercury					
Dissolved		100	P, G	Filter HNO_3 to pH<2	38 days (Glass) 13 days (Hard Plastic)
Total		100	P, G	HNO_3 to pH<2	38 days (Glass) 13 days (Hard Plastic)
Microorganisms	100- 200	--			
Nitrogen					
Ammonia	500	400	P, G	Cool, 4°C H_2SO_4 to pH<2	24 hours(4)
Ammonion	500	--			
Total Kjeldahl (Organic Nitrogen)	500- 1000	500	P, G	Cool, 4°C H_2SO_4 to pH<2	7 days(4)
Nitrate	10- 100	100	P, G	Cool, 4°C H_2SO_4 to pH<2	24 hours(4)
Nitrite	50- 100	50	P, G	Cool, 4°C	24 hours(4)
NTA		50	P, G	Cool, 4°C	24 hours
Oil & Grease	3000- 5000	1000	G only	Cool, 4°C H_2SO_4 to pH<2 or HCl	24 hours
Organic Carbon		25	P, G	Cool, 4°C H_2SO_4 to pH<2	24 hours

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Table 7-4 Cont.)

Measurement	Vol. Req., ml ASTM	Vol. Req., ml EPA	Container	Preservative	Recommended Maximum Holding Time(6)
pH					
Electrometric	100	25	P, G	Cool, 4°C Det. on site	6 hours(3)
Colorimetric	10- 20	--			
Phenolics	800- 4000	500	G only	Cool, 4°C H_3PO_4 to pH<4 1.0 g $CuSO_4$/l	24 hours
Phosphorus					
Orthophosphate Dissolved		50	P, G	Filter on site Cool, 4°C	24 hours(4)
Hydrolyzable (Polyphosphate)	100- 200	50	P, G	Cool, 4°C H_2SO_4 to pH<2	24 hours(4)
Total	50- 100	50	P, G	Cool, 4°C	7 days(4)
Total, Dissolved		50	P, G	Filter on site Cool, 4°C	24 hours(4)
Radioactivity	100- 1000	--			
Residue					
Filterable	50- 1000	100	P, G	Cool, 4°C	7 days
Non-Filterable	100-20000	100	P, G	Cool, 4°C	7 days
Total		100	P, G	Cool, 4°C	7 days
Volatile		100	P, G	Cool, 4°C	7 days
Settleable Matter		1000	P, G	None req.	24 hours
Selenium		50	P, G	HNO_3 to pH<2	6 months
Silica	50- 1000	50	P only	Cool, 4°C	7 days
Solvent Extracted Matter	1000-25000	--			
Specific Gravity	100	--			
Specific Conductance	100	100	P, G	Cool, 4°C	24 hours(5)
Sulfate	100- 1000	50	P, G	Cool, 4°C	7 days
Sulfide	100- 500	500	P, G	2 ml zinc acetate	24 hours
Sulfite	50- 100	50	P, G	Det. on site	No holding
Sulfur Dioxide (SO_2)	100	--			
Tannin and Lignin	100- 200	--			
Temperature	Flowing Sample	1000	P, G	Det. on site	No holding
Threshold Odor		200	G only	Cool, 4°C	24 hours
Toxicity	1000-20000	--			
Turbidity	100- 1000	100	P, G	Cool, 4°C	7 days
Volatile & Flaming Amines	500- 1000				

(1) More specific instructions for preservation and sampling are found with each procedure as detailed in EPA-60014-79-020. A general discussion on sampling water and industrial wastewater may be found in ASTM, Part 31, D-3370 Standard Practices for Sampling Water, 1979.

(2) Plastic or Glass

(3) If samples cannot be returned to the laboratory in less than 6 hours and holding time exceeds this limit, the final reported data should indicate the actual holding time.

(4) Mercuric chloride may be used as an alternate preservative at a concentration of 40 mg/l, especially if a longer holding time is required. However, the use of mercuric chloride is discouraged whenever possible.

(5) If the sample is stabilized by cooling, it should be warmed to 25°C for reading, or temperature correction made and results reported at 25°C.

(6) It has been shown that samples properly preserved may be held for extended periods beyond the recommended holding time.

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properly prepared prior to analysis, the ultimate water analysis, while being analytically correct, will not represent the water being sampled due to chemical changes occurring within the sample container. To avoid this occurrence, procedures have been suggested for various chemical parameters. Table 7-3 is a summary of the currently accepted preservation techniques based on the EPA Publication, "Methods for Chemical Analysis of Water and Wastes" and the ASTM "Methods of Water Analysis, Vol. 19" (see Bibliography). In general, the determination of chemical parameters on-site is always preferable as long as accuracy can be assured. However, the analytical problems of on-site analysis preclude this possibility for most analysis. To provide on-site analysis capability, various manufacturers, such as HACH, Fisher, ORION, etc., have marketed on-site or portable analysis equipment that, in general, operates on colorimetric or electrometric principles. Unfortunately, the resulting data is normally unacceptable to regulatory agencies which require analysis by qualified laboratories using EPA approved methods. Thus the bulk of the chemical analysis must normally be accomplished in qualified laboratories.

MONITORING COSTS

The cost of implementing and conducting a monitoring program at an ash disposal site is highly site specific. For example, the cost of installing groundwater monitoring wells will depend on the number of wells, the depth of the wells, and the subsurface strata they penetrate, as well as the accessibility of the well locations on the surface. The degree of analysis will depend on the ash characteristics and the frequency of sampling may depend on the rate of groundwater flow. Table 7-5 presents a cost breakdown for three different sites. To illustrate monitoring program costs, only the cost of groundwater monitoring is addressed. Site 1 is the dry disposal area of Figure 7-2; Site 2 is the wet disposal area of Figure 7-5; and Site 3 is a fictitious dry disposal area on a flat terrain with four 50-foot wells. The groundwater flow rate at Site 3 is slow enough that only annual comprehensive sampling is required. The monitoring requirements for an actual disposal site will vary according to site conditions, size, and state or local regulations.

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Table 7-5

COST EXAMPLES FOR THREE GROUNDWATER MONITORING PROGRAMS

	Site 1 (Fig. 7-2)	Site 2 (Fig. 7-5)	Site 3 (Dry, Flat)
Installation			
Monitoring Wells	U1(65') $ 1,625 D1(75') 1,875 D2(125') 3,125 D3(50') 1,250	U1(50') $ 1,250 U2(50') 1,250 D1(75') 1,875 D2(50') 1,250 D3(75') 1,875 D4(100') 2,500 D5(150') 3,750	U1(50') $ 1,250 D1(50') 1,250 D2(50') 1,250 D3(50') 1,250
(Drilling and Monitoring Wells @ $25/vertical foot)			
Total Drilling Costs	$ 7,875	$ 13,750	$ 5,000
First Year Background Monitoring			
Monthly Comprehensive Analysis			
Labor @ $125/man-day x 12 days	1,500	1,500	1,500
Analysis @ $500/sample	24,000	42,000	24,000
Total Background Monitoring Cost	$25,500	$ 43,500	$25,000
Accumulated Annual Cost (30-year Site Life)	Quarterly Sampling 1 Comprehensive 3 Minimum	Quarterly Sampling 1 Comprehensive 3 Minimum	Annual Sampling 1 Comprehensive
Labor @ $125/man-day	15,000	15,000	3,750
Analyses: @ $500/Comprehensive; $50/Minimum	78,000	136,500	60,000
Total 30-Year Annual Sampling Cost	$93,000	$151,500	$63,750
Summary			
Installation	7,875	13,750	5,000
First Year Background Monitoring	25,500	43,500	25,500
Accumulated Annual Cost	93,000	151,500	63,750
Total Site Monitoring Costs	$126,375	$208,750	$94,250

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Section 8

SITE RECLAMATION

INTRODUCTION

The advent of recent federal and state laws involving clean water and waste disposal standards has created a need to closely manage the progression and final closure of ash disposal sites. The implementation of a well conceived reclamation program, including plans for erosion control and revegetation, in compliance with the laws, promises benefits for the site owner in terms of reduced post-closure maintenance and increased future land use options. The purpose of this section is to provide the designer and operator of ash disposal sites with basic reclamation practices to be initiated during the progressive retirement of an ash disposal site. Actual details, particularly concerning plant species adaptation and soil nutrient requirements, are site specific and may require assistance from local agricultural extension services or a private consultant. Reference sources that contain more specific information on erosion control, surface water hydrology, and revegetation are presented at the end of this section. This section presents a stepwise procedure for developing a comprehensive site retirement plan. Specific topics include:

- Federal regulations affecting site management,
- Development of a post-closure land-use statement,
- Predisturbance site investigation and inventory,
- Erosion and sediment control practices,
- Revegetation planning,
- Vegetation establishment procedures,
- Post-closure maintenance.

FEDERAL REGULATIONS

The major regulatory act which presently affects the operation and retirement of ash disposal sites is the Clean Water Act of 1977 (CWA). The Clean Water Act supercedes the Federal Water Pollution Control Act Amendments of 1972. This basic federal water pollution control law accomplishes three basic tasks: 1) regulation of discharges of pollutants from point sources, 2) regulation of spills

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of oil and hazardous substances, and 3) financial assistance for construction of public water treatment facilities.

The strength of the CWA lies in its regulation of point source pollutants. Guidelines for effluent quality have been promulgated which restrict chemical and physical characteristics of discharge water. Total suspended solids (TSS) and pH are two major parameters regulated in water discharged from ash landfills. Effluent guidelines for ash storage piles for steam electric power generating point-source discharge are:

TSS	50 mg/l (50 ppm)
pH	6.0 to 9.0

These standards are presently also applicable to ponds upon retirement. The most efficient method of meeting the guidelines for total suspended solids and avoiding high site maintenance costs is by minimizing erosion of the disposal site. The alternate approach is to treat the runoff prior to discharge. If the pH of ash landfill effluent lies outside the guideline range, then effluent treatment will be required.

The other federal law which is likely to affect ash disposal site operation and maintenance is the Resource Conservation and Recovery Act (RCRA). This law and regulations are discussed in Section 4 of this manual. Under RCRA, hazardous waste sites are regulated in terms of closure and post-closure care, and funding must be established to ensure proper closure. There are no such rules under Subtitle D, however, and since utility ash has been ruled non-hazardous, closure regulations have been left to the individual states. Regulations for several states are described in Section 4.

On March 26, 1979, the EPA published suggested guidelines for state compliance which could have a significant impact on erosion control, revegetation, and closure of ash disposal sites including:

- Runoff diversion structures should be constructed.
- Terraces should be included at 20-foot vertical intervals.
- The final soil cover should be seeded.
- Landfill grades should not be in excess of 33 percent.
- Uncontaminated on-site runoff should be routed to a sedimentation basin prior to discharge.

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- Final landfill cover should be 6 inches (15 centimeters) of clay followed by 18 inches (45 centimeters) of soil capable of supporting vegetation, the upper 6 inches (15 centimeters) of which is to be topsoil.
- The landfill should be maintained in an aesthetic manner.

POST-CLOSURE LAND-USE STATEMENT

In some states, permitting of solid waste disposal sites may require development of a post-closure land-use statement. In any event, a permit application accompanied by a comprehensive land-use statement that complies with state and federal standards will more likely be permitted than the application containing a sketchy, nonspecific statement. Public opposition to the disposal of utility solid waste may be lessened if a productive end-use is planned. In general, a post-closure land-use statement has the advantage of providing an immediate plan of operations for on-going reclamation activities. The investigations necessary for development of a comprehensive land-use statement may bring to light the opportunity for alternate end-use choices and should help to minimize the overall economic impact of closure and post-closure maintenance. At a minimum, a post-closure land-use statement should include the following topics:

- Summary of ash disposal regulations and guidelines pertinent to that particular site,
- Results of investigative work to determine surrounding land-use,
- Proposed use(s) of site after closure,
- General outline for operation and closure procedures.

Solid Waste Disposal Regulations

State and local regulations pertaining to solid waste disposal should be reviewed to determine if they will influence planning for the site's end use. Any requirements set forth by the state may be more strict and/or comprehensive than federal regulations. More stringent requirements may affect the final proposed use of the site, or the format and information contained in the post-closure statement itself.

Surrounding Land-Use

An assessment of surrounding land-use may be helpful in the planning of possible site uses after closure. For example, an ash disposal site located in a predominantly agricultural area could be designated for future use as an agricultural area or wildlife habitat. Conversely, a site located in a developing area could be used as a recreational area or commercial development area after closure. Regional

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and/or local planning agencies can provide information concerning surrounding land-use and assistance in assessing possible land-use alternatives.

Proposed Site Use(s) After Closure

It should be noted that the term "proposed use(s)" is used in the discussion of this topic. A statement containing several alternative end uses will increase the flexibility in site closure methods and allow for changing land use of the surrounding area that may affect the site's ultimate use. As an example, a site originally planned for recreational development in 1980 (when filling operations began), may in the year 2010 (when filling operations have ceased) be better suited for industrial use. A statement containing both end-use alternatives would allow more flexibility at the time of final site closure than one which contained a single end-use.

Table 8-1 shows general land-use categories and their requirements. These categories are intended to provide a general list of possible ash site end uses. A delineation of more specific end uses may be possible in the writing of a post-closure land-use statement where site-specific information is available. The EPRI Manual CS-1515, FGD Sludge Disposal Manual (1) provides more information concerning possible site uses after closure, along with factors which may affect the ultimate choice of land use, such as economic return. The EPRI Manual Fly Ash Structural Fill Manual (2) contains information pertaining to the placement of ash in landfills which have projected future use as commercial or light industrial development areas.

PREDISTURBANCE SITE INVESTIGATION AND INVENTORY

As part of the initial site selection process considerable information will be gathered that impacts directly on later reclamation decisions. Of particular importance to reclamation planning is specific information concerning the site's climate, local vegetation habitat, and soil types and distribution.

Climatological Data

Climatological data is of importance in the selection of plant species suitable for revegetation, in the scheduling of planting, and in the design of erosion control structures. Detailed information is required on precipitation (amounts, distribution and intensity) and temperature (mean monthly, diurnal and monthly ranges, frost-free period and degree days). Local climatological data may be obtained from nearby U.S. Weather Bureau or Agricultural Experiment (university and government) Stations. Site specific data may be available from investigations conducted for

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Table 8-1

POST-CLOSURE LAND-USE CATEGORIES FOR ASH DISPOSAL SITES

Possible Site Use After Closure	Requirements
Wildlife Habitat, Wilderness	Adequate cover and vegetation.
Limited Agriculture or Recreation grazing hunting	Adequate cover and vegetation, added protection of fill or embankment slopes to prevent erosion resulting from animal or vehicle traffic, maintenance of vegetation.
Developed Agriculture or Recreation crop land athletic fields golf courses	Possible increase in soil cover depth, management and maintenance of vegetation, stable underlying ash, possible increased erosion control to prevent the exposure of ash.
Light Commercial and Industrial Development warehouse shopping plaza parking lot materials storage lot light industry	Stable underlying ash capable of foundation support (where required), increased erosion control and drainage considerations, management and maintenance of vegetation.

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the preparation of environmental impact statements or for the monitoring of fugitive emissions. Later on this information, coupled with soil test data and soil drainage characteristics of the disposal site, will provide the basis for the proper selection of plant species best adapted to the individual site.

Local Vegetation Habitat

If the objective of the revegetation plan is to bring a site back into harmony with its surrounding natural habitat, it is reasonable to establish a final long term vegetation cover that readily adapts to the environmental conditions at that site. This may be done by using plant species already successfully established within and near the proposed ash disposal site. The existing plant species will reflect preferential growth conditions such as soil drainage, light and wind exposure intensities, available moisture, and nutrient requirements. These growth conditions can then be matched with similar conditions anticipated on the disposal site, and a rational selection of plant species can be made within the constraint of seed availability.

Table 8-2 and Figure 8-1 illustrates the format for a vegetation inventory. Data collection in this example is based on a grid-system sampling pattern. At each respective sampling site, the surveyor would mark off a sampling plot ranging from 1 square yard (0.8 square meters) at a grassy site, to 10 square yards (8 square meters) within forested stand. The plot would then be inventoried for its representative plant species, their estimated surface coverage, the degree of slope, soil pH, and degree of exposure and light intensity. Plant identification will need to be checked by a competent plant taxonomist, either in the field or from collected specimens. Soil-plant relationships including drainage, moisture, nutrient, and textural requirements can then be estimated by superimposing the observed plant species identified during reconnaissance onto a soil survey map of the area.

Soil Types and Distribution

An integral part of any site selection process should be a detailed investigation of existing soil conditions. The quality, thickness and spatial distribution of this potential cover soil resource could impact greatly on the subsequent success of sediment control practices and site revegetation, soil amendments, stabilization and long term maintenance.

The primary objective of a predisturbance soils inventory is the determination of

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Table 8-2

EXAMPLE OF DATA COLLECTION SHEET FOR SITE VEGETATION INVENTORY

Plot Number	Area ($ft.^2$)	Degree Slope					Soil pH						Light Exposure				Soil Drainage Class*						Surface Texture Class							Availability Moisture** (inch/in soil)				Fertility Rating***		
		0 to 3	3 to 8	8 to 15	15 to 30	GT. 30	LT. 4.0	4.0 to 4.9	5.0 to 5.9	6.0 to 6.9	7.0 to 7.9	GT. 8.0	Low Intensity		High Intensity		Very Poor	Poor	Poor Wet	Moderately Well	Well		Clay	Clay Loam	Silt Loam	Loam	Sandy Loam	Loamy Sand	Sand	0 to .4	.4 to .8	.8 to .12	.12 to .16	Low	Mod.	High
1a	20		X						X						X			X							X					X				X	
1b	15	X								X						X		X							X					X			X		
1c	10	X							X							X			X								X		X				X		
2a	30	X							X							X			X							X				X			X		
2b	46		X								X				X				X							X				X			X		
2c	10	X							X							X		X							X						X		X		
3a	20	X								X						X		X							X						X			X	
3b	25	X							X							X				X							X		x					x	
3c	25		X							X					X				X							X				X			X		
4a	50	X								X						X			X							X				X			X		
4b	40	X						X								X			X							X				X			X		
4c	20		X						X							X			X							X						X		X	
5a	10			X					X						X			X									X		X				X		
5b	5			X						X					X				X								X		X				X		
5c	-																																		
6a	25	X									X					X			X							X				X				X	
6b	-																																		
6c	10		X						X							X		X							X				X				X		
Total Area	355	225	115	15	0	0	0	40	135	115	65	0	0	0	100	255	0	85	245	25	0	0	0	60	245	50	0	60	245	50	0	245	110	0
% in each Category	100	63	32	5	0	0	0	11	38	32	18	0	0	0	28	72	0	24	69	7	0	0	0	17	69	14	0	17	69	14	0	69	31	0

* Refers to the frequency and duration of periods when soil is free of saturation; i.e., a very poorly drained soil is waterlogged most of the year unless artifically drained whereas a well drained soil is rapidly drained and experiences seasonal drought.

** That portion of the soil water that can be readily absorbed by plant roots, generally water held up to approximately 15 bars. Available moisture can be approximated from textural and density data (1), and from results of soil series laboratory data (USDA).

***Information on the relative nutrient supplying capability of various soil types is available from local S.C.S. and Cooperative Extension offices.

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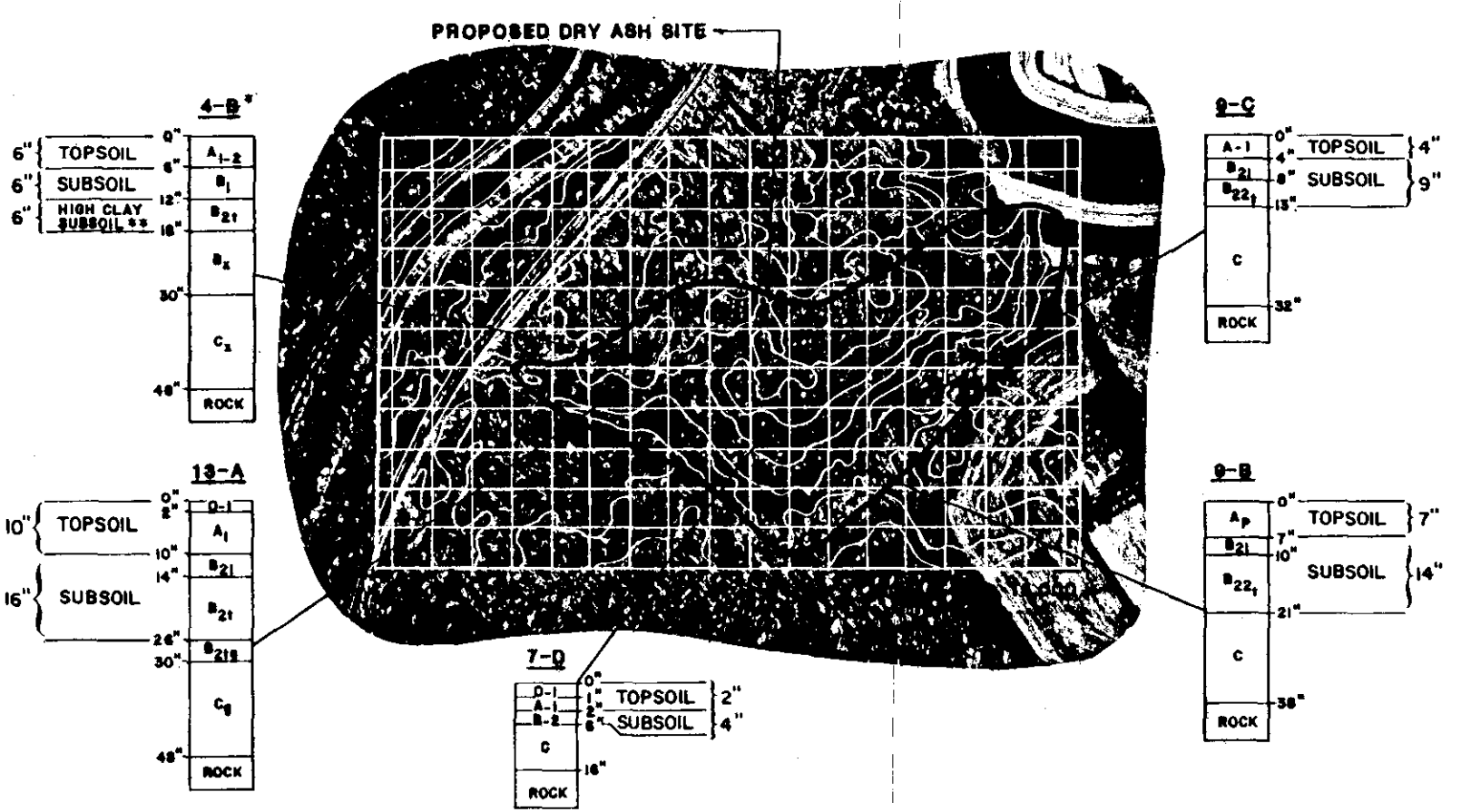

* SOIL TYPE DESIGNATION NUMBER AND SLOPE CLASS (A = 0-3° , B = 3-8° , C = 8-15° , D = 15-30° , E ≥ 30°)

** SUBSOILS SUITABLE FOR SOIL LINER ($k < 1 \times 10^{-7}$ cm/sec) FALL WITHIN THE FOLLOWING TEXTURAL CATEGORIES: CLAY, SILTY-CLAY, HEAVY SILTY-CLAY LOAM, CLAY LOAM.

Figure 8-1. High intensity soil survey of proposed ash disposal site with grid overlay for vegetation sampling and representative soil profiles.

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potential soil volumes within the disposal area suitable for use, as 1) topsoil, 2) friable subsoil and, 3) low permeability cover lining material. Rough estimates of soil volumes can be obtained using modern, air photo base, soil survey maps prepared by the Soil Conservation Service at a scale of 1:20,000. Modern surveys are not, however, available for all areas and are particularly incomplete in sparsely populated western states. In any event, it is recommended that a higher intensity soil survey of the disposal area be undertaken by a trained soil scientist to insure spatially detailed soil identification that will ultimately be used during the actual stripping operations.

Figure 8-1 illustrates a high intensity soil survey delineating the principle soil types found at a proposed disposal site. The basic profile characteristics of each soil type including depth and thickness of organic rich topsoil ('A' and 'O' horizons), friable subsoils suitable for plant root growth ('B' horizons excluding subsoils with high salt, coarse fragment and clay contents, and pan developments), and low permeability ($<1x10^{-7}$ cm/sec) subsoils, are shown as determined from the field reconnaissance. Using this information, the site planner can prepare a series of interpretative maps (Figures 8-2, 8-3, and 8-4) showing the quantities and distribution of the various cover soils.

The procedure for developing these interpretative maps requires setting up a legend with designated depth categories; e.g., 0 to 1.99 inches (0 to 5.05 centimeters) of topsoil, etc. Once the categories are defined, reference to the soil profiles prepared by the soil scientist will enable pigeon-holing of the respective soil units into their proper thickness category. Soil volumes are then calculated with the aid of a planimeter to determine the map area encompassed by each soil unit. Actual ground area is estimated using the average slope value determined by field measurement. A map unit designated 34-A would represent soil type 34 on A-slope (0° to 3°) having an average slope of 1.5 degrees. The ground area when multipled by the upper and lower limits of the appropriate thickness category provides an estimate of soil volume.

As an example of the calculation format consider the topsoil legend category: 3 to 5.99 inches (7.6 to 15.2 centimeters) which includes 6 distinct map units (Figure 8-2):

The volume of topsoil in the other legend categories could be calculated in a similar fashion, and when added together would provide an estimate of the strippable topsoil within the entire disposal site.

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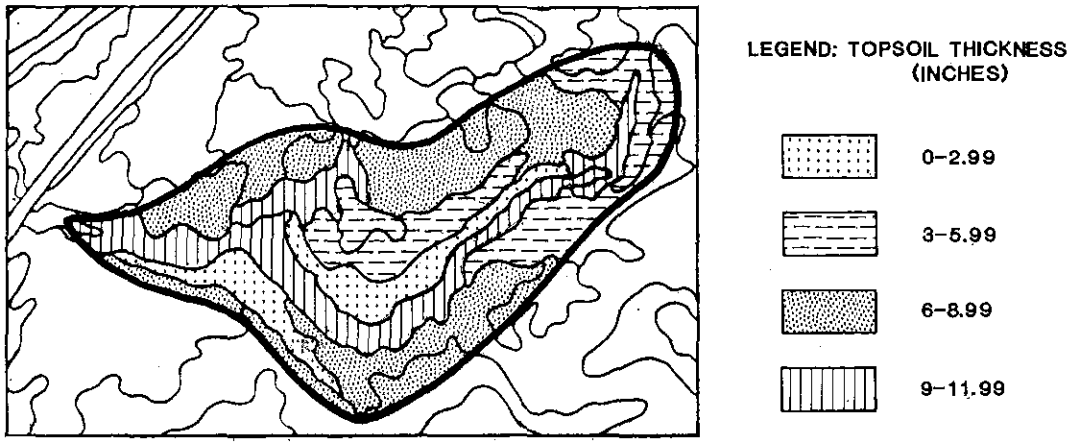

Figure 8-2. Interpretative soil map showing thickness of organic rich topsoil.

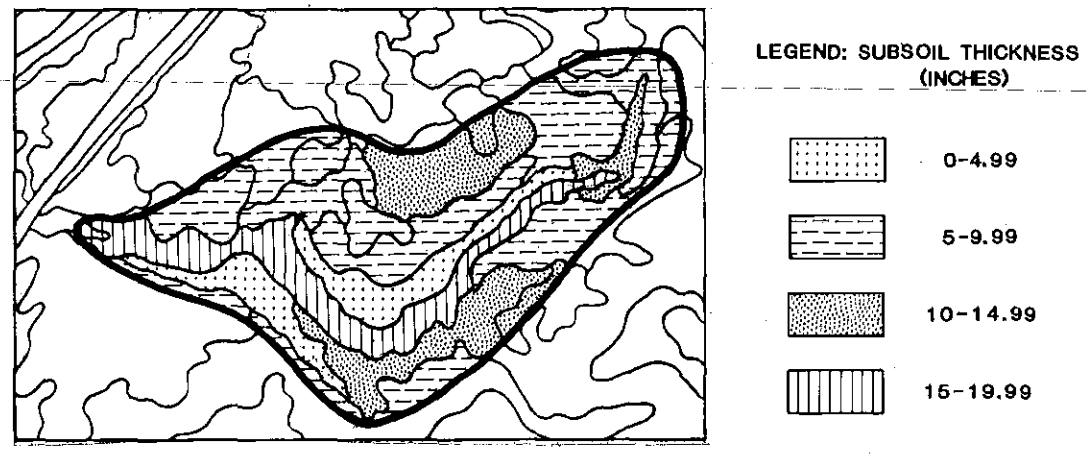

Figure 8-3. Interpretative soil map showing thickness of productive subsoil.

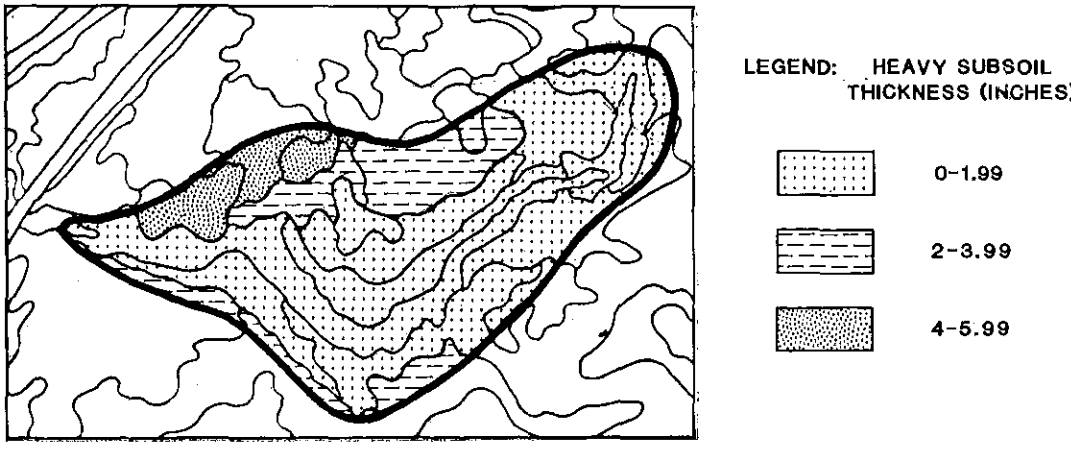

Figure 8-4. Interpretative soil map showing thickness of high clay subsoil.

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supplemental irrigation systems such as runoff collection in perimeter diversion ditches can be used for getting vegetative barriers established. If possible, the best protection is a dense cover of vegetation. Vegetation will not only absorb most of the wind's force, but root systems tend to hold soil in place while root exudates cement soil particles together.

Soil management practices, such as mulching and dry farming techniques including contour terracing, will help to conserve moisture and provide sufficient cover in semiarid regions. The use of chemical soil binders and stone surfacing can be applied where insufficient moisture exists to establish a permanent vegetation cover. Chemical soil stabilizers are designed to coat and penetrate the soil surface and physically bind particles together. Chemical stabilizers work best on dry, highly permeable soils subject to sheet rather than concentrated water flow. They are sometimes used in lieu of temporary mulch material or in conjunction with mulch to act as a combined mulch tack and soil binder.

REVEGETATION PLANNING

In planning the revegetation of ash disposal sites, consideration should be given to the properties and quality of ash for plant growth, required depth of final soil cover, the nature and available quantity of cover soil material, water availability and the selection of plant species. The choice of the proper revegetation techniques and plant species is largely site specific though general criteria exist. More detailed information and site assistance is readily available from agronomists associated with local Cooperative Extension and Soil Conservation Service Offices located in most counties.

Ash as a Growth Medium

Pilot experiments indicate that fly ash can be disposed beneficially in agricultural soils (13, 14). Fly ash is instrumental in increasing the plant available boron, molybdenum, phosphorus, potassium, and zinc, either by supplying soluble forms of these elements or by modifying the pH of the soil. Research on establishing vegetation directly on fly ash, including pilot and full scale demonstrations, tends to indicate that the direct growth of plants is restricted by toxic levels of certain compounds and the lack of nutrients within the rooting depth. Successful growth of vegetation directly on fly ash most likely occurs after alteration of the fly ash. For example, on older ash disposal sites, native vegetation has been reestablished as a result of surface weathering of the ash with subsequent leaching of growth inhibiting substances to nontoxic levels. Characteristics of fresh ash which may prevent or retard the establishment of new vegetation include soluble

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salt toxicity, alkalinity, concentration of plant available boron, self-hardening capability, and susceptibility to erosion. The importance of these factors in relation to attempts to establish vegetation directly on fly ash is discussed in the following paragraphs. It should be noted that chemical or organic additions to fresh ash may be used to alter some of these characteristics.

Soluble Salt Toxicity. If the concentration of soluble salts in the solution surrounding fly ash particles exceeds a certain level (Table 8-3), plants will have a difficult time absorbing water.

This difficulty in absorbing water arises from an imbalance in osmotic pressures between the fly ash particle solution and the internal solution of the plants. When the pressure is greater in the outer solution than in the plants, water absorption is impeded and plant growth retarded. Fly ash that has been leached or disposed of by the wet disposal methods will have a lower potential for soluble salt toxicity.

Table 8-3

ELECTRICAL CONDUCTIVITY OF SATURATION EXTRACTS OF SOILS

Electrical Conductivity of Saturation Extract, mmho/cm at 25° C.	Plant Response
0-2	Salinity effects usually negligible
2-4	Yield of very salt-sensitive crops may be restricted
4-8	Yield of salt-sensitive crops restricted
8-16	Only salt-tolerant crops yield satisfactorily
> 16	Only a few very salt-tolerant crops yield satisfactorily

Source: U S. Salinity Laboratory Staff. Diagnosis and Improvement of Saline and Alkali Soils. Washington, D.C.: U.S. Department of Agriculture Handbook 60, 1954.

Alkalinity. Alkalinity, usually expressed in terms of pH, will not by itself limit plant growth. However, the solubility and availability of various nutrients essential for plant growth are pH dependent. In a natural soil, pH values normally

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fall in the range of 5.0 to 7.0 where solubilities and availability of nutrient elements are in balance with plant requirements. The pH value of some dry, fresh ash may be in the range of 11 to 12. As alkalinity increases (pH increases above 7.5), the availability of phosphorus and several trace elements (zinc (Zn), iron (Fe), copper (Cu), etc.), decreases. This may result in a plant nutrient deficient medium. Attempts have been made to reduce the alkaline nature of disposed fly ash by making additions of sulfuric acid (H_2SO_4). The large amounts of acid required to bring alkaline fly ash into the pH range required for plant growth makes this treatment economically infeasible. Instead, a soil cover over the fly ash can be used to provide the proper pH medium suitable for plant growth.

In some cases, the alkalinity of fly ash has been used to aid the establishment of vegetation. If soil pH is less than 6.0, then fly ash may be used as a "liming" material. The fly ash should be incorporated (mixed) into the final cover as any other liming material, such as hydrated lime or limestone would. The proper amount of fly ash required to raise the pH to a suitable level (usually 6.0 to 7.0) can be determined by taking representative samples from the topsoil stockpile and mixing in increasing amounts of fly ash until the desired pH is attained. There should be a time allowance for an incubation period permitting the fly ash to react with the soil and for the pH to stabilize. Five tons of lignite ash, (high in calcium (Ca) and neutralizing power), is equivalent to approximately one ton of calcium carbonate (limestone). On average about 56 tons of bituminous coal ash must be added to equal 1 ton of limestone (13). Mixed samples of fly ash and soil at the desired pH should be sent to a testing lab to insure that toxic conditions will not prevail and to determine the remaining nutrient imbalance.

Plant Available Boron. Most fly ashes have plant available boron contents (10-600 ppm) which are much higher than that of most soils. Boron contents of fresh dry disposal ash can be toxic to plant growth. Table 8-4 will provide some guidance in estimating potential boron toxicity. Again, some attempts have been made to ameliorate boron toxic conditions existing on fly ash disposal sites, particularly where fresh, dry ash is present. As with efforts to mitigate alkaline conditions, these methods have proven either unsuccessful or impractical. Where there is potential boron toxicity, a soil cover will provide a medium for plant growth and establishment until toxic conditions are reduced.

Self-Hardening Properties. Self-hardening properties occur primarily with ash from subbituminous coal or lignite and can pose serious problems for growing vegetation. If fly ash were to set up, the folume of water available for plant

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Table 8-4

BORON PHYTOTOXICITY IN ASH LAGOONS

Concentration of Available B	Degree of Phytotoxicity
ppm	
Less than 4	Nontoxic
4-10	Slightly toxic
11-20	Moderately toxic
20-30	Toxic
Over 30	Highly Toxic

Source: D. R. Hodgson and W. N. Townsend. "The Amelioration and Revegetation of Pulverized Fuel Ash". In Proceedings of Internal Symposium on Ecology and Revegetation of Drastically Disturbed Areas, University Park, Pennsylvania, 1969.

growth and the rooting volume would be limited to that in the overlying soil layer. Enough soil cover should be placed so as to provide sufficient water storage. In some cases, this solution would cause more soil to be placed as final cover than is otherwise necessary simply to adequately support vegetation. Placing bottom ash as an intervening layer between cover soil and fly ash is a viable alternative. This method would increase water storing capacity above the fly ash, allow for disposal of additional waste material, and reduce the amount of soil cover required to cover the site.

Susceptibility to Erosion. Erosion is detrimental to the establishment of vegetative cover since it destroys the seedbed before the plants have sufficient time to become well established. The erodibility of fly ash is generally greater than most naturally occurring soils unless a surface crust has formed. Therefore, placing a soil cover with a topsoil surface layer over fly ash will reduce erosion and help establish a uniform vegetative cover.

Required Cover Soil Depth

Of primary concern in completing final site closure is determination of the "required" depth of soil cover. Many states (e.g. Arizona, Florida, Illinois, Kentucky, Missouri, Montana, Pennsylvania, Oklahoma, etc.), have solid waste disposal regulations defining minimum cover as having a two-foot depth. This amount of cover is not

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always necessary to successfully establish a permanent, erosion control vegetative cover. While vegetation can be established directly on fly ash, the characteristics discussed above often make revegetation without some soil cover difficult. Therefore, when soil is available for final cover, it is generally used in vegetating ash disposal sites.

Experimental studies (6, 7) have shown that certain plants could be grown on as little as six inches of topsoil overlying fly ash, although heavy fertilizer application was required. With twelve inches of topsoil, minimal toxic effects and satisfactory moisture conditions prevailed, suggesting that 12 inches of cover soil should provide adequate rooting and minimal susceptibility to drought in most instances. Increased thickness of soil cover will be required where:

- the soil is capable of holding limited amounts of available moisture (e.g. highly sandy or clayey soils),
- slope gradients are steep and rapid drainage produces droughty conditions,
- the climate is marked by severe deficiency of moisture during the growing season as typically found under West Coast Mediterranean and Mid-Latitude steppe and desert climates.

Various other factors which will affect the required depth of soil cover include the quality of the soil cover material, availability of water for growth, and the plant species selected.

Quality of Final Cover

The quality of cover material used for site closure will influence the depth of that material required to support vegetation. If the cover exhibits soil characteristics that are conducive to plant growth, the amount of cover needed will be reduced. If the available soil quality is less than optimum, then the thickness of the soil cover can be increased or soil supplements added to improve quality.

Once a soil is moved from its original position on the landscape, it loses many of the properties that make it a unique body. This is especially true of certain physical characteristics such as structure and relative proportion of air and water porosity. However, textural class is still intact and measurable. This should provide the most meaningful index to suitability for establishing vegetation.

A soil's textural class is determined by the proportional content of sand, silt and clay particles. Once the relative proportions of the various particle sizes is

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known, the textural class can be determined using Figure 8-13. Soils having United States Department of Agriculture (USDA) textures between sandy loam and silt loam are best suited for plant growth. Textural classes outside this range may require special management techniques. Soils possessing a coarser (sandier) texture may have low water holding capacity and so may be susceptible to drought. Additions of siltier textured soils or organic matter (sewage sludge, plant matter, animal manures, etc.) will increase water holding capacity, cation exchange capacity, and structural stability, and provide essential nutrients.

It is important to add "new" or "fresh" sources of organic matter to soil. Older sources and sources having a carbon to nitrogen ratio (C:N) of greater than 30:1 may cause nitrogen deficient conditions for plants. Sources with a C:N of 20 to 30:1 may or may not cause nitrogen deficient conditions, depending upon several external factors. Addition of organic matter with a C:N of less than 20:1 will usually result in additional nitrogen being made available for plant utilization (15).

Large applications of lime and fertilizer to sandy soils may soon be lost through leaching and are no substitute for organic matter additions. Fly ash may also be added to soil to improve the water holding capacity and add plant nutrients, particularly potassium (K). Care should be taken, however, not to create plant toxic conditions with fly ash applications to the final cover.

Soils having textures at the other extreme, clayey soils, may also represent management problems. Often water holding capacity is so high as to preclude sufficient air from being present or diffusing to respiring roots. This effect may seriously limit vegetative growth by inhibiting water and nutrient uptake. Additions of fly ash and/or organic matter may "loosen" a clay soil providing better aeration characteristics and, at the same time, augment plant nutrient supplies.

When soil removed from a disposal site is to be used as final cover, consideration should be given to its suitability to support plant growth. If a predisturbance soil survey is conducted as suggested earlier in this section, information on the relative suitability of the existing soil horizons for plant adaptation will be presented by the soil scientist in his report. Some advantages which the surface A and B horizons have over underlying material are higher nitrogen content, fertility, cation exchange capacity, plant seed content, and microbial population. All these factors can increase the chance for successful establishment of vegetative cover.

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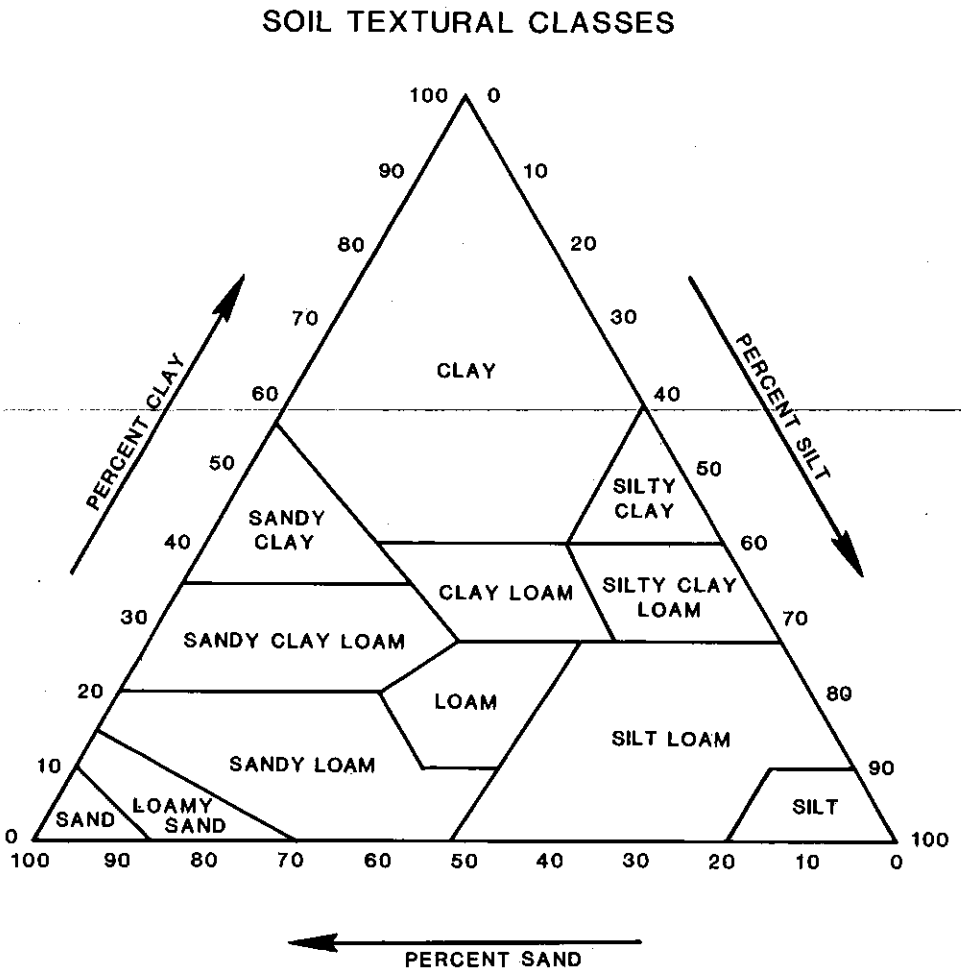

Figure 8-13. Relationship between the textural class name and particle size distribution. (Source: Soil Conservation Service. U. S. Department of Agriculture. Soil Taxonomy. Washington, D. C.: Government Printing Office, 1976. AH-436.)

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Final Cover Storage Procedures. Procedures for determining the potential volumes of on-site soils useful as cover soil was previously discussed under "Predisturbance Site Investigation." When stripping soil, it is strongly recommended that separate stockpiles be kept to segregate topsoil, productive subsoil and impermeable subsoil. These soil piles should be vegetated with a temporary, quick growing grass to prevent excessive erosion. From an environmental and agronomic viewpoint it would be correct to apply cover soil in the following sequence:

- an impermeable layer to serve as a protective seal preventing recharge and leachate generation.
- an intermediate subsoil with good rooting characteristics.
- an upper topsoil zone with high biological activity and nutrient content, that will encourage plant germination and reduce surface runoff.

Availability of Water

As water available for plant utilization increases, in general, minimum soil cover requirements should decrease. The reasoning is that plants will be able to obtain their needed water from a smaller volume of cover material assuming that available nutrients are also adequate within the volume of cover. If an ash disposal site planner is not familiar with moisture availability, precipitation records should be consulted. Distribution of precipitation is just as important to consider as total amount. For example, in an area where most of the precipitation arrives in the form of snow, most of which results in surface runoff when it melts, little moisture will actually be available for plant utilization. The detailed climatological data obtained during the predisturbance site investigation will provide useful, site specific data on precipitation and its distribution.

As the amount of precipitation increases, the speed of the weathering process which reduces any toxicities that may be present in fly ash will usually be accelerated. More precipitation means more water will be available to leach soluble salts and boron. Water leaching into fly ash will contain carbonic and organic acids that will help neutralize any alkalinity present in this material. Accelerated weathering would therefore tend to reduce the amount of soil necessary to establish vegetative cover.

Selection of Plant Species

Plant species selected for the final ground cover should be well adapted to conditions present at the site. The logical choice, in most cases, would be to select plant species native to the surrounding area as determined in the

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predisturbance investigation. These native species would already be adapted to the growing environment of the site, except where drainage and/or light conditions have changed. There will be cases when seeds for plantings of native vegetation are not available or prohibitively expensive and new vegetation must be selected. Table 8-5 lists grasses and Table 8-6 lists legumes commonly used in revegetation.

Plants selected must be tolerant of not only the environment normally encountered, but also of the possibility of having ash as a substantial part of its rooting medium. Generally, if the ash is not a good growth medium, the deeper the root system of the plant species selected for revegetation, the thicker the cover soil requirement. Converely the less nutrient and water demanding a vegetative cover, the shallower the cover soil need be.

Plant species selected should be able to meet the following criteria:

- Provide good surface coverage, preferably low growing and dense foliage,
- Have seed or stock readily available and at reasonable expense,
- Have a degree of tolerances for ash as a growing medium,
- Withstand erosion and traffic,
- Adapt to soil conditions at the site (pH, moisture, texture, fertility),
- Adapt to the climate of the site (sunlight-wind exposure, temperature, rainfall),
- Be compatible with other species selected for revegetation,
- Be capable of propagating,
- Be compatible with post-closure land use.

After the final cover is in place and before vegetation is planted, a chemical test to determine the nutrient status of the soil should be made. Many state universities and private companies offer soil testing services and kits outlining soil sampling procedures along with the containers to send samples to laboratories. These results will provide guidance in selection of amendments (lime and fertilizer) to be applied to the final cover. It is recommended that the local Soil Conservation Service representative, county agricultural extension personnel or agronomists be consulted for the final selection, since they will be most familiar with growing conditions and problems that may be encountered in vegetative establishment on a specific site.

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Table 8-5

CHARACTERISTICS OF COMMONLY USED GRASSES[a] FOR REVEGETATION PURPOSES

Common Name	Botanical Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry (not droughty)	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Bahiagrass	Paspalum notatum		X	X	X	X			P	4.5-7.5	X	X	X	Tall, extensive root system. Maintained at low cost once established. Able to withstand a large range of soil conditions. Scarify seed.
Barley	Hordeum vulgare	X			X	X			A	5.5-7.8	X		X	Cool season annual. Provides winter cover
Bermuda Grass	Cynodon dactylon		X	X	X	X	X		P	4.5-7.5	X	X	X	Does best at pH of 5.5 and above. Grows best on well drained soils, but not on waterlogged or tight soils. Propagated vegetatively by planting runners or crowns.
Bluegrass, Canada	Poa compressa	X		X	X	X			P	4.5-7.5	X		X	Does well on acid, droughty, or soils too low in nutrients to support good stands of Kentucky bluegrass.
Bluegrass, Kentucky	Poa pratensis	X			X	X	X		P	5.5-7.0	X	X	X	Shallow rooted; best adapted to well-drained soils of limestone origin.
Bluestem, big	Andropogon gerardi		X		X	X	X		P	5.0-7.5	X		X	Strong, deep rooted, and short underground stems. Effective in controlling erosion.

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Table 8-5
(Continued)

CHARACTERISTICS OF COMMONLY USED GRASSES FOR REVEGETATION PURPOSES

Common Name	Botanical Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry (not) droughty)	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Bluestem, little	Andropogon scoparius		X		X	X			P	6.0-8.0	X		X	Dense root system; grows in a clump to 3 feet tall. More drought tolerant than big bluestem. Good surface protection.
Bromegrass, field	Bromus arvensis	X			X	X	X		A	6.0-7.0	X		X	Good winter cover plant. Extensive fibrous root system. Rapid growth and easy to establish.
Bromegrass, smooth	Bromus inermis	X		X	X	X	X		P	5.5-8.0	X	X	X	Tall, sod forming, drought and heat tolerant. Cover seed lightly.
Buffalograss	Buchloe dactyloides		X			X	X		P	6.5-8.0	X		X	Drought tolerant. Withstands alkaline soils but not sandy ones. Will regenerate if overgrazed.
Canarygrass, reed	Phalaris arundinacea	X		X	X	X	X	X	P	5.0-7.5	X	X	X	Excellent for wet areas, ditches, waterways, gullies. Can emerge through 6 to 8 inches of sediment.
Deertongue	Panicum clandestinum		X	X	X	X	X	X	P	3.8-5.0	X	X		Very acid tolerant; drought resistant. Adapted to low fertility soils. Volunteers in many areas. Seed not available.

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Table 8-5
(Continued)

CHARACTERISTICS OF COMMONLY USED GRASSES FOR REVEGETATION PURPOSES

Common Name	Botanical Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry (not) droughty)	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Fescue, creeping red	Festuca rubra	X		X	X	X	X		P	5.0-7.5	X	X	X	Grows in cold weather. Remains green during summer. Good seeder. Wide adaptation. Slow to establish.
Fescue, tall	Festuca arundinacea	X			X	X	X		P	5.0-8.0	X	X	X	Does well on acid and wet soils of sandstone and shale origin. Drought resistant. Ideal for lining channels. Good fall and winter pasture plant.
Grama, blue	Bouteloua gracilis		X	X	X	X	X		P	6.0-8.5	X			More drought resistant than sideoats grama. Sod forming. Extensive root system. Poor seed availability.
Grama, sideoats	Bouteloua curtipendula		X		X	X			P	6.0-7.5	X		X	Bunch forming; rarely forms a sod. May be replaced by blue grama in dry areas. Feed value about the same as big bluestem. Helps control wind erosion.
Indian grass	Sorgastrum nutans		X			X	X		P	5.5-7.5	X		X	Provides quick ground cover. Rhizomatous, tall. Seed available.
Lovegrass, sand	Eragrostis trichodes		X		X				P	6.0-7.5	X		X	A bunchgrass of medium height. Adaptable to sandy sites. Good for grazing. Fair seed availability.

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Table 8-5
(Continued)

CHARACTERISTICS OF COMMONLY USED GRASSES FOR REVEGETATION PURPOSES

Common Name	Botanical Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry (not droughty)	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Lovegrass weeping	Eragrostis curvula		X	X	X	X	X		P	4.5-8.0	X			Bunchgrass, rapid early growth. Grows well on infertile soils. Good root system. Low palatability. Short-lived in Northeast.
Millet, foxtail	Setaria italica		X	X	X	X			A	4.5-7.0	X		X	Requires warm weather during the growing season. Cannot tolerate drought. Good seedbed preparation important.
Oats	Avena sativa	X		X	X				A	5.5-7.0	X		X	Bunch forming. Winter cover. Requires nitrogen for good growth.
Oatgrass, tall	Arrhenatherum elatius	X		X	X				P	5.0-7.5	X		X	Short-lived perennial bunchgrass, matures early in the spring. Less heat tolerant than orchardgrass except in Northeast. Good on sandy and shallow shale sites.
Orchardgrass	Dactylis glomerata	X		X	X	X	X		P	5.0-7.5	X		X	Tall-growing bunchgrass. Matures early Good fertilizer response. More summer growth than timothy or bromegrass.
Redtop	Agrostis alba	X		X	X	X	X	X	P	4.0-7.5	X	X	X	Tolerant of a wide range of soil fertility, pH, and moisture conditions. Can withstand drought; good for wet conditions. Spreads by rhizomes.

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Table 8-5
(Continued)

CHARACTERISTICS OF COMMONLY USED GRASSES FOR REVEGETATION PURPOSES

Common Name	Botanical Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry (not droughty)	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Rye, winter	Secale cereale	X		X	X	X			A	5.5-7.5	X		X	Winter hardy. Good root system. Survives on coarse, sandy spoil. Temporary cover.
Ryegrass, annual	Lolium multiflorum	X			X	X	X		A	5.5-7.5	X		X	Excellent for temporary cover. Can be established under dry and unfavorable conditions. Quick germination; rapid seedling growth.
Ryegrass, perennial	Lolium perenne	X			X	X	X		P	5.5-7.5	X		X	Short-lived perennial bunchgrass. More resistant than weeping love or tall oatgrass
Sandreed, prairie	Calamouilfa longifolia		X	X	X				P	6.0-8.0	X			Tall, drought tolerant. Can be used on sandy sites. Rhizomatous. Seed availability poor.
Sudangrass	Sorghum sudanense		X	X	X	X	X		A	5.5-7.5	X		X	Summer annual for temporary cover. drought tolerant. Good feed value. Cannot withstand cool wet soils.
Switchgrass	Panicum vergatum		X		X	X	X		P	5.0-7.5	X	X	X	Withstands eroded, acid and low fertility soils. Kanlow and Blackwell varieties are most often used. Rhizomatous. Seed available. Drainageways, terrace outlets.

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Table 8-5
(Continued)

CHARACTERISTICS OF COMMONLY USED GRASSES FOR REVEGETATION PURPOSES

Common Name	Botanical Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry (not droughty)	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Timothy	Phleum pratense	X			X	X	X	X	P	4.5-8.0	X		X	Stands are maintained perennially by vegetative reproduction. Shallow, fibrous root system. Usually sown in a mixture with alfalfa and clover.
Wheat, winter	Triticum aestivum	X		X	X	X			A	5.0-7.0	X		X	Requires nutrients. Poor growth in sandy and poorly drained soils. Use for temporary cover.
Wheatgrass, tall	Agropyron elongatum	X		X	X	X	X	X	P	6.0-8.0	X	X	X	Good for wet, alkaline areas. Tolerant of saline conditions. Sod forming. Easy to establish.
Wheatgrass, western	Agropyron smithii	X		X	X	X	X	X	P	4.5-7.0	X	X	X	Sod forming, spreads rapidly, slow germination. Valuable for erosion control. Drought resistant.

[a] Grasses should be planted in combination with legumes. Seeding rates, time, and varieties should be based on local recommendations.
[b] P - perennial; A = annual.
[c] Many species survive and grow at lower pH; however, optimum growth occurs within these ranges.
[d] Hay, pasture, green manure, winter cover, and nurse crops are primary agricultural uses.

Source: Erosion and Sediment Control, Surface Mining in the Eastern U.S. Washington, D. C.: U.S. Environmental Protection Agency, Vol. 1 and 2, 1976. EPA-625/3-76-006.

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Table 8-6

CHARACTERISTICS OF COMMONLY USED LEGUMES[a] FOR REVEGETATION PURPOSES

Common Name	Scientific Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Alfalfa	Medicago sativa	X		X	X	X			P	6.5-7.5	X		X	Requires high fertility and good drainage
Clover, Alsike	Trifolium hybridium	X			X	X	X	X	P	5.0-7.5	X		X	Good for seeps and and other wet areas. Dies after two years.
Clover, red	Trifolium pratense	X			X	X			P	6.0-7.0	X		X	Should be seeded in early spring.
Clover, white	Trifolium repens	X			X	X	X		P	6.0-7.0	X		X	Stand thickness decreases after several years.
Flatpea	Lathyrus sylvestris	X		X	X	X	X		P	5.0-6.0	X			Seed is toxic to grazing animals. Good cover.
Lespedeza, common	Lespedeza striata		X		X	X			A	5.0-6.0	X			Low-growing, wildlife-like seed. Kobe variety most often used Acid tolerant.
Lespedeza, Korean	Lespedeza stipulacea		X	X	X	X	X		A	5.0-7.0	X			Less tolerant of acid soils that common lespedeza.
Lespedeza, sericea	Lespedeza cuncata		X	X	X	X	X		P	5.0-7.0	X	X		Woody, drought tolerant, seed should be scarified. Bunchlike growth.
Milkvetch, cicer	Astragalus cicer			X	X	X	X		P	5.0-6.0	X		X	Drought tolerant. Low growing. No major diseases. Hard seed coat.

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Map Units (3 to 5.99 in.)	Av. Slope of Map Unit (θ) (Degrees)	Map Area (×) (sq. yds.)	Ground Area (×/cos. θ) (sq. yds.)	Volume Estimate (cu. yds.) Lower Limit	Upper Limit
4C	11.5	66,157	67,512	5,626	11,233
7-B	5.5	10,615	10,665	889	1,775
9-C	11.5	72,828	74,320	6,193	12,366
15-A	1.5	26,121	26,129	2,177	4,348
15B	5.5	83,553	83,940	6,995	13,966
17B	5.5	19,100	19,188	1,600	3,192
Topsoil Volume Range in 3 to 5.99 Inch Category				= 23,480	46,880

Estimated Topsoil Volume (Av.) in 3 to 5.99 Inch Cat. = 35,680 cubic yards

Variations in the method of calculating soil volumes more suited to the operational schedule of the site could be devised. For instance, at a dry ash valley disposal site where clearing and disposal proceed progressively up-valley, it may be preferable for storage reasons to estimate strippable soil volumes expected with the building of successive lifts. Stockpile(s) reduction from the progressive covering of retired portions of the site could then be weighted against anticipated cover soil additions in formulating a cover soil allocation scheme.

EROSION AND SEDIMENT CONTROL

The detachment of soil particles from their initial resting place by wind or water describes the process of erosion. When placed in motion these particles become sediment, a potential water pollutant. Whereas erosion control practices are designed to prevent soil particles from being detached, sediment control practices aim to prevent the detached particles from leaving the site at unacceptable levels.

Some degree of erosion and sediment loss is natural and not considered harmful in most cases. However, when an area is highly disturbed and soil and/or ash is exposed to the erosive agents, the natural rate of erosion and sediment yield from the area will greatly accelerate to unacceptable levels. While it is particularly important to design ash disposal sites to minimize erosion after site closure, it is also important to control erosion during site development and operation. Generally, the best means of accomplishing this is to minimize exposure of ash and

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stripped soil surfaces. This can be done by developing a dry site in stages with the progressive reclamation of the retired portions of the ash site, and by maintaining a temporary cover on exposed surfaces in active areas. At wet ash disposal sites, ash is effectively controlled during site operations by proper maintenance of water levels in the pond.

Water Erosion

Water is capable of detaching and moving soil particles through energy transferences associated with the impact of raindrops on the soil surface and as more concentrated overland flow known as runoff. Surface runoff occurs when precipitation exceeds the rate at which water can infiltrate the soil. Both forms of water erosion interact to some extent, and factors controlling the effectiveness of erosion by raindrop impact also affect the generation of surface runoff.

Controlling Raindrop Erosion. The soil erosion process by water begins when raindrops impact on the soil surface. The force transmitted to the surface by the impacting raindrop influences erosion in a number of ways including:

- Detaching soil particles or breaking down soil aggregates and thereby making transport by surface runoff easier,
- Destroying surface soil structure producing puddling or crusting that reduces rainfall infiltration and increases runoff.
- Transporting detached soil particles downslope in the resulting raindrop splash.

Rainsplash erosion has been found to be a major process for the release and transport of sediment downslope where the surface is unprotected by vegetation (3). Particularly severe erosion occurs during heavy downpours where the rate of sediment movement is proportional to 1.0 to 1.5 power of rainfall intensity (4). Studies on unvegetated slopes in Arizona (5) indicated mean annual transport by rainsplash in accordance with the relationship:

$$S = 0.3 \left(\frac{R}{100}\right)^{2.2} \qquad (8\text{-}1)$$

where S = Rate of rainsplash transport ($cm^3/cm/yr$)

R = Mean annual rainfall in millimeters

Reducing the force of the raindrop impact at the soil surface will serve to protect the integrity of the soil aggregates while suppressing rainsplash by breaking the impact of the raindrops. Covering the soil surface with either dense grassy or

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shrubby vegetation, or applying an artificial cover such as organic mulch, has proven effective in controlling rainsplash erosion, as illustrated in Figure 8-5.

The establishment of vegetation and application of mulches is discussed later in this section.

Controlling Surface Runoff Erosion. The causal factors affecting runoff and subsequent erosion are identified in the "universal soil-loss equation" stated as follows:

$$A = R\ K\ L\ S\ C\ P$$

Where A, the computed soil loss per unit area, is the product of the following factors:

R = rainfall inputs
K = soil characteristics
LS = slope length and gradient
C = crop or vegetation cover
P = erosion control practice

Controlling the rate of surface erosion therefore requires a manipulation of these causal factors or the implementation of erosion control structures which intercept and divert runoff flow. Some physical and climatic factors including the amount, intensity and duration of precipitation, and the antecedent moisture content of the soil before a storm, can not be readily controlled. As these factors are increased, the volume of surface runoff will invariably increase as well. Soil, vegetation, and slope characteristics that can be managed to reduce runoff and the potential soil loss are as follows:

Vegetation Cover. The tremendous difference between rates of soil loss on vegetated and unvegetated slopes, on the order of 1,000 to 10,000 times (Figure 8-6), shows that the presence or absence of vegetation is the over-riding factor in affecting the rate of erosion. Vegetation acts to reduce runoff and its velocity and thereby decreases the ability of water to carry away soil particles by:

- Intercepting precipitation, reducing the amount of water available for surface runoff,
- Breaking the impact of raindrops (discussed previously),

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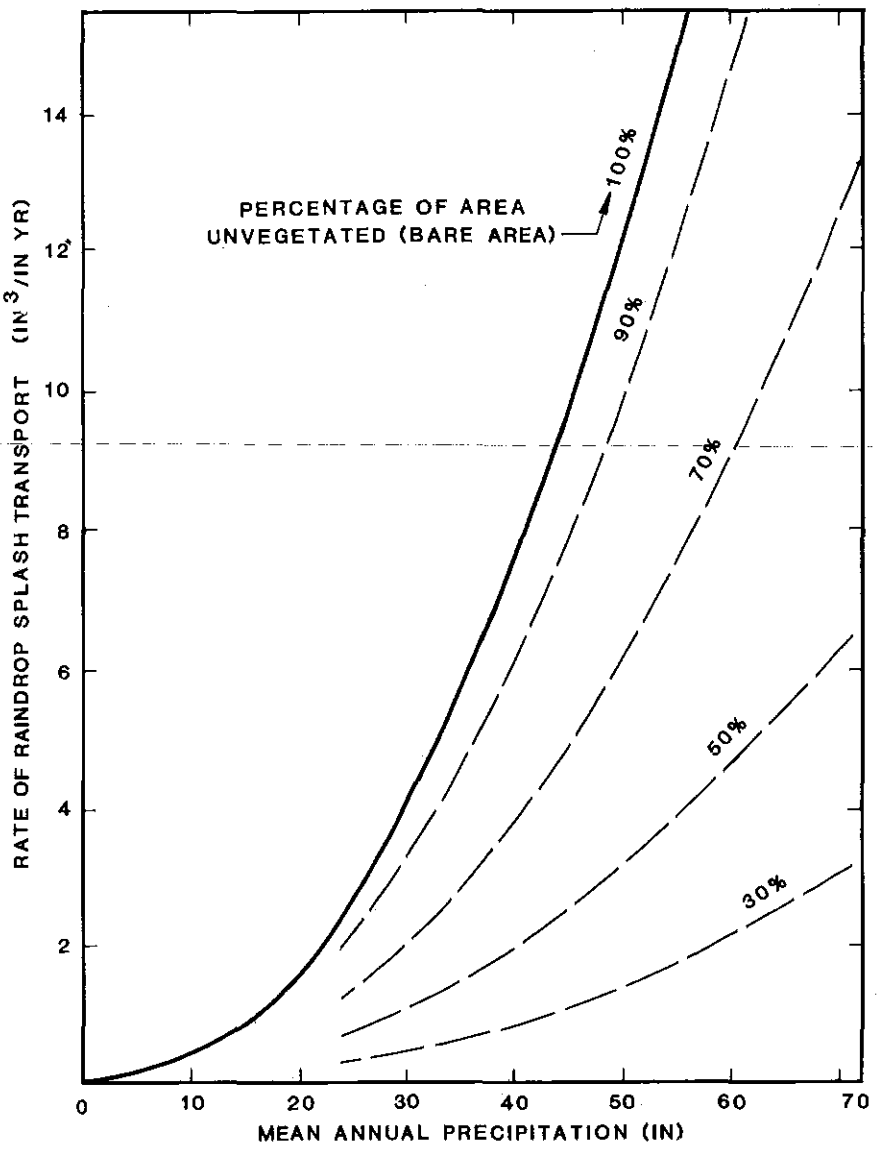

Figure 8-5. Probabilistic variation of raindrop splash erosion with extent of vegetation cover expressed in terms of mean annual precipitation.

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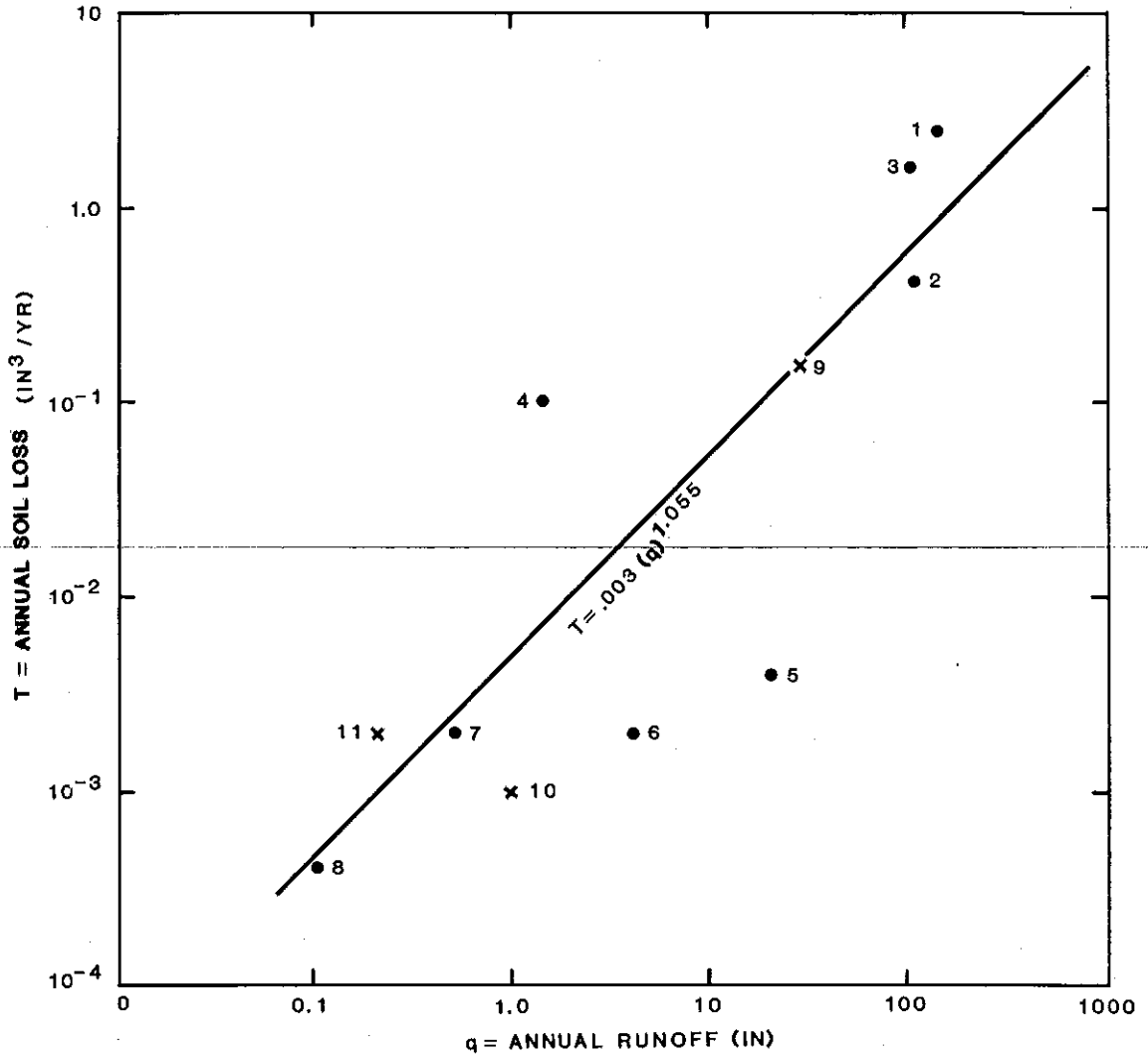

Figure 8-6. The Influence of Vegetation on Runoff and Erosion

Data Source: Meginnis, H. G. Effect of Cover on Surface Run-off and Erosion In the Loessial Uplands of Mississippi. Washington, D. C.: U. S. Department of Agriculture, Circular 347, 1935. Hudron, N. W., and D. C. Jackson. Erosion Research: Report of Progress, 1958-1959. Henderson Research Station, Rhodesia: Ministry of Agriculture, 1959.

Data Points: 1. Cultivated Cotton: Rows Downslope. 2. Cultivated Cotton: Rows on Contour. 3. Barren Abandoned Land. 4. Black Locust-Osage Orange Plantation. 5. Scrub Oak Woodland. 6. Bermuda Grass Pasture. 7. Broomsedge Field. 8. Oak Forest. 9. Bare Soil. 10. Mosquito Gauze Over Bare Soil. 11. Dense Grass.

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- Improving soil structure and infiltration within the soil around roots,
- Interrupting and slowing overland flow,
- Physically building the soil forming a root mat.

The proper planting of various combinations of grasses, legumes and shrubs will insure long-term soil stabilization. Not all types of vegetative cover are equally effective in reducing soil loss. Those plants that produce a low, dense cover such as crownvetch or lespedeza would offer greater protection than plants consisting mostly of stems with few leaves. The exact type and mixture of individual plant species to be used will depend on soil and drainage conditions, erosional stresses and post-closure land-use. Considering the high erosive potential of bare surfaces, the planting of quick growing perennials and annuals to provide temporary protection is recommended on stockpiled cover soil, or where seasonal constraints prohibit the establishment of more permanent plant species.

Soil Characteristics. The sediment yield of a hillslope or embankment is largely determined by the amount of runoff accumulating downslope, and by the erodibility of the soil. The amount of runoff is influenced by variations in the infiltration capacity of the soil while the erodibility is dependent on the texture and degree of aggregation of surface soil particles.

The erodibility of exposed fly ash by both wind and water is exceedingly high as might be anticipated from its textural similarities with wind deposited glacial loess, one of the most erosive natural sediments (Figure 8-7). Composed primarily of low density silt size particles, the erosive force required to initiate transport is low relative to other size fractions (Figure 8-8). Without the benefit of some clay and organic matter which provides cohesive strength and forms erosion resistant aggregates in most topsoils, fly ash, particularly freshly placed fly ash, will present a major sediment pollution hazard. To prevent excessive sediment loss from exposed fly ash, it is imperative that a protective surface cover be applied. The growing of vegetation directly on fly ash has been investigated with minimal success (6, 7). This research tends to indicate that high concentrations of soluble salts and plant available boron commonly found in some fly ash are toxic for the long term establishment of most plant species. A covering layer of topsoil is therefore usually recommended. In addition to providing a suitable growth media, topsoil has the advantage of reducing runoff by promoting percolation

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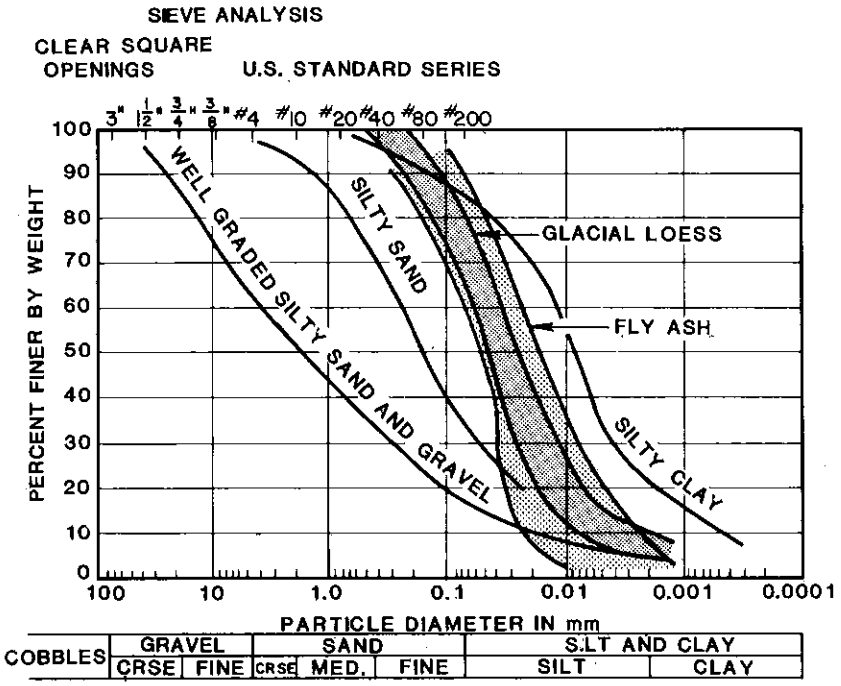

Figure 8-7. Composite of grain size distributions for bituminous fly ash and glacial loess. (Sources: Pewe, T. L. "Origin of Upland Silt Near Fairbanks, Alaska." Geological Society of America Bulletin, Vol. 66, 1955, p. 701 and Figure 2-2 of this manual.)

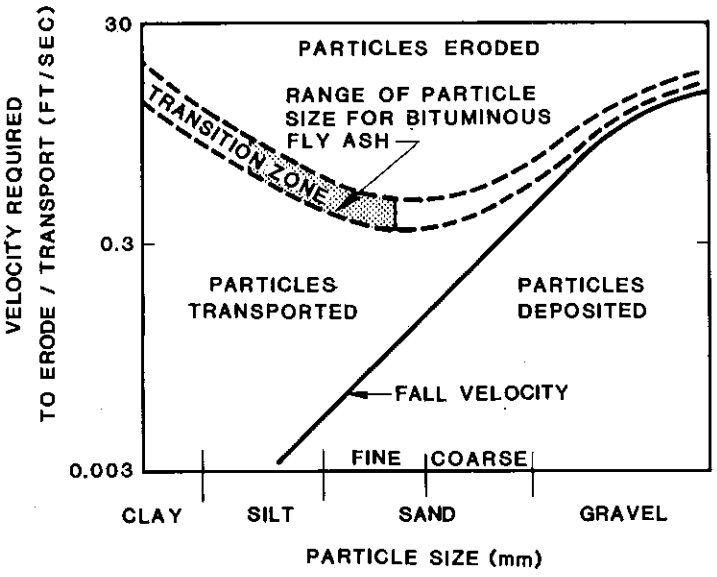

Figure 8-8. Velocities required for particle erosion, transport and deposition.

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of surface water. The high infiltration rate of topsoil is related to its open structure, the result of particle aggregation by decomposed organic matter and the by-products of micro-organisms. These organic stabilized aggregates tend to be water resistant and resist the detaching forces of falling raindrops which readily crusts surfaces without organic bound aggregates. Working easily decomposed organic matter such as grasses, animal manure and sewage sludge into the topsoil before seeding will help to loosen soil structure, promote plant growth, and reduce runoff and subsequent erosion (8).

In areas where a temporary cover is desired, mulching of the surface has proven effective in controlling runoff erosion. Reference to points 10 and 11 in Figure 8-6 clearly demonstrates that a surface covering of gauze is nearly as effective as a dense grass cover in controlling erosion. Used in conjunction with revegetative planting, mulch protects seedbeds from excessive erosion prior to seed germination and provides a favorable environment for plant development. As an easily applied and relatively inexpensive erosion control method, organic and inorganic mulch materials are effective for short-term erosion control in areas of active operations. A common method of controlling fugitive dust from fly ash is the placement of a surface layer of heavier and coarser textured bottom ash.

Mechanical roughening of the soil surface to increase depression storage and infiltration is an established moisture conservation technique. When used in conjunction with seedbed preparation, surface roughening is effective in reducing runoff and erosion during plant development. Common methods of loosening and/or roughening a soil surface include scarification, gouging, tracking, and furrowing (9). The objective of all these methods is to form a series of small depressions or ditches oriented with the slope contour that serve to intercept surface water flow and detain water for latter infiltration.

Slope Length and Gradient. The erosive force of overland flow increases with both its distance from the divide and the slope gradient (Figure 8-9). As water flows downslope it picks up velocity and concentrates in increasingly larger rills and gullies where its capacity to transport and erode is intensified. In substances where it is relatively easy to dislodge particles, the resulting pattern of rills and gullies will shift about lowering the surface evenly. However, in older fly ash deposits where a surface crust has formed, gullies that have formed in the crust will be maintained and further

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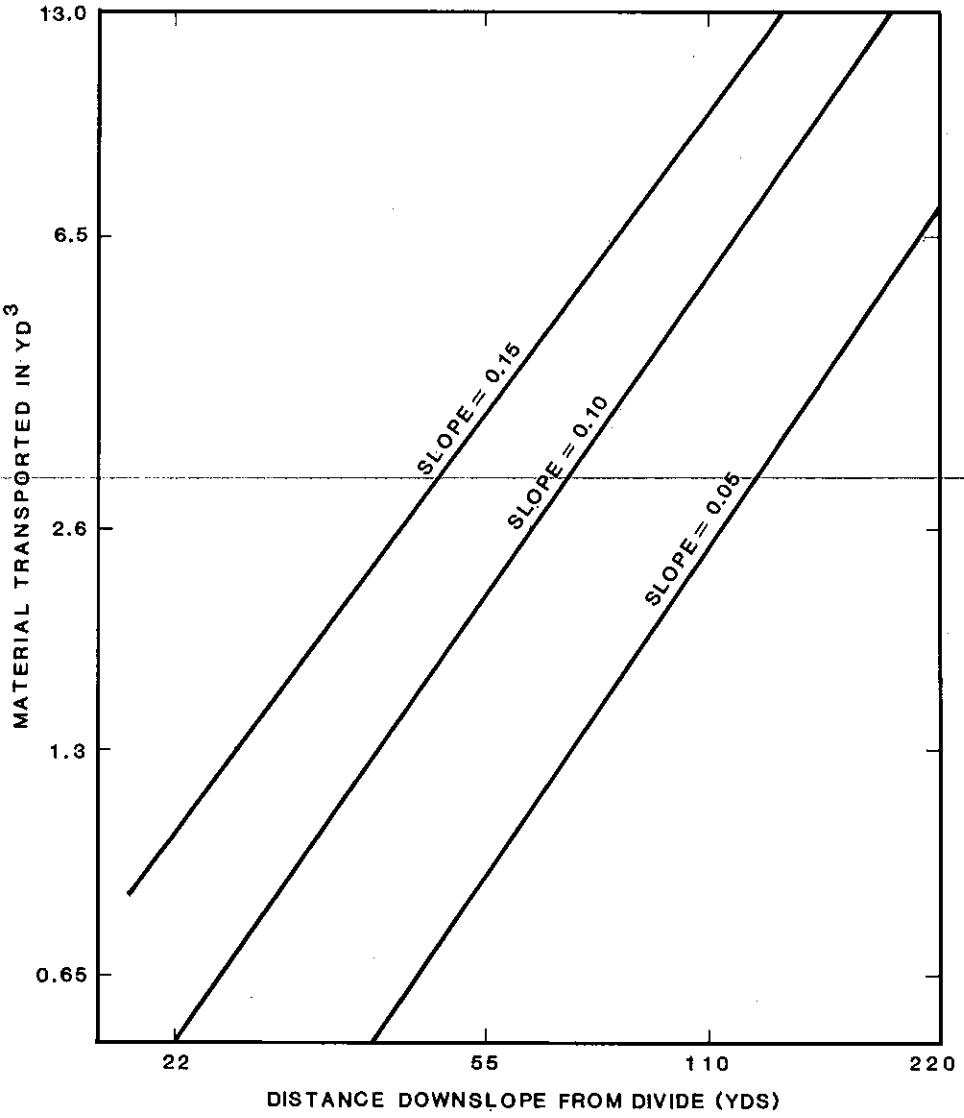

Figure 8-9. Graphic representation of empirical model: Transport $\propto$ $(\text{Distance})^{1.35}$ $(\text{Slope})^{1.35}$, for unvegetated field soils. (Source: Musgrave, G. W. "Quantitative Evaluation of Factors in Water Erosion - A First Approximation." Journal of Soil and Water Conservation, Vol. 2, 1947, p. 133.)

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accentuated. Consequently, it is important to grade sites to drain sheet flow across ash and to repair or line gullies as they form.

Where slopes are steep, as on the face of lifts and pond embankments, or where slopes are exceedingly long, as on top of landfills and retired ash ponds, it is important to restrict the velocity and volume of runoff through the use of diversion structures. These structures, including reverse benches, slope benches, and diversion dikes (Figure 8-10), decrease the overall length of slope and provide for the retention and positive control of runoff in erosion protected ditches (10). It must be remembered that shorter and flatter slopes are less erodible. It is important to consider that slopes greater than 2:1 (50 percent) place severe limitations on the ability of plant roots to hold and bind soil particles. As a rule of thumb, a 2:1 slope is assumed to be the maximum slope upon which vegetation can be established and maintained satisfactory. However, maximum vegetative stability cannot be attained on slopes steeper than 33 percent (3:1). The maximum-slope rule should only be applied to ideal soil conditions where the soil is not highly erodible and has adequate moisture holding capacity.

The shape of a slope also has a major bearing on soil loss. Assuming that conditions remain uniform through the slope, the base of a slope is more susceptible to erosion than the top since the volume and velocity of runoff increase downslope. Constructing a convex slope obviously magnifies the problem, whereas a concave slope would reduce it. Leaving a relatively flat slope near the base not only reduces erosion and the tendency to form gullies, but also traps sediments from upper portions of the slope (11).

Erosion Control Practices. It is desirable to limit the amount of runoff and channelized flow entering the site. In most cases, a system of diversion ditches and waterways can be constructed to prevent outside runoff from entering the site and contributing to surface erosion and leachate generation problems.

In arid and semi-arid regions, however, the diversion system could be designed for spreading collected runoff onto vegetated portions of the landfill at nonerosive rates, if permitted by prevailing regulations. Figure 8-11 shows a plan view of diversion and interception ditches around a valley fill. Water diverted around the site passes into an existing waterway while water intercepted from the site is channeled to a sedimentation pond. Diversion ditches should be capable of handling surface water runoff from upland drainage areas from specified storm events.

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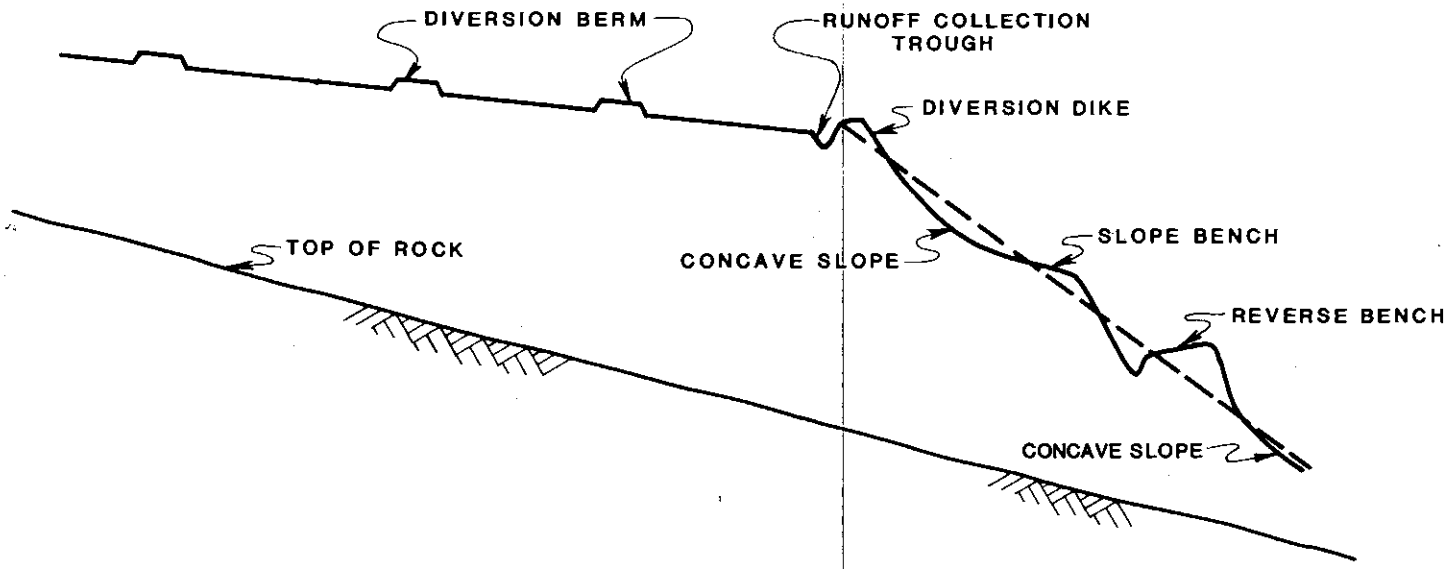

Figure 8-10. Slope Reduction Methods

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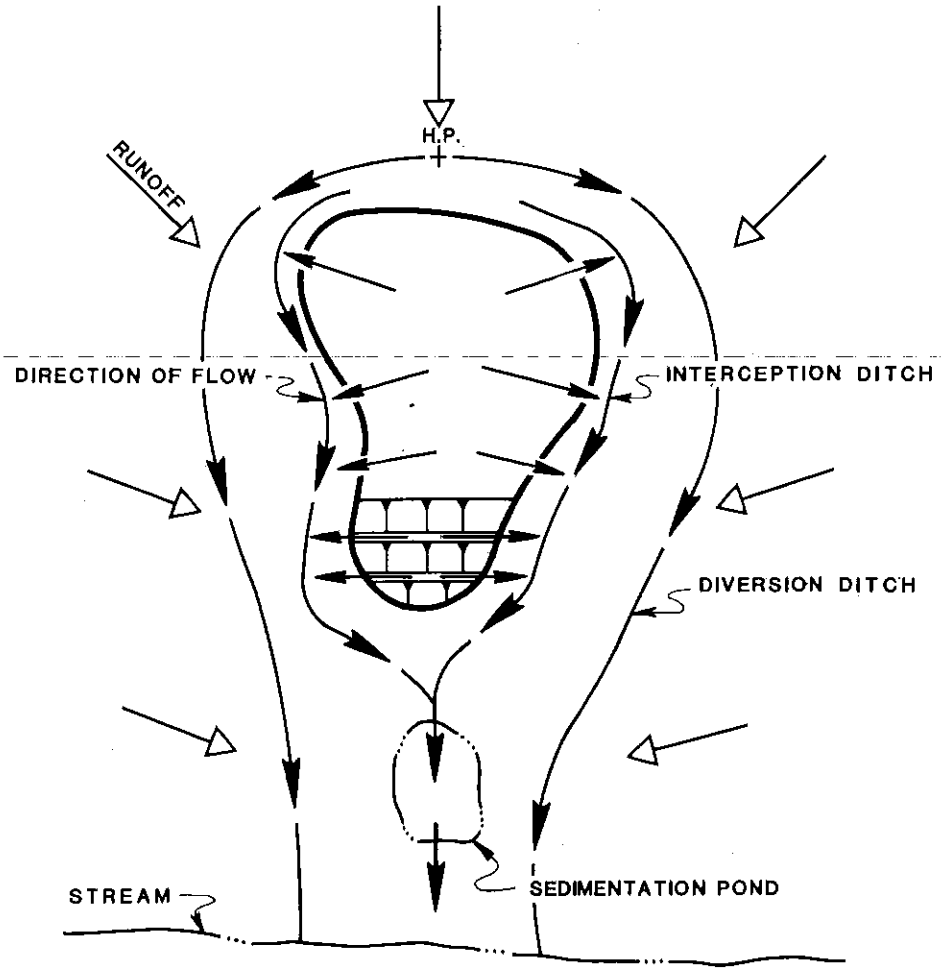

Figure 8-11. Schematic plan view of interception and diversion ditches around a valley landfill.

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Federal regulations designate the following design precipitation events:

- Hazardous waste; 25 year 24 hour,
- Non-hazardous waste; 10 year 24 hour.

Interception ditches are currently required, by federal regulations, to be able to handle the site runoff from a 10 year 24 hour precipitation event. As previously mentioned, research of prevailing state and local regulations should be made prior to ash disposal site design to ascertain the most stringent, prevailing criteria governing ash disposal practice.

The design of diversion and interception ditches falls under the broad topic of open channel flow. References outlining specific design criteria and methodologies are found in the bibliography at the end of this section. These references contain information covering the calculation of runoff, open channel hydraulics, rainfall intensities for storms of various frequencies, and design charts for sizing open channels. In general, the following factors must be known or assumed before an analysis of required ditch size and type can be made:

- Design flow from stormwater runoff,
- Slope reaches for ditch segments,
- Ditch lining and Manning's roughness coefficient.

Ditches are commonly rectangular, trapezoidal, or triangular in cross-section, and typically have grass, rock, or concrete linings, depending on anticipated flow velocities, for erosion control.

In addition to controlling the amount of runoff entering the site, it is desirable to construct entrapment structures to limit the amount of sediment leaving the disposal area. These devices include sediment basins or ponds, check dams, vegetative buffers, and filters. As shown on Figure 8-11, interceptor ditches carry sediment eroded from the site to a sedimentation pond. The primary purpose of the pond is to reduce total suspended solid concentrations of the ash disposal site effluent to meet state and federal effluent regulations. To accomplish this requirement, sedimentation ponds should be designed to provide a sufficient settling time for suspended solids carried off the site by a designated stormflow. Current federal regulations state that sedimentation ponds should be able to handle a 10 year 24 hour storm and provide an effluent with a maximum total suspended solids concentration of 50 mg/l. In addition to providing sediment removal, a sedimentation pond should also have sufficient volume to provide sediment storage in order to

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preclude the need for frequent sediment removal. In general, the following parameters should be known or assumed to undertake a pond design (11):

- Design outflow rate (design stormflow),
- Anticipated grain-size distribution of the incoming sediment,
- Expected suspended solids concentration in the inflow,
- Specific gravity of the incoming solids,
- Anticipated pond water temperature.

The settling of solids is theoretically related to the pond outflow rate, the surface area of the pond and critical settling velocity of the particles in the pond influent. This relationship can be stated as follows (11):

$$\text{Required settling area} = \frac{\text{outflow rate}}{\text{critical settling velocity of the smallest particle to be retained}}$$

However, it is unlikely that ideal settling conditions will occur, due to a number of disrupting factors. These include (11):

- short circuiting,
- bottom scour,
- turbulence,
- nonuniform deposition of materials,
- entrance and exit effects,
- shape of the suspended particles,
- velocity of the suspending liquid.

Conversely, it may be possible to improve the pond removal efficiency. These techniques include (11):

- Using baffles to increase detention time,
- Constructing two or more ponds in series instead of one larger pond,
- Constructing energy dissipators at the pond entrance to reduce inflow velocity,
- Wrapping a filter cloth around a standard perforated riser,

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- Constructing a very wide overflow weir instead of a standard weir pipe to reduce outflow velocity,
- Using coagulants to enhance particle settling.

Detailed design information for sedimentation basins can be found in the bibliography references listed at the end of this section.

Wind Erosion

As was the case for water erosion, the loss of soil by wind movement involves two processes, detachment and transportation. The abrasive action of wind results in some detachment of small soil grains; however, its abrasive action is increased greatly when the wind is laden with soil particles. Once in motion, particles are transported in one of several ways including:

- saltation, where particles move in a short series of bounces along the ground surface,
- creep, or rolling and sliding of larger particles,
- suspension, where particles of fine sand size and smaller are moved upward in wind currents.

Susceptibility to wind erosion is related to moisture content; i.e. the higher the moisture content, the less susceptible a soil will be to wind erosion. Hence, wind erosion is more a problem in the western half of the country, particularly in the semi-arid and arid southwest where there is either little or no water surplus at any time, or a distinct seasonal moisture deficit. A soil with a higher moisture content resists wind erosion by binding capillary forces created by the water film covering soil particles. Resistance is greatest when the film joining all particles is continuous. When the film becomes discontinuous, as the soil dries out, the capillary forces among the particles starts to decrease and susceptibility to wind erosion increases.

The severity of wind erosion is also related to the velocity and turbulence of the wind, as well as the surface characteristics of the soil. Tests have shown that wind speeds of about 12 mph are required to initiate soil movement (12). At higher wind speeds, the severity of soil movement is proportional to the wind velocity cubed. Thus at wind speeds in excess of 12 mph, the quantity of soil carried by the wind goes up very rapidly. Certainly not all size particles are equally susceptible to erosion, nor require identical wind velocities to initiate movement (Figure 8-12). Reference to Figure 8-8 indicates that particles about 0.1 mm in diameter are most easily stripped from the surface. Again, it would be anticipated

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that exposed fly ash should be highly susceptible to wind erosion. Yet other soil characteristics, including the mechanical stability of dry soil aggregates and the presence of a stable crust, must also be considered. The importance of cementing

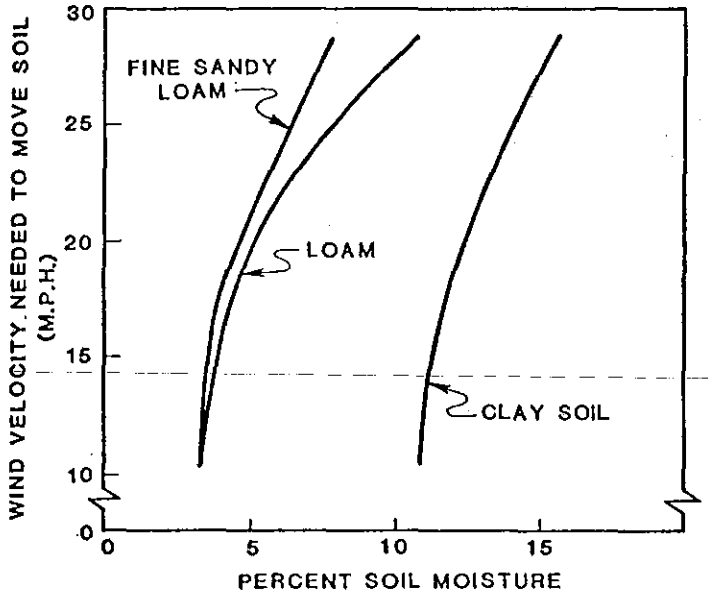

Figure 8-12. Effect of soil moisture and texture on the wind velocity required to move soils. (Source: Bisal, F., and J. Hsiek. "Influence of Moisture on Erodibility of Soil by Wind." Soil Science, Vol. 102, 1966, p. 143).

agents is quite apparent. In the western states particularly, where high lime ash is produced from the burning of subbituminous coal or lignite, little wind erosion may occur provided the self-hardening, pozzolanic reaction is rapidly developed and a stable crust is formed.

Two major types of wind erosion control measures are used. The first type retards surface wind velocities while the second type affects the soil characteristics. Wind breakers, shelterbelts, and contour strips are effective in controlling wind erosion by reducing the wind velocity and its competence to erode the surface. These measures effectively control erosion up to a distance of 10 times the height of the barrier. Even roughening the surface or plowing in stubble mulch, perpendicular to the prevailing wind direction, may be effective in significantly reducing surface wind velocities while trapping moving particles. In arid regions,

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Table 8-6
(Continued)

CHARACTERISTICS OF COMMONLY USED LEGUMES FOR REVEGETATION PURPOSES

Common Name	Scientific Name	Season			Site Suitability				Growth Habit[b]	pH range[c]	Use Suitability			Remarks
		Cool	Warm	Dry	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained			Erodible Areas	Waterways and Channels	Agriculture[d]	
Sweetclover, white	Melilotus alba	X		X	X	X			B	6.0-8.0	X		X	Requires high pH spoil. Tall growing. Produces higher yields. Less reliable seed production.
Sweetclover, yellow	Melilotus officinalis	X		X	X	X			B	6.0-8.0	X		X	Requires high pH spoil. Tall growing. Can be established better than white sweetclover in dry conditions.
Trefoil, birdsfoot	Lotus corniculatus	X		X	X	X	X		P	5.0-7.5	X		X	Survives at low pH. Inoculate with special bacteria. Plant with a grass.
Vetch, crown	Coronilla varia	X		X	X	X			P	5.5-7.5	X		X	Excellent for erosion control. Drought tolerant. Winter hardy
Vetch, hairy	Vicia villora	X		X	X	X			A	5.0-7.5	X		X	Adapted to light sandy soils as well as heavier ones. Used most often as a winter cover crop.

[a] Legumes should be inoculated. Use four times normal rate when hydroseeding.

[b] A = annual; B = biennial; P = perennial.

[c] Many species survive and grow at lower pH; however, optimum growth occurs within these ranges.

[d] Hay, pasture, green manure.

Note: Prepared in cooperation with the Soil Conservation Service plant material specialists and State conservationists.

Source: Same as Table 8-5.

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VEGETATION ESTABLISHMENT PROCEDURES

Disturbed land surfaces should be revegetated as quickly as possible to avoid serious erosion and sediment loss from the disposal area. Embankments and dikes at wet disposal sites should be revegetated soon after construction while unused portions of dry ash sites should be graded and revegetated immediately upon retirement from use. Grasses, legumes, trees and shrubs can be planted on most sites with adequate cover soil, but their growth may be hindered by extremes in pH, lack of available plant nutrients, toxicities, improper selection of adapted varieties and poor drainage. A wide variety of plant species can be used if their specific growth requirements are met (16). Recognizing that establishment procedures vary with climatic and soil conditions, it is the intent here to present common establishment practices in general use in the Eastern United States with examples of specific regional recommendations (17) available from local Agricultural Extension Services.

Plant Selection

Each plant species has its own growth characteristics that determine its value in stabilizing soil. Grasses and legumes are the most effective plant materials for controlling erosion in early stages of reclamation. Trees and shrubs are not effective in controlling erosion in the early stages of their development, but later on as grasses and legumes die off, the trees and shrubs form a protective canopy and organic leaf litter for controlling runoff.

Grass provides a quick, dense ground cover with a high degree of adaptability. Species are available for different exposure conditions, and for planting during the spring, summer and fall. Some species are highly tolerant of wetness while others do well on dry, droughty soils. The ability of many grasses to spread by surface and underground runners (stolons and rhizomes) is an important consideration. Given time, these grasses are able to heal minor breaches in the ground cover resulting from erosion.

Legumes are commonly used in combination with various grasses. They are important because of their ability to take nitrogen from the air and store it in their roots and make it available to other grasses requiring nitrogen. Before planting, the seeds are treated with the proper inoculant to insure the presence of nitrogen-fixing bacteria needed to carry out fixation. Tables 8-7, 8-8, and 8-9 give the species and varieties of grasses and legumes recommended for erosion control and conservation planting in the northeastern states. Suggested rates of application

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Table 8-7

SPECIES AND VARIETIES FOR EROSION CONTROL AND CONSERVATION PLANTINGS

Species	Forms Sod	Soil Drainage Tolerance		Tolerates Low Fertility	pH Tolerance		Shade Tolerant	Minimum Seed Specifications				Preferred Varieties
		Droughty	Wet		Very Acid Below 5.5	Moderately Acid 5.5 to 6.0		Purity (%)	Ready Germ (%)	Hard Seed (%)	Total Germ	
Deertongue grass**	no	yes	yes	yes	yes	yes	no	95	75		75	Tioga
Kentucky bluegrass	yes	no	no	no	no	yes	no	85	75		75	
Red fescue	yes	yes	no	yes	yes	yes	yes	95	80		80	
Tall fescue	no	yes	yes	yes	no	yes	yes	95	80		80	Ky 31
Reed canarygrass	yes	yes	yes	yes	no	yes	yes	95	75		75	
Redtop	yes	yes	yes	yes	yes	yes	no	95	80		80	
Annual Ryegrass	no	no	no	no	no	yes	no	95	85		80	
Perennial rye-grass	no	no	no	no	no	yes	no	95	85		85	Pennfine or Manhattan
Crownvetch †	yes	yes	no	yes	no	yes	no	98	35	35	70	Penngift
Birdsfoot tre-foil* †	no	no	yes	yes	yes	yes	no	98	50	25	75	Empire & Viking or Maitland
Flatpea** †	yes	yes	no	yes	no	yes	yes	98	55	20	75	Lathco
Winter Wheat	no	no	no	no	no	yes	no	98	85		85	
Winter Rye	no	no	no	yes	no	yes	no	98	85		85	
Spring Oats	no	no	no	no	no	yes	no	98	85		85	
Sudangrass	no	yes	no	no	no	yes	no	98	85	85	85	

† Needs specific legume inoculation. Inoculant suitable for garden peas and sweetpeas is satisfactory for flatpea.

* A 50-50 mixture of Empire variety and either Viking or Maitland varieties or European common seed is recommended. Birdsfoot trefoil is adapted over the entire state except in the extreme southeast where crown and root rots may injure stands.

**Seed limited; do not specify in large amounts.

Source: College of Agriculture Extension Service. 1979 Agronomy Guide. University Park, Pennsylvania: Pennsylvania State University, 1979.

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Table 8-8

SEED MIXTURES FOR PERMANENT COVER FOR CONSERVATION PLANTINGS IN THE NORTHEAST

Mixture Number*	Species	Seeding Rate (lb/acre)	Seeding Rate kg/ha
1**	Tall fescue, or	35	39
	Red fescue, or	35	39
	Kentucky bluegrass,	25	28
	plus Redtop, or	5	6
	Perennial ryegrass	15	17
2	Birdsfoot trefoil, plus	10	11
	Tall fescue, plus	30	34
	Redtop	5	6
3	Birdsfoot trefoil, plus	10	11
	Reed canarygrass, plus	25	28
	Redtop	5	6
4	Crownvetch, plus	10	11
	Tall fescue, or	20	22
	annual ryegrass	20	22
5	Birdsfoot trefoil, plus	4	5
	Crownvetch, plus	6	7
	Tall fescue	20	22
6	Flatpea, plus	40	45
	Tall fescue, or	20	22
	annual ryegrass	20	22
7**	Tall fescue, plus	40	45
	Red fescue	10	11
8	Deertongue grass, plus	8	9
	Birdsfoot trefoil	6	7
9	Deertongue grass	15	17

* Mixture numbers are used in Table 8-9.

**These mixtures suitable for frequent mowing. Do not cut shorter than 3 inches.

Source: Same as Table 8-7.

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Table 8-9

MIXTURES FOR VARIOUS NORTHEASTERN SITES

Grass and legume-grass mixtures suitable for erosion control and stabilization of various conservation structures are recommended below. Use Tables 8-6 and 8-7 to select constituents of a seed mixture. Use only seed high in germination. Variable drainage refers to areas where well-drained soils and poorly-drained soils are intermingled.

Type of Area	Seed mixture*
Slopes and Banks (non-mowed)	
(a) Well-drained	4 or 6
(b) Variable drainage	2 or 5
Gullies and Eroded Areas	2, 4 or 5
Conservation Structures	
(a) Sod waterways, spillways, and other frequent water flow areas	1, 2 or 3
(b) Drainage ditches	
(1) shallow, less than 3 feet deep	1 or 2
(2) deep, non-mowed	4 or 5
(c) Pond banks, dikes, levees, dams, diversion channels, and occasional water flow areas	
(1) mowed areas	1 or 2
(2) non-mowed areas	4 or 5
(3) for hay or silage on diversion channels and occasional water flow areas	use adapted hay mixtures
Highways	
(a) Non-mowed areas	
(1) well-drained	4, 5, 6, or 7
(2) variable drainage	2 or 5
(b) Areas mowed several times per year	1 or 7
Utility Right of Way	
(a) Well-drained	4 or 6
(b) Variable drainage	2 or 5
Effluent Disposal Areas	2 or 3
Sanitary Landfill Areas	2, 4, 5, 8, or 9
Strip Mine Spoil Banks, Mine Wastes, Fly Ash, Slag, Settling-Basin Residues, and Other Severely Disturbed Areas	
(a) pH initially below 5.0 (lime according to soil test)	2, 5, 8 or 9
(b) pH initially above 5.0 (lime according to soil test)	2, 4, 5 or 6

*See Table 8-8.

Source: Same as Table 8-7.

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and mixtures for various erosion control purposes are also indicated. For areas outside the northeastern United States, the U.S. Soil Conservation Service (SCS) and the county agricultural extension agency should be contacted for species and varieties of grasses best suited for erosion control and conservation planting.

Spreading of Cover Soil

After the ash has been graded to its final form, the final cover should be placed. Most blade type machinery may be used to spread the final soil cover. The major concern in this step of site revegetion is to monitor the degree of densification that occurs within the soil cover during placement. For proper plant establishment and growth, a dry bulk density of the soil cover falling in the range of 1.2 to 1.6 g/cm^3 (75 to 100 pcf) is recommended. Bulk densities higher than this range may result in poor root permeability and low soil oxygen content. If the ash surface is crusted, it should be roughened before the cover is applied to insure that a sound bond can be formed. If an impervious layer is spread over the ash, it should be densified as much as possible to insure minimum permeability. Final covers should be spread and allowed to air dry before compaction. Spreading soil at higher moisture contents over a site and allowing machinery to travel on it could result in the formation of a crust upon drying that would make plant growth difficult.

Preparation for Seeding

The goal in establishing cover is to apply soil amendments and plant the seed in as few steps as possible. Surface soil crusting resulting from delays in seeding can result in poor seed germination and loss of seed due to wind action and surface runoff. Immediately after placement of the final cover, fertilizer and lime, or its equivalent in fly ash, should be added at application rates determined from soil tests on representatives samples of the cover material. Seedbed preparation is accomplished by disk harrowing the surface to a depth of six to eight inches. This operation serves to mix the amendments into the cover soil. Herbicides can be used to control competing vegetation, but should also be compatible with the vegetation that is to be used.

Seeding

Once the seed-bed is harrowed, seeds may be planted by a number of methods. Some of these are:

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- Broadcast - The seed is dispersed by means of a fly wheel mechanism as seed falls from a container. Uniform distribution is difficult on sloping areas or areas difficult to negotiate with planting equipment.

- Seed Drill - Seed placement (distribution and depth) is nearly guaranteed. Probably the preferred method for establishing herbaceous vegetation. Cannot be used on slopes greater than 3 horizontal to 1 vertical.

- Hydro-Seeding - Most common method (not necessarily preferred) for seeding disturbed areas. Application of seed and possibly fertilizer and mulch is made by spraying a slurried mixture over the surface. Can be used on steeper slopes than drilling or broadcasting.

- Aerial Seeding - Basically a broadcast method from the air. Can cover large areas in a short period of time. No guarantee of distribution. A lot of establishment problems may arise (largely because of uncertain distribution). Probably not the first choice for seed application.

It is important to obtain a uniform distribution of seed. Open or sparsely seeded areas could induce erosion that would eventually expand into vegetated areas. In the northeastern U.S., fall legume seedings need a growing period of at least 10 weeks to produce a seedling large enough and hardy enough to survive the winter. Grasses generally require at least 4-5 weeks of growth prior to hard frost. After these dates it is preferable to seed the grass alone (Table 8-10) and seed the legumes as a dormant hard coated seed in the fall or frost seed in late winter when the ground thaws during the day. For quicker growth on critical slopes or other problem areas, crownvetch and flatpea have received widespread use. On bare areas, annual ryegrass seed should be applied to provide a temporary cover until the crownvetch plants are established.

Mulching

Mulching is required to protect the newly seeded area from soil erosion during and immediately following the germination period. In addition, mulching provides a better environment for germination and plant development by ensuring soil moisture, moderating soil temperature, and providing soil nutrients. Mulching materials include hay, straw, wood chips, and some artificial materials (Table 8-11). Some materials, especially straw and hay, require stabilization to prevent them from being uncovered by wind and water. This is accomplished by applying chemical tacks that bind the mulch material together and to the soil surface. Hay and straw may also be "crimped" into the surface to secure their position. When performed along the ground contour, crimping produces a surface texture that inhibits surface

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Table 8-10

TEMPORARY COVER FOR EROSION CONTROL ON CONSTRUCTION SITES AND OTHER SEDIMENT-PRODUCING AREAS IN THE NORTHEAST

MULCHING

Mulches alone will help protect areas from erosion. Mulches also provide initial protection if area is to be seeded later. Seed may be hydroseeded on top of the mulch. Use hay or straw at a rate of 2.5 tons per acre (5.6 metric ton per hectare). For other suitable mulching materials, contact your PENNDOT District Roadside Specialist.

SITE PREPARATION

Apply 1 ton (2.2 metric tons per hectare) agricultural-grade limestone plus fertilizer at the rate of 40-40-40 pounds of N-P_2O_5-K_2O per acre (45-45-45 kg/ha) and work in where possible. Secure a soil-test before making a permanent seeding. After seeding, mulch with hay or straw at a rate of 2.5 tons per acre (5.6 metric tons per hectare).

SEED MIXTURES	lb/acre	kg/ha
For Spring Seeding: (up to June 30)		
(a) Annual ryegrass, or	40	45
(b) Spring oats, or	96 (3 bu)	108
(c) Spring oats plus annual ryegrass	96 oats + 26 ryegrass	108 + 29
For Late Spring and Summer Seeding: (May 15 to August 15)		
(a) Sudangrass, or	40	45
(b) Annual ryegrass		
For Late Summer and Fall Seedings: (August 15 on)		
(a) Annual ryegrass, or	40	45
(b) Winter rye, or	168 (3 bu)	188
(c) Winter wheat	180 (3 bu)	202

Source: Same as Table 8-7.

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Table 8-11

EROSION CONTROL MATERIALS

Material	Temporary Soil Stabilization	Mulch	Mulch Tack	Application Method	Application Rate	Remarks
Bagasse	X	X		Straw mulcher	1-2 tons/ac (2.2-4.5 metric tons/ha)	Waste product from sugar cane industry.
Bark	X	X		Modified straw mulcher	25-30 yd^3/ac (47-56 m^3/ha)	Waste product from lumber industry. Can cause nitrogen deficiency if mixed into seed bed.
Wood Chips	X	X		Modified straw mulcher	30 yd^3/ac (56 m^3/ha)	Can cause nitrogen deficiency if mixed into seed bed.
Excelsoir	X	X		Blank or loose		Secure blanket with staples or stakes. Tack material can be used to stabilize loose excelsior.
Manure	X	X		Spreader	8-10 tons/ac (18-22 metric tons/ha)	Has nutrient value as well as mulching ability.
Paper	X	X		Hydroseeder (slurry)	1,500 lb/ac (1.7 metric tons/ha)	Not as long lasting as straw tacked with asphalt or wood fiber.
Sawdust		X		Spread/mix	275-810 yd^3/ac (520-1530 m^3/ha)	Can be used as mulch or soil amendment. Should be mixed 2 to 6 inches into soil. Subject to wind and water erosion. Requires additional nitrogen addition.
Straw/Hay	X	X		Straw mulcher	2 tons/ac (4.5 metric tons/ha)	Most commonly used mulch. Should be crimped into soil, or held in place with asphalt tack or netting.
Wood Fiber	X	X		Hydroseeder	1,000 to 1,500 lb/ac (1.1-1.7 metric tons/ha)	Best utilized on steep slopes. Can be applied along with seed, lime and fertilizer.
Fiber Glass	X			Hand place mat, spray loose strands	Mat or loose strands	Erosion resistant when held by staples. Loose strands can help reinforce rootmat.
Gravel, Bottom Ash	X			Front end loader, dozer	3 to 6 in. depth (8 to 15 cm)	Provides good erosion protection. Can be used in combination with vegetation.
Netting	X	X		Hand place		Can be jute, fiber glass, plastic, or paper yarn. Can be used to hold straw, hay, or wood chips. Should be stapled to ground.
Chemical Binders	X	X	X	Hydroseeder or nonair entraining equipment	Varies	Wide varieties of materials available. Can be applied with seed, fertilizer, and mulch as a binder, or applied as a tack.

Source: Same as Table 8-6.

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runoff. Between 1 and 2.5 tons (2.2 and 5.6 metric tons per hectare) of mulch should be applied per acre.

POST-CLOSURE MAINTENANCE

The degree of post-closure maintenance required at ash disposal sites is largely dependent upon the post-closure land-use of the site, method of ash placement, and federal or state regulations. The basic purpose of post-closure maintenance is to preserve the integrity of the site and prevent exposure or escape of disposed ash. Possible post-closure maintenance items include:

- cover and vegetation,
- access and haul roads,
- earth embankments,
- erosion and sediment control structures.

Cover and Vegetation

The primary purpose of soil cover and vegetation is to aid in the control of erosion of underlying ash deposits. Depending upon plant species selected and soil conditions, periodic refertilization may be required to keep vegetation healthy. In addition, impact on vegetation and soil cover from post-closure site uses should be closely monitored and controlled in order to prevent the unwanted loss of erosion protection. For example, the uncontrolled use of a closed site by off-road vehicles, such as motorcycles, can lead to loss of vegetative and soil cover, thus leading to extensive maintenance. Conversely, land intensive uses, such as a agriculture, which are properly operated can decrease maintenance requirements and increase site usefulness.

Access and Haul Roads

After closure, roads used for access and hauling may require maintenance to prevent erosion and subsequent transport of sediment from the site. There are two common ways of controlling the potential erosion of abandoned roadway: providing a wearing surface such as gravel or asphalt, or establishing a vegetative cover. In the case where an ash site is being developed it may be expeditent to upgrade access roads by covering them with a wearing surface. If a site is to be designated as a wildlife habitat, the establishment of vegetation and blocking of roadways to prohibit uncontrolled vehicle traffic would probably be the preferred way of minimizing erosion and additional future maintenance.

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Earth Embankments

Earth embankments constructed for wet disposal sites or sedimentation ponds require post-closure maintenance and inspection in order to ensure their continuing integrity. Maintenance requirements are dependent upon a number of factors including site use, surrounding land use, and climate. In some cases it may be possible to dismantle or breach an embankment. An example of this might be the dismantling of a sedimentation pond embankment when the site effluent is capable of meeting federal or state standards without treatment. Embankment maintenance commonly includes maintenance of vegetation, protective coverings such as riprap, and overflow structures.

Erosion and Sediment Control Structures

Erosion and sediment control structures, including interceptor ditches, diversion ditches, and sedimentation ponds, require maintenance after site closure to ensure proper operation. In addition to maintaining the structural integrity of these structures, accumulated sediment should be removed in order to ensure the functioning of these structures at design levels. Removed sediment should be handled and disposed of in a manner that will prevent immediate return into runoff diversion and collection systems. Essentially this entails the use of erosion and sediment control techniques discussed previously in this section.

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Section 9

ECONOMIC ANALYSIS

INTRODUCTION

This section presents a method for making an economic comparison of alternative coal ash disposal systems developed for new power stations. The approach presented is based on EPRI recommended procedures for comparison of alternative investments by investor-owned, regulated utilities (1, 2). Additional assumptions concerning the relationship of certain capital and operating costs are based on TVA experience (3, 4, 5, 6, 7). The total cost obtained using these economic premises may not be applicable to a specific facility, but the use of the methods presented should provide a valid economic comparison of disposal system alternatives. The basic assumptions presented can be modified when required. A methodology for preparing site specific estimates is presented.

A computer program, ASHDAL, was developed to generate cost estimates for several coal ash disposal systems operating in varying topographies, operating under alternative strategies, operating at various distances from the power station, and handling ash quantities ranging from approximately 200,000 to 1,700,000 dry tons per year (8). Results from the computer program, the revenue requirement expressed as levelized dollars per dry ton of ash disposed, are included.

A basic cost estimating procedure for coal ash disposal systems for new investor-owned utilities is described. The cost analysis procedure presented is not applicable for existing plants. Such information may be found in EPRI Manual RP 1685-2, Upgrading of Existing Disposal Facilities. Flue Gas Desulfurization (FGD) wastes are also not considered in cost estimates found in this section. Disposal costs for those wastes have been described in EPRI Manual CS-1515, FGD Sludge Disposal Manual.

ECONOMIC ANALYSIS

There are four basic categories of ownership of electric utilities. These categories are investor-owned companies, Federal agencies, Public Power Districts, and Cooperatives. The type of ownership affects the types of expenses and investment

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rates for a utility. Each category of utility ownership has a different cost of capital.

Costs for the alternative disposal schemes were divided into three categroies: capital, replacement, and operation and maintenance (O&M) costs. For the example given later in this section it was assumed that the major facilities such as the ash disposal pond embankment, dry ash disposal site development, etc., would be completed in 1980 and become part of the capital cost of the facility. This cost would include the in-plant handling system, the out-of-plant transport system, and the disposal area. Replacement of capital items was handled separately, as a replacement cost. Operation and maintenance items of the in-plant handling system were assumed to be those items necessary to maintain the system. Transport operation and maintenance included the cost to where the coal ash is dumped or placed into the disposal area. Maintenance and operaton costs of the disposal area included spreading, compaction, ash redistribution, and regrading of the site.

The economic analysis of the disposal system cost was performed using EPRI's levelized revenue requirement method (1). This approach utilized a weighted cost of capital which combines the inflation rate with the cost of capital. The weighted cost of capital represents the impact of the cost of capital to the utility. The following equation was utilized in the determination of the weighted cost of capital:

$$(1 + r) = (1 + x)\ (1 + i)$$

or

$$r = [(1 + x)\ (1 + i)] - 1 \qquad (1)$$

where:

r = discount rate (weighted cost of capital in the presence of inflation)

x = cost of capital in the absence of inflation

i = inflation rate

The assumptions and methodology presented are based on the economics applicable to investor-owned utilities regulated by a Public Utility Commission (PUC).

Alternative disposal schemes and sites were compared on the basis of the present worth of the levelized revenue required annually by each disposal scheme during the time period covered by the analysis. These revenue requirements include fixed costs due to the investment of capital in the facility and operating costs such as

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labor, materials, and maintenance.

The annual fixed capital cost for a disposal system, referred to as the Levelized Capital Requirement (LCR), is an amortization of the capital investment in the system. This capital investment is called the Total Capital Requirement (TCR).

Since the operating costs for a disposal system will generally be different during each year in the time period covered by the analysis, it is necessary for comparison to express the varying operating costs as a uniform payment which would have to be paid annually during the lifetime of the facility. This constant annual payment is referred to as the Levelized Operating Cost (LOC).

The total Levelized Annual Revenue Requirement (LARR) is defined as the sum of the Levelized Capital Requirement (LCR) and the Levelized Operating Cost (LOC).

LARR = LCR + LOC

Since operating costs are subject to general inflation as well as escalation relative to inflation, these effects should be considered when determining the Levelizing Factor for operating costs. This Levelizing Factor is applied to the First Year Operating Costs (FYOC) to compute the Levelized Operating Costs. Operating costs, which are expected to be incurred in an uneven pattern over the life of the facility, i.e. replacement costs, should be levelized for their expected pattern. The Total Capital Requirement (TCR) is not subject to escalation relative to inflation, since capital costs are estimated at a specific point in time. The Levelized Capital Requirement is affected by inflation's effect on the weighted cost of capital. The effect of inflation is included in the Fixed Charge Rate. This Fixed Charge Rate is used to spread the Total Capital Requirement over the facility life.

Assumptions

Section V of the EPRI Technical Assessment Guide (1) provides a detailed description of how to calculate the Levelized Annual Revenue Requirement. Formulas for calculating the Levelizing Factor for operating costs and the Fixed Charge Rate are given along with values for several combinations of the parameters. Also illustrated are calculations necessary to levelize and sum these costs to obtain the Levelized Annual Revenue Requirement (LARR). In a Present Worth Analysis, LARR represents an Equal Payment series of the capital and operating costs.

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The Fixed Charge Rate is applied to the Total Capital Requirement to determine the Levelized Capital Requirement. The Levelizing Factors were computed assuming that there is no real escalation of operating and maintenance costs relative to inflation.* This factor is applied to the estimated First Year Operating Costs to determine the Levelized Operating Costs. The Present Worth Factors should be applied to future costs which are expressed in 1980 (Commercial Operation Date) dollars.

Prior to starting an economic analysis for coal ash disposal systems, the following publications should obtained and read:

- Technical Assessment Guide (EPRI PS-1201-SR) (1).
- Economic Premises for Electric Power Generating Plants (EPRI) (2).
- ASHDAL (EPRI RP 1260-24) (8).

COST ESTIMATES

In the EPRI publication, Economic Premises for Electric Power Generating Plants (2), four classes of estimating costs for power plants are detailed. These classes are:

- Class I - Simplified,
- Class II - Preliminary,
- Class III - Detailed,
- Class IV - Finalized.

Table 9-1 lists the classes, detailing the requirements for each class. The following sections describe the cost estimating procedure for the four classes.

CLASS I - SIMPLIFIED DESIGN COST ESTIMATES

During the site selection and conceptual design stages for an ash disposal system, it is often desirable to make simplified cost estimates (Class I as described in Table 9-1) for each of the alternatives being considered.

The economic analysis procedure for a Class I estimate is as described in the EPRI

*Although the annual maintenance costs might be expected to increase as the facility ages, this increase is assumed to be offset by the normal decrease in the operating capacity factor as the power plant ages.

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Table 9-1

DESIGN AND COST ESTIMATE CLASSIFICATIONS

Item	Design/ Estimate Description	Project Contingency Range	Design Information Required	Cost Estimate Basis		
				Major Equipment	Other Materials	Labor
Class I	Simplified	20% to 30%	General site conditions, geographic location and plant layout. Process flow/operation block diagram. Product Output capacities.	By overall project or section-by-section based on capacity/ cost graphs, ratio methods, and comparison with similar work completed by the contractor, with material adjusted to current cost indices and labor adjusted to site conditions.		
Class II	Preliminary	15% to 20%	As for Type Class I plus engineering specifics, e.g.: Major equipment specifications. Preliminary P&I flow diagrams.	Recent purchase costs (including freight) adjusted to current cost index.	By ratio to major equipment costs on plant parameters.	Labor/material ratios for similar work, site conditions and using expected average labor rates.
Class III	Detailed	10% to 15%	Complete process design. Engineering design usually 20% to 40% complete. Project construction schedule. Contractual conditions and local labor conditions.	Firm quotations adjusted for possible price escalation with some critical items committed. Pertinent taxes and freight included.	Firm unit cost quotes (or current billing costs) based on detailed quantity take-off.	Estimated man-hour units (including assessment) using expected labor rate for each job classification.
Class IV	Finalized	5% to 10%	As for Class III - with engineering essentially complete.	As for Class III - with most items committed.	As for Class III - with material on approximately 100% firm basis.	As for Class III - some actual field labor productivity may be available.

Source: Economic Premises for Electric Power Generating Plants. Palo Alto, Calif.: Electric Power Research Institute, July 26, 1978.

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Technical Assessment Guide (1). As the design process proceeds, detailed, site-specific, cost estimates (Class II, III or IV) will be required. A computer program, ASHDAL, was developed during the course of this project. ASHDAL outputs a Class I-Simplified Design cost estimate for a variety of disposal alternatives.

Estimates were prepared for specific cases and were used as numerical data for the computer program. The plant location and fuel characteristics are consistent with EPRI recommendations, given in Power Plant Design Premises (9). Much of the additional information has been adapted from detailed estimates for FGD sludge disposal prepared by TVA (3, 4, 5, 6) and EPRI (10). Additional cost and production invormation was obtained from References (11) through (20).

CLASS II, III and IV COST ESTIMATES

The preparation of Class II, III, and IV cost estimates is necessary to properly evaluate the several disposal alternatives which, on the basis of simplified cost estimates and the various other non-economic considerations discussed in Section 1, are selected from those initially considered. A detailed, cost comparison may be necessary for several alternate disposal systems (e.g., pipeline to a pond vs. trucking to a landfill) or for particular aspects of a particular system (e.g., landfill compaction vs. no compaction).

Table 9-1 defines the level of design and estimating effort required for Class II, III, and IV cost estimates. The basic steps necessary to make such estimates for a disposal alternative are:

Step 1: Establish design assumptions

Step 2: Establish the disposal system

Step 3: Determine the Total Capital Requirement

Step 4: Determine the First Year Operating Costs

Step 5: Determine the Levelized Annual Revenue Requirement

Step 1. Establish Design Assumptions

The basic design assumptions, both economic and technical, must be established before a detailed cost estimate can be prepared for any system. For investor-owned, regulated utilities the economic premises discussed previously are appropriate. In addition, the EPRI References Economic Premises for Electric Power Generating Plants (2) and Power Plant Design Premises (9) provide guidance for design and economic assumptions. All technical design assumptions, discussed in detail in other Sections of this manual, should also be stated at the outset.

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These assumptions include:

- The anticipated operating life of the disposal system. Sufficient disposal volume is usually included to account for the total life of the power plant.
- The annual coal ash disposal requirement. This value depends upon many factors which include the power plant size, the capacity factor, the percent ash in the coal, the efficiency of the collection system, and the amount sold or otherwise consumed (see Section 5).
- The method of ash collection and handling. The collection and handling system must be known to insure a compatible disposal alternative.

Step 2. Establish the Disposal System

Table 9-1 outlines the design information required and the cost estimating basis for Class II, III, and IV designs. For example, to prepare a Class III Detailed Cost Estimate, the process design should be essentially complete, and 20 to 40 percent of the engineering design finished. A detailed flow diagram and equipment list with descriptions should be developed and firm price quotations obtained for all major equipment items. Unit prices for other materials should be based on a detailed quantity take-off. The construction schedule should be considered when estimating labor costs as well as local labor conditions.

Step 3. Determine the Total Capital Requirement

The components of the Total Capital Requirement include capital and replacement costs and are described later in this section. The Detailed Cost Estimate should be prepared in this standard format, an outline of which is given in Table 9-2.

Step 4. Determine the First Year Operating Costs

The operating costs should be estimated for the first year of the disposal system operation for use in developing a Levelized Annual Revenue Requirement. The items included as operating costs will be discussed in detail later in this section. The format given in Table 9-2 should be used for presenting these costs.

Step 5. Determine the Levelized Annual Revenue Requirement

The Levelized Annual Revenue Requirement (LARR) is the sume of the Levelized Capital Requirement (LCR) and the Levelized Operating Costs (LOC). The LCR is determined by multiplying the Total Capital Requirement (TCR) by the appropriate Fixed Charge Rate (FCR), while the LOC is determined by multiplying the First

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Table 9-2

FORMAT FOR COMPUTING TOTAL CAPITAL REQUIREMENT, FIRST YEAR OPERATING COST, AND LEVELIZED ANNUAL REVENUE REQUIREMENT SUMMARIES(2)

Item	Cost	
Plant Investment		
Process Capital*	A	
General Facilities Capital	B	
Engineering and Home Office Fees	C	
Project Contingency	D	
Process Contingency	E	
Sales Tax**	F	
Total Plant Investment		TPI
Royalty Allowance		G
Preproduction Costs		H
Inventory Capital		I
Initial Catalyst and Chemicals		J
Allowance for Funds During Construction		K
Land Acquisition		X
TOTAL CAPITAL REQUIREMENT		TCR
Fixed Operating and Maintenance		
Operating Labor	L	
Maintenance Labor	M	
Maintenance Materials	N	
Administrative and Support Labor	P	
Total Fixed O&M Cost		FOM
Variable Operating and Maintenance		
Consumables	S	
Variable Maintenance	U	
Total Variable O&M Cost		VOM
Byproduct Credit		V
TOTAL FIRST YEAR OPERATING COST		FYOC

30-Year Levelized Costs

Levelized Operating Cost	LOC = LF x FYOC
Levelized Capital Requirement	LCR = FCR x TCR
Levelized Annual Revenue Requirement	LARR = LOC + LCR
	FCR = Fixed Change Rate
	LF = Levelizing Factor

*A detailed breakdown of the Process Capital should be performed.
**Sales tax should be included as a separate item unless included in the line items.

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Year Operating Costs (FYOC) by a Levelization Factor (LF). Table 9-2 illustrates the relationships among these costs.

By adding these two levelized annual costs, the Levelized Annual Revenue Requirement is established. Although the LARR is an annual cost ($/year), it is often informative to express the cost as mills/kWh or as dollars/dry-ton of coal ash. These unit revenue requirements are determined by dividing the LARR by the annual production (kWh and dry tons of ash, respectively). Naturally, the former must be multiplied by 1000 mills/$ to obtain the correct units.

To help in estimating the components for Class II, III, and IV costs estimates listed in Table 9-2, the following outline is provided.

Total Capital Requirement

The Total Capital Requirement (TCR) for the disposal systems of a regulated utility includes all capital necessary to complete the entire facility. These items include: a) Total Plant Investment; b) Royalty Allowance; c) Preproduction Costs; d) Inventory Capital; e) Initial Catalyst and Chemicals; f) Allowance for Funds During Construction; and g) Land Acquisition.

Total Plant Investment. The Total Plant Investment (TPI) is comprised of five parts: Process Capital, General Facilities Capital, Engineering and Home Office Fees, Project Contingency, and Process Contingency. These items and their components are discussed below.

Process Capital. Process capital is the direct cost of all facilities required for the disposal system. Included under this item are the capital costs of in-plant ash handling system, transport equipment, transport pipelines, electrical equipment, excavation and site preparation. Major items in this category include the landfill development cost for dry disposal or the pond construction cost for wet disposal. However, since the landfill development costs are generally incurred during the life of the site, only that portion which must be expended prior to the commercial operation date of the facility should be charged as a capital cost under site preparation. Site reclamation costs for wet and dry disposal are also incurred differently. Pond reclamation cost is incurred primarily at the end of the site's life; therefore, the present worth of that expense can be included as a capital cost. Landfill sites, on the other hand, generally must be reclaimed during the life of the site, and the cost can be included as an operating expense.

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General Facilities Capital. The General Facilities Capital includes the cost of off-site facilities such as roads, buildings, shops, laboratories, parking lots, tools, fences, etc., which are not directly involved in the disposal operation. These costs include both permanent and temporary facilities. Generally, the costs for these facilities range from 5 to 20 percent of the Process Capital Costs (2).

Engineering and Home Office Fees. The engineering fee and the home office overhead and fee are included in these costs. The salaries and expenses for security personnel at the site during construction should be considered a home office fee. These costs range from 10 to 15 percent of the Process Capital (2).

Project Contingency. A capital cost contingency factor should be developed for the disposal system. This factor is intended to cover additional equipment or costs which would result from a more detailed design for an actual site. Table 9-1 presents guidelines for relating the project contingency to the level of design/estimating effort.

Process Contingency. This capital cost contingency is applied to new technology in an effort to quantify the uncertainty in the cost of a commercial-sale operation. Table 9-3 provides guidelines for assigning process contingency allowances.

Royalty Allowance. Any prepaid royalties applicable to the system should be included as a capital cost.

Preproduction Costs. This item is intended to cover personnel training, equipment checkout, major changes which may be required, and inefficient operation during start-up. The costs may be estimated as the sum of 1/2 (one month) of the First Year Operating Cost (FYOC), and 2 percent of the Total Plant Investment (TPI) (2).

Inventory Capital. A one-month supply of consumables is capitalized and included.

Initial Catalyst and Chemicals. The initial cost of any catalyst or chemicals that are contained in the process equipment (but not in storage) is to be included.

Allowance for Funds During Construction. This allowance is necessary to update construction expenditures from the time that construction begins up to the commercial

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Table 9-3

PROCESS CONTINGENCY GUIDELINES (2)

State of Technology Development	% of Installed Cost
New Concept with Limited Data	25% and up
Concept with Bench-Scale Data Available	15-25%
Small Pilot Plant Data (e.g., 1 MW Size) Available	10-15%
A Full-Size Module Has Been Operated (e.g., 20-100 MW)	5-10%
The Process is Used Commercially	0-5%

operation date for the facility. An Allowance for Funds During Construction (AFDC) is computed by estimating the center of gravity (cg) of all capital expenditures and calculating the interest charge for the Total Plant Investment (TPI) from that point in time until the operation date of the facility (2). The AFDC can be calculated as follows:

$$AFDC = [(1 + \text{Annual Interest Rate})^{cg} - 1] \times (TPI)$$

The center of gravity time period (cg) is estimated. Representative centers of gravity for power plants are as follows:

Total Design-Construction Time	Center of Gravity (cg)
5 years	2 years
3 years	1 year
2 years	0.5 year

Land Acquisition. Land costs are highly site dependent. The disposal site, after closure, may even have a value equal to or greater than the acquisition costs if the disposal operation has significantly improved the site, as could be the case in the filling of abandoned mine or quarry areas. Unless a specific use can be anticipated and its value estimated, the land aquisition cost should be treated as a capital cost, with no anticipated return.

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Annual Operating Costs

The operating costs for a disposal facility should be estimated for the first year of operation. This First Year Operating Cost (FYOC) is then levelized using the appropriate Levelizing Factor. This cost should be projected forward to the commercial operation date for the disposal system. The FYOC is the total of all costs which result from operating and maintaining a disposal system. These costs which include Fixed Operating and Maintenance Costs, Variable Operating and Maintenance Costs, and Byproduct Credit are described in general terms below. Guidelines for assigning values to the items are presented later in this section.

Fixed Operating and Maintenance Costs (FOM). These costs for a disposal system include the Fixed Operating Labor, Fixed Maintenance Costs, and Overhead.

Fixed Operating Labor. The operating labor is the product of the estimated number of jobs necessary to operate the disposal system, the estimated average labor rate, and the estimated number of hours that the facility will be operated annually.

Fixed Maintenance Costs. The estimated annual costs for system maintenance must be included in the FOM. Labor and materials should be evaluated and reported separately, if possible, but a 40:60 labor to material ratio may be used if other information is not available (2). Although the amount of equipment maintenance required for each hour of operation generally increases with age, the annual plant operation time generally also decreases to the extent that the total maintenance costs are assumed to be relatively constant over the life of the facility (2). Table 9-4 presents a range of maintenance costs which is considered representative for several processing conditions.

Table 9-4

MAINTENANCE COSTS (2)

Type of Processing Conditions	Maintenance % of Process Capital Cost/Year
Corrosive and Abrasive Slurries	6 - 10 (& higher)
Severe (Solids, High Pressure & Temperature)	4 - 6 (& higher)
Clean (Liquids and Gases Only)	2 - 4
Off-Site Facilities & Steam/ Electrical Systems	1.5

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Overhead. The cost of administrative support labor overhead should be included and may be estimated as 30 percent of the fixed operating and maintenance labor. General and administrative expense should not be included in the cost estimate (2).

Variable Operating and Maintenance Costs (VOM). The VOM is dependent on the amount of ash that is disposed of during the year. The disposal quantity is estimated for the first year of the facility operation and the associated VOM is calculated for that quantity.

Consumables. Costs associated with ash disposal which are included under this item include the power costs for operation, such as electricity for ash sluicing. Also, additional operating costs which are incurred as a function of the quantity of ash disposal. The primary items under this category are operation contracts with private contractors for services such as hauling, placement, compaction, and land reclamation.

Variable Maintenance. A variable component of the maintenance cost should be included if there is a basis for estimating how maintenance costs vary with capacity factor.

Byproduct Credit. The net revenue from the sale of byproducts should be subtracted from the annual operating costs. Since the sale of ash usually involves additional handling and storage expenses, it is important to include only the net revenue (or expense) associated with this use.

30-Year Levelized Costs

The 30-year levelized cost is calculated from the First Year Operating Costs (FYOC) and the Total Capital Requirement (TCR). The FYOC is levelized, as stated earlier, using a Levelization Factor. Similarly, the TCR is levelized over the life of the facility using a Fixed Charge rate. To facilitate the comparison of cost estimates, all estimates should be prepared in the format presented in Table 9-2, which was established by EPRI (2). An example of a 30 year levelized cost calculation is presented in the subsection "Development of Base Case Estimates."

CLASS I BASE CASES COST ESTIMATES

The purpose of the Class I estimates developed in this section is to compare the relative costs of wet and dry methods of ash disposal for five ash disposal

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quantities, ranging from 200,000 to 1,700,000 tons/year. The ash quantities and number of power plant units are as follows:

Ash Quantity (tons/year)	Units
200,000	1
400,000	2
600,000	2
870,000	3
1,700,000	4

Conceptual disposal schemes, shown in Figure 9-1, were developed. These disposal schemes include a number of options within major segments of the disposal process to allow for variable conditions, such as disposal site topography.

ASHDAL Computer Program

A computer program, ASHDAL, was developed to calculate the levelized annual cost of various ash disposal alternatives (8). This program provides an economic analysis of various methods for coal ash disposal. In this program, the coal ash can be disposed by wet or dry disposal systems, can be transported by several means of transportation, and can be compacted or left uncompacted. There are other parameters upon which a decision must be made before the disposal method is completely described. This program evaluates many possible combinations from an economic standpoint, and provides a levelized annual cost for each alternative.

ASHDAL consists of 10 subroutines in addition to the main program. Figure 9-2 is the flow chart for the program, illustrating the program logic. Each subroutine, except for the economic analysis subroutine, utilizes only input data and does not rely on values computed by another subroutine. The economic analysis subroutine sums up the capital costs, first year operation and maintenance cost, and the replacement cost from the other subroutines, and performs an economic analysis on the total.

The following are the data inputs to ASHDAL:

- total ash produced per year,
- type of in-plant handling system,
- type of transport system,
- type of disposal system,

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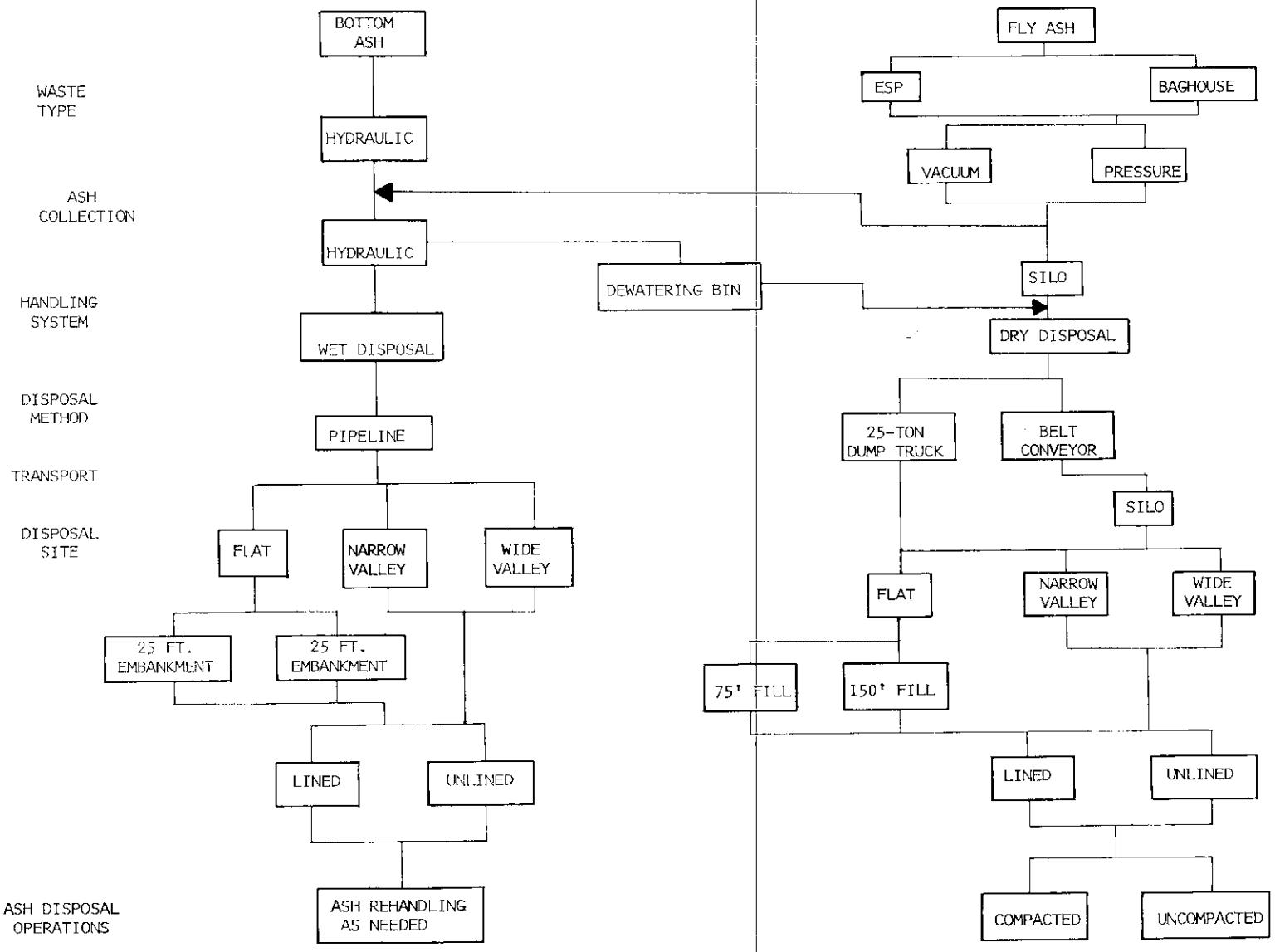

Figure 9-1. Specific Ash Disposal Schemes Considered for Cost Estimating

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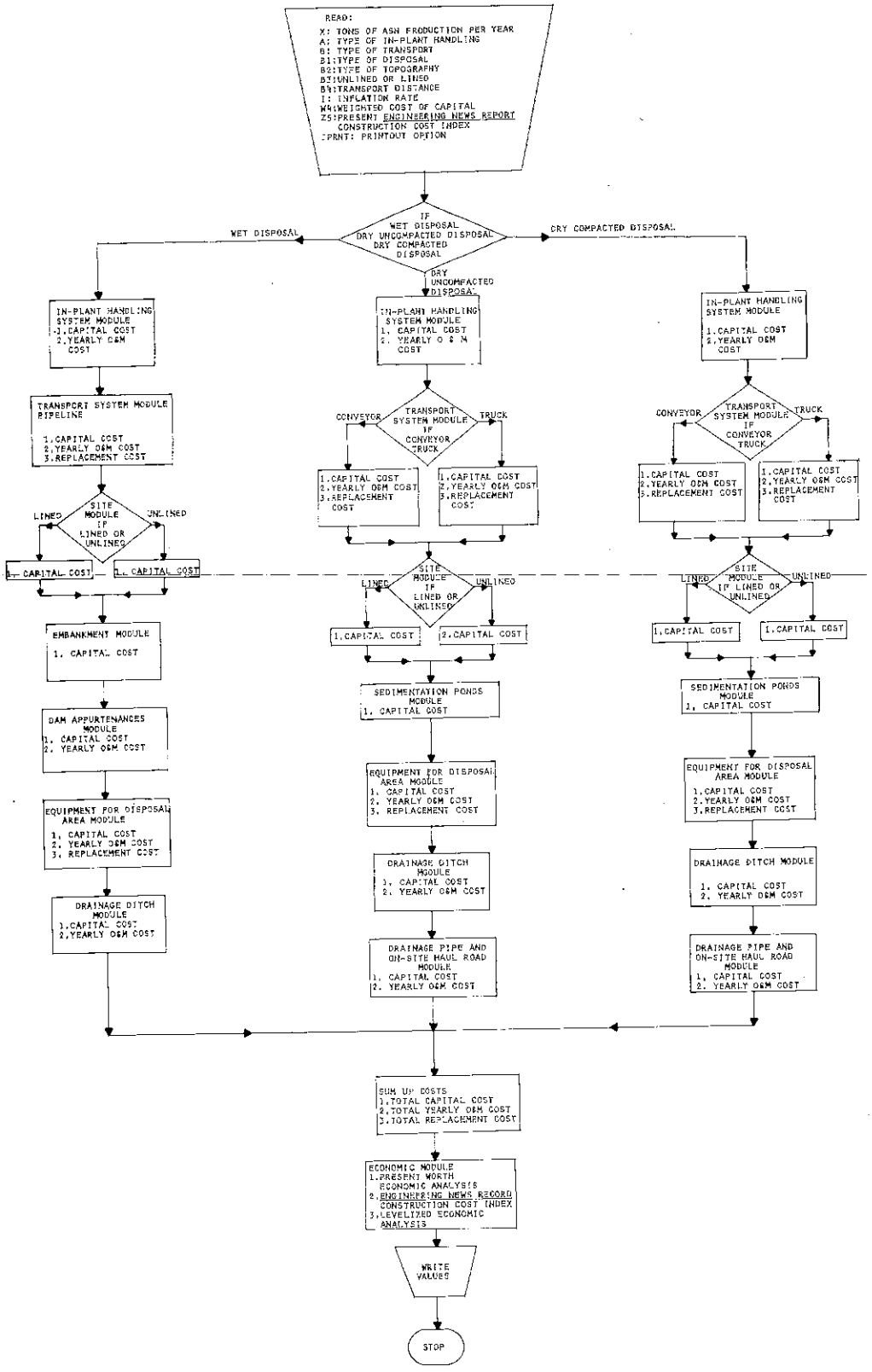

Figure 9-2. Flow Chart for ASHDAL Computer Program

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- type of topography,
- use of site liner,
- transport distance,
- inflation rate,
- weighted cost of capital,
- current Engineering News Record construction cost index.

The output from the program consists of the the various subroutines; capital cost, yearly O&M cost, and replacement cost of the individual modules, if applicable; total capital cost; total yearly O&M cost; total 30 years O&M cost in 1980 dollars; total replacement cost; and total levelized annual revenue requirement. Enough values are presented to follow the development of the total cost throughout the program.

The computer program ASHDAL was written in FORTRAN IV for use on a Digital Equipment Corporation (DEC) 11/40 computer system having 32K words available in memory for programs. The program can be readily adapted to other computer systems.

Base Cases. The primary assumptions which were made specifically for the Class I estimates are described. Table 9-5 describes the bulk densities of bottom ash and fly ash used in the cost estimates. System parameters, such as unit heat input requirement, coal heating value, fly ash:bottom ash ratio, and collection efficiency can be included by calculating their effect on the total coal ash disposal quantity. This value can then be used as an input to ASHDAL (8).

Table 9-5

ASH DENSITIES*

Method of Ash Placement	Bottom Ash (lb/ft^3)	Fly Ash (lb/ft^3)	Composite Density lb/ft^3
Wet (Slurry)	60	40	45
Dry Uncompacted	80	60	65
Dry Compacted	100	80	85

* All densities are expressed as dry bulk densities.

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This section compares the relative costs of wet and dry methods of ash disposal for five coal ash quantities, ranging from 200,000 tons/year to 1,700,000 tons/year. Disposal schemes include a number of options within major segments of the disposal process to allow for variable conditions, such as disposal site topography. Table 9-6 lists the variables tested and the conditions examined.

Table 9-6

VARIABLES TESTED AND RANGE STUDIED IN ECONOMIC ANALYSIS

Parameter	Conditions Examined
Ash Conditon	Wet, Dry
Disposal Method	Flat land, Narrow Valley, Wide Valley
Transporation	Conveyor Belt Transport, Pipeline, Truck
Transport Distance	1, 5, 10, and 25 miles
Inflation Rate	6, 10, and 14 percent
Cost of Capital (absence of inflation)	3, 3.8, and 5 percent

Simplified cost estimates necessarily limit the parameters which can be varied. Therefore, the basic assumptions which have been used to estimate the disposal costs are presented below. If these combinations of parameters are not reasonable for a particular disposal system, adjustments may be made or a more detailed cost estimate, as outlined earlier in this section, may be prepared.

Disposal System. The following system assumptions have been made:

1. Newly-constructed baseload, power plant and disposal system with an estimated life for the disposal site of 30 years from the mid-1980 startup date.

2. Baseload plant with a levelized capacity factor of 48.5 percent with a 70 percent capacity factor for the initial years of operation. Peak in-plant and out-of-plant conveyance capability is provided to handle a 100 percent capacity factor.

3. Power unit heat input requirement is 9000 Btu/kWhr (9500 kJ/kWhr).

4. Coal ash quantities range from 200,000 to 1,700,000 tons/year (181,400 to 1,541,900 metric tons/year).

5. Coal ash is 80 percent fly ash and 20 percent bottom ash.

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6. Fly ash collection efficiency is near 100 percent.

7. Disposal cost estimates include in-plant handling, out-of-plant transportation, and disposal site costs.

Economics. The following economic assumptions have been made:

1. Midwestern plant location. Site has no special problems.

2. Capital costs are calculated for 1980.

3. Annual operation and maintenance costs are calculated for a mid-1980 startup.

4. Annual capital and operating costs have been levelized over a 30-year period.

5. The 30-year Fixed Charge Rate ranges from 16.0 to 26.6 percent per year.

6. The 30-year Levelizing Factor for operating and maintenance costs ranges from 1.820 to 3.444.

Wet Disposal Assumptions

Ash Sluicing to pond.

--Hydraulic in-plant ash handling system.

--Slurry water recycled, not treated.

--Pumps and transport lines have the capacity to transport all coal ash collected from a plant operating at 100 percent capacity factor, while the disposal pond size is based on a levelized capacity factor of 70 percent over the 30-year life.

--Spare pumps and a pipeline are included for slurry delivery. No spare pumps are provided for water recycle, but there is a spare pipeline.

--Disposal is for fly ash and bottom ash; pyrites are excluded.

--Coal ash slurry pumped at 10 percent ash by weight.

--Pond location varies from one mile (1.6 kilometers) to 25 miles (40 kilometers) from plant.

--Fly ash slurry settles to a dry density of 60 pounds per cubic foot (960 kilograms per cubic meter). Excess water is recycled to sluicing system.

--Disposal site is lined to prevent groundwater contamination by leachate from the coal ash.

--Four disposal site configurations were examined, wide valley with dam, narrow valley with dam, and ponds with 25 feet (7.6 meters) or 50 feet (15.2 meters) embankments on flat land.

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Dry Ash Disposal Assumptions

1. Truck transport to disposal site.

   --Pressure or vacuum pneumatic in-plant ash handling system.

   --Hauling, placing, and compaction (if done) are performed by the utility.

   --Existing public and/or private roads are utilized in addition to haul roads constructed on-site.

   --Compaction by on-site equipment and a towed, 5-ton (45 metric ton) roller, but without strict field control, results in an in-place density for dry coal ash (composite fly ash/bottom ash) of 85 pounds per cubic foot (1360 kilograms per cubic meter).

   --Disposal site location varies from 1 mile (1.6 kilometers) to 25 miles (40 kilometers) from plant.

   --Four disposal site configurations were examined: wide valley with toe, narrow valley with toe, and flat land sites with 75 feet (22.8 meters) or 150 feet (45.6 meters) embankments.

2. Conveyor belt transport to disposal site.

   --A pressure or vacuum pneumatic in-plant ash handling system.

   --Transport, placing, and compaction (if done) are performed by the utility.

   --Disposal site location varies from 1 mile (1.6 kilometers) to 25 miles (40 kilometers) from plant.

   --Four disposal site configurations were examined: wide valley with dam, narrow valley with dam, and flat landfills with 75 feet (22.8 meters) or 150 feet (45.6 meters) embankments.

   --A totally enclosed system with an 18 inch (0.45 meter) belt is used for up to 870,000 tons (790,000 metric tons) of ash per year.

   --A totally enclosed system with a 36 inch (0.90 meter) belt is used for over 870,000 tons (790,000 metric tons) of ash per year.

   --Yearly O&M cost for the conveyor belt is assumed to be 17% of total capital cost (4).

   --The conveyor belt has the capacity to carry all the coal ash collected from a plant operating at 100 percent capacity factor, while the landfill size is based on a capacity factor of 70 percent over the 30-year life.

Development of Cost Estimates. The base case estimates were used in the development of the computer program, ASHDAL. These estimates were prepared using the assumptions

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and methodology outlined and are applicable to regulated, investor-owned utilities. The scope of the base case disposal system cost estimates includes in-plant handling, transportation, and disposal of the coal ash. The cost data and assumptions which were made for the base case estimates are detailed below.

As an aid in understanding the cost estimating methodology, Table 9-7 was prepared to demonstrate a Class I Simplified Cost Estimate for a typical wet disposal base case, while Table 9-8 provides the same type of cost data for a typical landfill base case. Cost assumptions which make up the Total Capital Requirement are provided for the example estimate.

Capital Cost Estimates

1. Transport Equipment-Wet. Pumps for the sluicing system are the primary equipment required for wet disposal. Costs for this equipment have been adapted from the detailed estimates prepared by TVA. The ash slurry pipeline costs were aslo adapted from TVA estimates (4).

2. Transport Equipment-Dry. Hauling and compaction equipment purchased for dry disposal by the utility would be included in this item.

3. Excavation and Site Preparation. The primary excavations for wet disposal are the trenches for underground transport pipelines (4). Pond excavation costs are not included under this tiem. The landfill development is the major cost item for dry disposal.

4. Pond Construction. Detailed estimates by TVA (4) and the results from a computer model study (21) indicate that cost per acre for a disposal pond, when built at its optimum geometry, is realtively constant. This assumes that there is no constraint of the amount of flat land available for the pond. The cost for this optimum size pond has been calculated to be approximately $18,000 per acre ($44,500/hectare), excluding the land cost. For the given assumptions (25 foot (7.6 meters) pond depth and 60 pounds per cubic foot (960 kilograms per cubic meter) settled ash dry density), one acre (0.40 hectare) of pond area is required for each 32,700 tons (30,000 metric tons) of ash which must be disposed of.

5. Site Reclamation. The site reclamation costs for wet disposal are assumed to be incurred at the end of the life of the site. Site reclamation costs for dry disposal are incurred over the life of the site. The costs are incorporated in the levelized cost economics by calculating the present worth of the cost and including it as a capital cost. Since the reclamation cost estimate has been made in current dollars, this future cost can be brought forward using the weighted cost of capital in the absence of inflation which is 3.8 percent (1).

6. Land Acquisition. A cost of $1,500 per developed acre ($3,700/hectare) is assumed in accordance with Reference (2).

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Table 9-7

Levelized Annual Revenue Requirement
Sluicing to Pond Base Case

		Estimated Cost in Thousand of Dollars
Total Capital Cost		
In-Plant Handling System		2,285
Dam Appurtenances		100
Embankments		9,617
Site Preparation		11,339
Drainage Ditch		573
Equipment for Disposal Area		194
Transport System		590
	Total	24,698
Total Replacement Cost		
Transport System		1,663
Equipment for Disposal Area		295
	Total	1,958
Yearly O&M Cost		
In-Plant Handling System		388
Dam Appurtenances		10
Drainage Ditch		57
Equipment for Disposal Area		93
Transport System		713
	Total	1,381
Total Levelized Cost (per year)		7,515
Levelized Cost per Dry Ton		$12.51/ton

Note:

1. Pond With 50 Feet Embankments.
2. 600,000 Tons of Coal Ash Per Year.
3. 10 Percent Weighted Cost of Capital.
4. 1 Mile Transport Distance.

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Table 9-8

Levelized Annual Revenue Requirement
Truck Transport to Landfill Base Case

		Estimated Cost in Thousands of Dollars
Total Capital Cost		
In-Plant Handling System		$ 6,168
Sedimentation Ponds		30
Site Preparation		20,855
Drainage Ditch		445
Equipment for Disposal Area		262
Transport System		180
Drainage Pipe		90
On-Site Haul Road		45
	Total	28,075
Total Replacement Cost		
Transport System		210
Equipment for Disposal Area		533
	Total	743
Yearly O&M Cost		
In-Plant Handling System		1,049
Drainage Ditch		45
Equipment for Disposal Area		156
Transport System		182
On-Site Haul Road		9
	Total	1,441
Total Levelized Cost		8,277
Levelized Cost per Dry Ton		$13.78/ton

Note:

1. Landfill With 150 Feet Embankments.
2. 600,000 Tons Coal Ash Per Year.
3. 10 Percent Weighted Cost of Capital.
4. 1 Mile Transport Distance.

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Operating and Maintenance Costs. The following operating costs are assumed to be independent of the facility capacity factor.

Operating Labor. Based on the ash disposal site visits made in conjunction with the preparation of this manual and the experience of TVA (3, 4, 5, 6), it has been concluded that one person is required full time for operation of an ash disposal facility. The high capital cost required for an increase in disposal capacity makes it most economical to operate wet disposal facilities during the full operation time of the plant (6132 hours/year for the first year capacity factor of 70 percent). Dry disposal operations, however, are not capital intensive and are generally economical when operated only during a normal work week. Assuming an additional 5 percent to cover occasional overtime, the first year operation time for dry disposal is 2184 hours. A labor rate of $13.85/person hour, as recommended by EPRI (2), was utilized.

Maintenance Costs. Maintenance costs for the base case wet disposal facilities were estimated, based on the TVA experience (3, 4, 5, 6), as four percent of the Process Capital excluding the pond construction cost and three percent of the pond construction cost. The base case dry disposal maintenance costs were estimated to be four percent of the Process Capital. The 40:60 labor cost to material cost ratio suggested by EPRI (2) was used.

Although the percentages for wet disposal are somewhat less than the recommended allowance of 6-10 percent shown in Table 9-4 for Corrosive and Abrasive Slurries, TVA's experience was considered to be appropriate for these estimates. The 4 percent is within the range recommended in Table 9-4 for handling solids.

Overhead. The administrative and support personnel overhead were estimated to be 30 percent of the operating and maintenance labor costs (2).

Consumables. The primary consumable operating cost item for wet disposal systems is the electricity required to operate the sluice pumps. The amount and cost of the electric power required was estimated from the TVA information (4) using an average price of $0.030/kWh. The operating contracts for dry disposal were estimated using References (11, 12, 13, and 17). The site preparation costs are estimated to be $21,600/acre ($8,750/ hectare) which amounts to about $720/acre ($290/hectare) each year during the 30-year life of the site. The hauling unit price varies with the transport distance while the

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placement and compaction unit price was estimated at $1.60/dry ton ($1.45/dry metric ton) [$1.48/compacted c.y. ($1.94/ cubic meter)]. Site reclamation costs for the dry disposal operation are assumed to be incurred uniformly over the life of the site. These reclamation costs were estimated at $7,400/acre ($3,000/hectare). Wet disposal site reclamation costs are assumed to be incurred primarily at the end of the site life and, therefore, are included in the capital costs using the present-worth of the cost as described earlier.

30-Year Levelized Costs

The First Year Operating Costs (FYOC) should be levelized using the 30-year levelization factor to determine the Levelized Operating Cost (LOC). Similarly the Total Capital Requirement (TCR) should be recovered over the assumed 30-year life of the site. Thus:

Levelized Operating Cost, LOC = LF x FYOC
Levelized Capital Requirement, LCR = FCR x TCR

The sum of these two levelized costs is the Levelized Annual Revenue Requirement (LARR). This annual cost can be expressed as dollars/year, or dollars/dry-ton of ash disposed. These calculations are shown on Tables 9-7 and 9-8 for the base case disposal system examples.

Table 9-9 summarizes the economic conditions utilized in the analysis. The range of capital costs utilized portray typical capital recovery rates for the electric power industry (22). The cost of capital, as related to disposal economics, represents the utilities' anticipated rate of return on investment in the absence of inflation. The 3.0 percent value is the approximate long-term cost for a non-profit or government utility, the 3.8 percent cost of capital is EPRI's (2) current recommendation for investor-owned utilities, and 5.0 percent represents current cost of capital for investor-owned utilities in the absence of inflation.

ASHDAL Results

ASHDAL was run using many input conditions to provide a broad data base of Class I estimates. In general, the results presented will be for a 6 percent inflation rate and a 10 percent weighted cost of capital, unless otherwide noted. These percentages represent current EPRI policy, as presented in Technical Assessment Guide (1). The data presented represent Class I estimates, previously described in this section.

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Table 9-9

COST OF CAPITAL, INFLATION RATES, AND WEIGHTED COSTS OF CAPITAL UTILIZED IN THE ECONOMIC ANALYSIS OF COAL ASH DISPOSAL ALTERNATIVES

Capital Cost Percent	Inflation Rate Percent	Weighted Cost of Capital Percent
3.0	6.0	9.2
3.0	10.0	13.3
3.0	14.0	17.4
3.8	6.0	10.0
3.8	10.0	14.2
3.8	14.0	18.3
5.0	6.0	11.3
5.0	10.0	15.5
5.0	14.0	19.7

Table 9-10 presents the levelized cost for various ash disposal systmes. The 10 percent weighted costs of capital reflects EPRI economic premises. The costs range from $10.40/ton ($9.43/metric ton) to $233.03/ton ($211.40/metric ton, with many alternatives in the $10-$20/ton ($9-$18/metric ton) range. In all cases, the cost per dry ton of ash disposed decreased as the quantity of ash increased. With the exception of wet disposal on flat land, most costs were within $2 to $3/dry ton of each other. For smaller quantities of ash, wet disposal in a narrow valley is the least cost option. Larger quantities of ash are handled less costly by compaction and truck transport to a landfill with high (150 feet) embankments.

The results indicate that compaction reduces the cost of disposing dry ash. It costs approximately $2/dry ton less to handle, transport, and dispose of compacted ash than uncompacted ash. The table also illustrates that truck transport is a less costly alternative for dry ash than conveyor belt transport.

Table 9-10 also illustrates the effect of increasing transport distance on the various disposal alternatives. In all cases, the cost per ton increases with increasing transport distance. For truck transport, this increase is less than 40 percent when the transport distance is varied from 1 mile to 25 miles. The other two transport alternatives, pipeline and conveyor belt, increase in cost over 100 percent from 1 mile to 25 miles transport distance. At 25 miles the cost differential between the various site topographies decreases. For belt transport of compacted or uncompacted ash, the difference between the various alternatives is a

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Table 9-10

ASH DISPOSAL SYSTEM

LEVELIZED COST IN DOLLARS ($) PER DRY TON

DISPOSAL METHOD	200,000 Transport Distance 1 Mile	5 Miles	10 Miles	25 Miles	400,000 Transport Distance 1 Mile	5 Miles	10 Miles	25 Miles	1 Mile
Pipeline Transport									
Wet Ash									
Flat 25' Embankments	28.67	50.45	77.67	159.32	23.88	39.50	59.03	117.61	22.04
Flat 50' Embankments	35.27	57.04	84.26	165.91	24.70	40.32	59.85	118.43	20.94
Narrow Valley	16.69*	38.46	65.68	147.33	14.29*	29.91	49.44	108.02	12.51*
Wide Valley	17.31*	39.09	66.31	147.96	14.84*	29.96	49.48	108.07	12.76*
Truck Transport									
Dry Uncompacted Ash									
Flat 75' Embankments	17.79*	18.59*	19.60*	22.63*	15.88*	16.69*	17.70*	20.73*	15.25
Flat 150' Embankments	16.90*	17.71*	18.72*	21.74*	13.79*	14.60*	15.61*	18.64*	12.76*
Narrow Valley	17.17*	17.98*	18.99*	22.02*	16.97	17.77*	18.78	21.81*	14.93*
Wide Valley	19.72	20.53	21.54	24.56*	20.12	20.92	21.93	24.96	16.81
Dry Compacted Ash									
Flat 75' Embankments	15.95*	16.76*	17.77*	20.79*	14.04*	14.84*	15.85*	18.88*	13.78*
Flat 150' Embankments	15.84*	16.64*	17.65*	20.68*	12.73**	13.54**	14.54**	17.57**	12.07**
Narrow Valley	15.40**	16.21**	17.22**	20.25**	14.87*	15.67*	16.68*	19.71*	13.78*
Wide Valley	17.19*	18.00*	19.01*	22.04*	17.75	18.55	19.56	22.59	15.55
Belt Transport									
Dry Uncompacted Ash									
Flat 75' Embankments	26.14	60.30	103.00	231.10	19.92	37.00	58.35	122.39	17.85
Flat 150' Embankments	25.26	59.41	102.11	230.21	17.83	34.91	56.26	120.31	15.36
Narrow Valley	25.53	59.69	102.39	230.48	21.00	38.08	59.43	123.48	17.53
Wide Valley	28.08	62.24	104.93	233.03	24.15	41.23	62.58	126.63	19.40
Dry Compacted Ash									
Flat 75' Embankments	24.31	58.46	101.16	229.26	18.07	35.15	56.50	120.55	16.37
Flat 150' Embankments	24.19	58.35	101.05	229.15	16.76	33.84	55.19	119.24	14.67*
Narrow Valley	23.76	57.92	100.62	228.71	18.90	35.98	57.33	121.38	16.38
Wide Valley	25.55	59.71	102.41	230.50	21.78	38.86	60.21	124.26	18.15

**Least cost option per column
*Less than 25 percent greater than least cost option

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Table 9-10
(Continued)

DISPOSAL METHOD	500,000 Transport Distance 5 Miles	10 Miles	25 Miles	870,000 1 Mile	Transport Distance 5 Miles	10 Miles	25 Miles	1,700,000 1 Mile	Transport Distance 5 Miles	10 Miles	25 Miles
Pipeline Transport											
Wet Ash											
Flat 25' Embankments	34.24	49.49	95.22	20.98	31.73	45.17	85.49	19.86	28.99	40.39	74.61
Flat 50' Embankments	33.14	48.38	94.12	18.69	29.44	42.88	83.21	16.24	25.36	36.77	70.99
Narrow Valley	24.71	39.96	85.69	11.49	22.24	35.68	76.00	10.40**	19.53	30.93	65.16
Wide Valley	24.95	40.20	85.94	11.85	22.60	36.04	76.36	10.91*	20.03	31.44	65.66
Truck Transport											
Dry Uncompacted Ash											
Flat 75' Embankments	16.06*	17.07*	20.10*	15.12	15.93	16.94	19.96*	14.68	15.49	16.50	19.53
Flat 150' Embankments	13.57*	14.58*	17.61*	12.38*	13.19*	14.20*	17.23*	11.67*	12.48*	13.49*	16.51*
Narrow Valley	15.74*	16.75*	19.78*	13.94*	14.74*	15.75*	18.78*	12.53*	13.33*	14.34*	17.37*
Wide Valley	17.61	18.62	21.65	15.03	15.83	16.84	19.87*	12.73*	13.54*	14.55*	17.58*
Dry Compacted Ash											
Flat 75' Embankments	14.59*	15.60*	18.62*	13.27*	14.08*	15.09*	18.11*	12.96*	13.77*	14.78*	17.81*
Flat 150' Embankments	12.88**	13.89**	16.92**	11.32**	12.13**	13.13**	16.16**	10.74*	11.54**	12.55**	15.58**
Narrow Valley	14.59*	15.60*	18.62*	12.76*	13.57*	14.58*	17.60*	11.88*	12.69*	13.70*	16.72*
Wide Valley	16.36	17.37	20.40*	13.85*	14.66*	15.67*	18.70*	12.21*	13.01*	14.02*	17.05*
Belt Transport											
Dry Uncompacted Ash											
Flat 75' Embankments	29.23	43.47	86.17	17.34	27.25	39.65	76.83	15.65	20.61	26.80	45.39
Flat 150' Embankments	26.74	40.98	83.68	14.60	24.52	36.91	74.09	12.64*	17.59	23.79	42.38
Narrow Valley	28.91	43.15	85.85	16.15	26.07	38.46	75.64	13.49	18.45	24.65	43.24
Wide Valley	30.79	45.02	87.72	17.24	27.16	39.55	76.73	13.70	18.66	24.85	43.44
Dry Compacted Ash											
Flat 75' Embankments	27.76	41.99	84.69	15.49	25.40	37.79	74.97	13.93	18.89	25.08	43.67
Flat 150' Embankments	26.05	40.29	82.99	13.53*	23.45	35.84	73.02	11.70*	16.66	22.86	41.45
Narrow Valley	27.76	41.99	84.69	14.98	24.89	37.28	74.46	12.85*	17.80	24.00	42.59
Wide Valley	29.53	43.77	86.47	16.07	25.98	38.38	75.56	13.17	18.13	24.33	42.91

**Least cost option per column
*Less than 25 percent greater than least cost option

Note: 1. 10 Percent weighted Cost of Capital
2. 1 Mile Transport Distance

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maximum of $4/ton, with the average at $43.00/ton, for 1,700,000 tons ash per year.

It is interesting to note that these results mirror current ash disposal practices. In the east, where most disposal occurs in hilly terrain, wet disposal predominates. Table 9-10 indicates that wet disposal is the least expensive option with valley fills. Similarly, in the west, where most disposal occurs on flat land, dry disposal predominates. Table 9-10 indicates that dry disposal is the least expensive flat land option.

Table 9-11 shows the categorical breakdown of disposal system component costs for several disposal alternatives. Within each transport category, only the cost for disposal differs. The in-plant handling and transport costs are equal. A similar situation occurs with in-plant handling costs. In-plant handling costs are essentially equal for the same ash category, regardless of disposal option.

Ash Utilization. An alternative to disposal of coal ash is utilization of the ash. A wide variety of uses has been found for power plant ash. For some of the applications, criteria have been established to specify the properties that a particular ash must have to perform adequately in the given application. Other uses have not been as well documented or researched, and detailed material specifications have not been developed; however, many have been performed successfully. The categories listed represent areas of utilization:

- Fill and cover material,
- Soil imporvement,
- Roadways and pavements,
- Drainage,
- Pozzolan,
- Structural products,
- Lightweight aggregate,
- Grout and mortar,
- Metal extraction.

Pozzolan applications have historically represented the largest outlet for fly ash, but the other areas are utilizing increasing amounts of coal ash as natural resources continue to decrease in supply or availability.

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Table 9-11

ASH DISPOSAL SYSTEM
LEVELIZED COST IN DOLLARS ($) PER DRY TON

DISPOSAL METHOD	In-Plant Handling Capital	In-Plant Handling O&M	Transport Capital	Transport O&M	Disposal Capital	Disposal O&M	Total
Pipeline Transport							
Wet Ash							
Flat 25' Embankments	$ 0.71	1.28	$ 0.71	2.37	$16.67	0.31	22.04
Flat 50' Embankments	0.71	1.29	0.71	2.36	15.53	0.34	20.94
Narrow Valley	0.71	1.28	0.71	2.36	6.92	0.53	12.51
Wide Valley	0.71	1.28	0.70	2.36	7.15	0.56	12.76
Truck Transport							
Dry Uncompacted Ash							
Flat 75' Embankments	$ 1.94	3.48	$ 0.12	0.59	$ 8.66	0.46	15.25
Flat 150' Embankments	1.93	3.46	0.13	0.60	6.24	0.40	12.76
Narrow Valley	1.93	3.48	0.12	0.60	8.35	0.45	14.93
Wide Valley	1.93	3.48	0.12	0.61	10.18	0.49	16.81
Dry Compacted Ash							
Flat 75' Embankments	$ 1.93	3.47	$ 0.12	0.61	$ 6.96	0.69	13.78
Flat 150' Embankments	1.93	3.48	0.12	0.60	5.30	0.64	12.07
Narrow Valley	1.93	3.47	0.12	0.61	6.96	0.69	13.78
Wide Valley	1.93	3.47	0.12	0.61	8.69	0.73	15.55
Belt Transport							
Dry Uncompacted Ash							
Flat 75' Embankments	$ 1.93	3.46	$ 1.04	2.28	$ 8.68	0.46	17.85
Flat 150' Embankments	1.94	3.47	1.04	2.27	6.24	0.40	15.36
Narrow Valley	1.93	3.47	1.03	2.28	8.36	0.46	17.53
Wide Valley	1.92	3.47	1.05	2.27	10.20	0.49	19.40
Dry Compacted Ash							
Flat 75' Embankments	$ 1.93	3.47	$ 1.05	2.28	$ 6.95	0.69	16.37
Flat 150' Embankments	1.94	3.47	1.04	2.27	5.32	0.63	14.67
Narrow Valley	1.93	3.47	1.05	2.28	6.96	0.69	16.38
Wide Valley	1.92	3.48	1.03	2.27	8.72	0.73	18.15

Note:

1. 600,000 Tons Ash Per Year.

2. 1 Mile Transport Distance.

3. 10 Percent Weighted Cost of Capital.

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Table 9-12 is a comparison of costs for disposing of 600,000 tons/year between ash management schemes of 100 percent disposal and 50 percent disposal/50 percent utilization. The savings resulting from ash utilization are approximately 25 percent of the cost. The savings are primarily from reduced capital costs for disposal area development.

The effect of increasing the weighted cost of capital on disposal system cost is illustrated in Figure 9-3. This figure illustrates that as the cost of capital increases, the ash disposal system cost per dry ton also increases. This increase occurs whether the weighted cost of capital increases due to increased inflation or increased cost of capital in the absence of inflation. The ranking of each alternative remains the same, regardless of the weighted cost of capital.

In general, at EPRI recommended conditons, 6 percent inflation and a 10 percent discount rate, the estimated costs are within the same range, except for wet disposal on flat land.

SUMMARY

The computer program, ASHDAL, is useful for preliminary comparison of disposal alternatives. The estimates can be adjusted for some differences with the basic assumptions as indicated. Some differences may require the preparation of a specific estimate; however, it may be appropriate to merely modify one of the base case estimates described in this section by changing a unit price or an assumed capacity factor.

It is important to note that the simplified and base case example estimates are levelized over a 30-year period in accordance with EPRI guidelines. Therefore, the computed levelized costs are nearly 90 percent higher than those which would be experienced in 1980, the first year of operation.

Detailed cost estimates, as outlined in Table 9-1, require that the system be more fully defined so that firm prices can be established. The form of the estimate should follow that given in Table 9-2 so that it can readily be compared with other estimates.

Conclusions

The following general conclusions may be made based on the economic analysis:

- Dry compacted ash disposal is less expensive than dry uncompacted disposal.

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Table 9-12

ASH DISPOSAL AND UTILIZATION SYSTEM
LEVELIZED COST IN DOLLARS ($) PER DRY TON

DISPOSAL METHOD	In-Plant Handling Capital	In-Plant Handling O&M	Transport Capital	Transport O&M	Disposal Capital	Disposal O&M	Total
Pipeline Transport							
Wet Ash							
Narrow Valley 100% Disposed	$ 0.71	1.28	$ 0.71	2.36	$ 6.92	0.53	12.51
Narrow Valley 50% Utilized 50% Disposed	0.71	1.29	0.47	1.76	3.91	0.37	8.51
Truck Transport							
Dry Uncompacted Ash							
Narrow Valley 100% Disposed	$ 1.93	3.48	$ 0.12	0.60	$ 8.35	0.45	14.93
Narrow Valley 50% Utilized 50% Disposed	1.94	3.47	0.05	0.30	4.97	0.40	11.13
Dry Compacted Ash							
Narrow Valley 100% Disposed	$ 1.93	3.47	$ 0.12	0.61	$ 6.96	0.69	13.78
Narrow Valley 50% Utilized 50% Disposed	1.93	3.49	0.06	0.30	4.09	0.39	10.26
Conveyor Transport							
Dry Uncompacted Ash							
Narrow Valley 100% Disposed	$ 1.93	3.47	$ 1.03	2.28	$ 8.36	0.46	17.53
Narrow Valley 50% Utilized 50% Disposed	1.93	3.47	0.97	2.12	4.98	0.40	13.87
Dry Uncompacted Ash							
Narrow Valley 100% Disposed	$ 1.93	3.47	$ 1.05	2.28	$ 6.96	0.69	16.38
Narrow Valley 50% Utilized 50% Disposed	1.94	3.47	0.96	2.13	4.11	0.39	13.00

Note:
1. 600,000 Tons Ash Per Year.

2. 1 Mile Transport Distance.

3. 10 Percent Weighted Cost of Capital.

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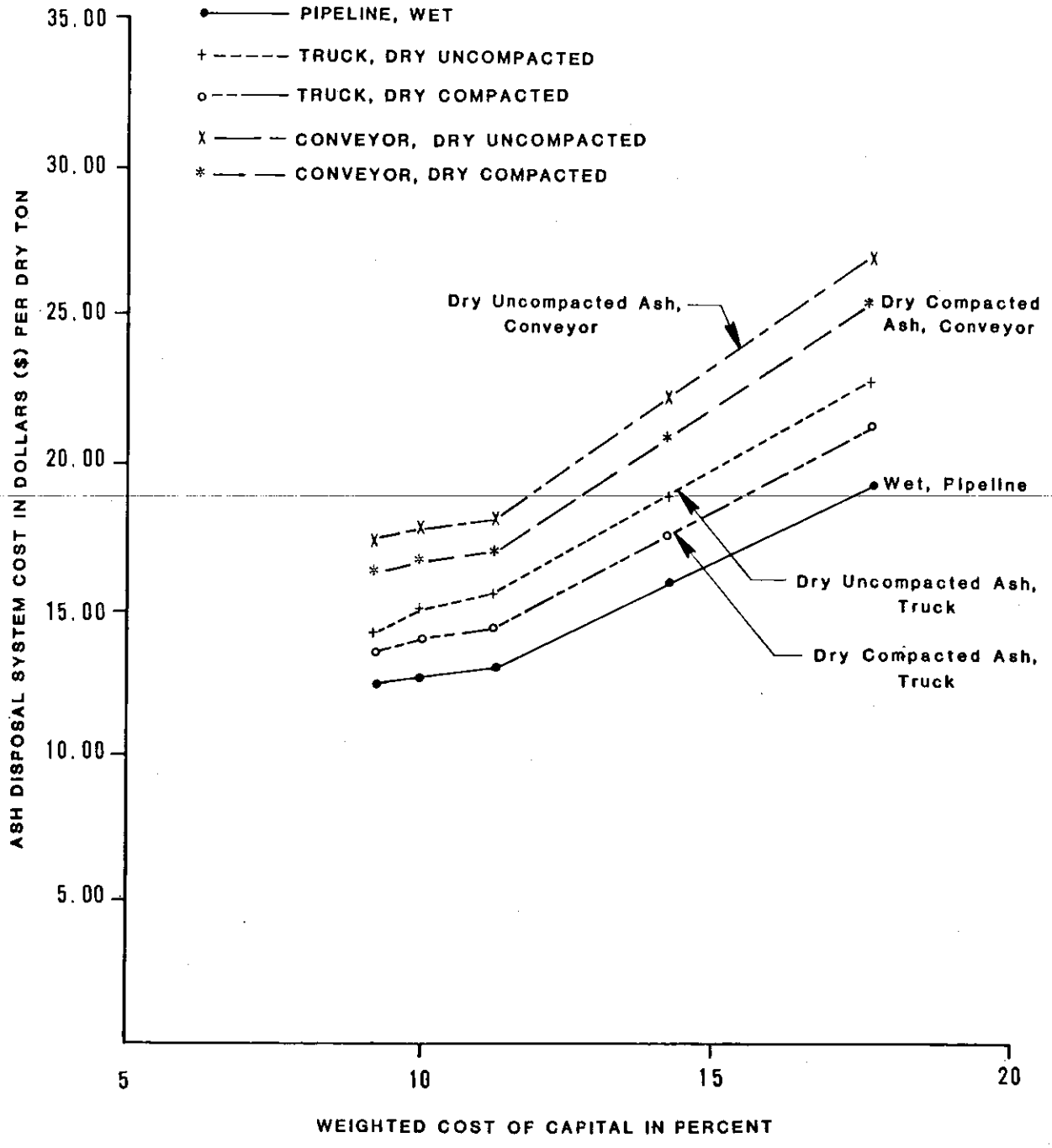

Figure 9-3. Ash Disposal System Levelized Cost in Dollars ($) Per Dry Ton, 600,000 Tons Ash Per Year, and 1 Mile Transport Distance, In A Narrow Valley

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- Truck transport is less expensive than conveyor transport.
- Site topography can significantly impact overall disposal system economics.
- Variation in the economic premises utilized in the analysis can alter certain disposal system decisions.

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APPENDIX A

LINER INSTALLATION PROCEDURES

SOURCE: Solids and Hazardous Waste Research Division, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio, and Southwest Research Institute, San Antonio, Texas

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Figure A-1. Sheepsfoot Roller used for subgrade compaction.

Figure A-2. Vibratory roller used for subgrade compaction.

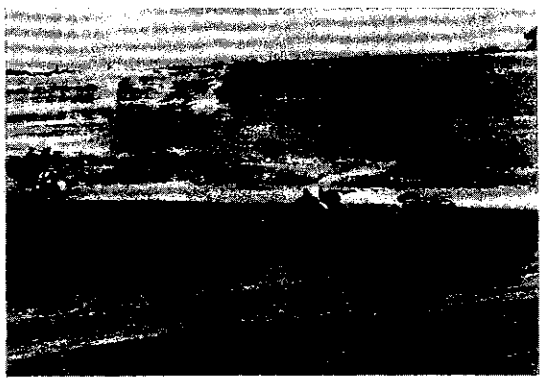

Figure A-3. Large watering vehicle used for dust control.

Figure A-4. Surface scraper used for final smoothing.

Figure A-5. Undesirable subgrade surface texture.

Figure A-6. Disc suitable for soil blending.

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Figure A-7. Workmen removing small rocks during subgrade inspection.

Figure A-10. Liner replacement due to "salt grass" damage.

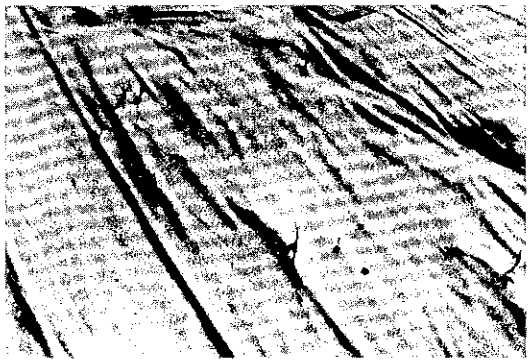

Figure A-8. "Salt grass" growing through a flexible membrane liner.

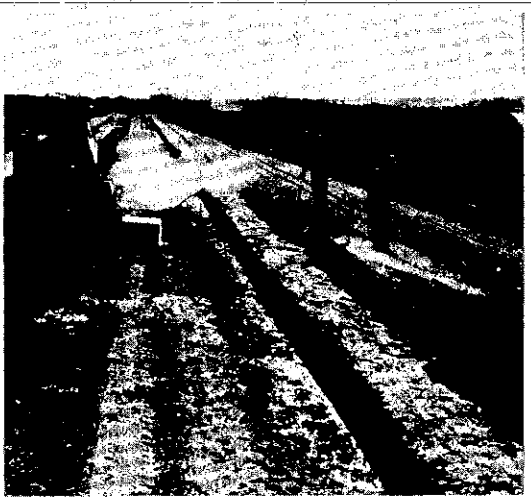

Figure A-11. Application of an herbicide to the subgrade for soil sterilization.

Figure A-9. Liner repair required due to "salt grass" damage.

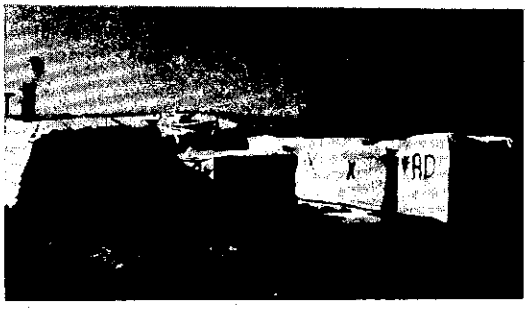

Figure A-12. Site storage of liner material showing protective plastic.

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Figure A-13. Initial placement of a liner into an anchor trench.

Figure A-16. Differential settlement of a concrete subgrade.

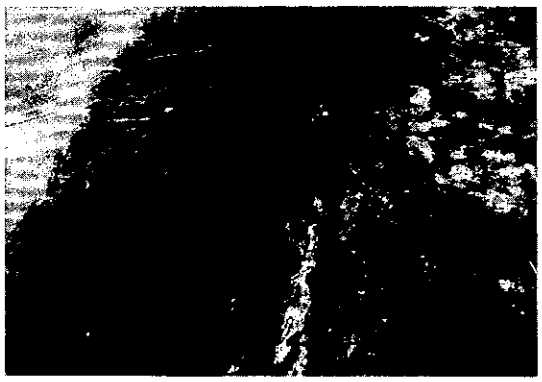

Figure A-14. Anchor trench filled with concrete.

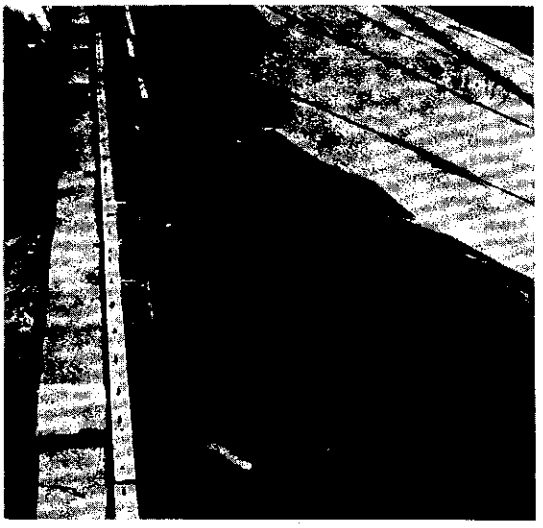

Figure A-17. Stainless steel batten strips securing a liner to concrete.

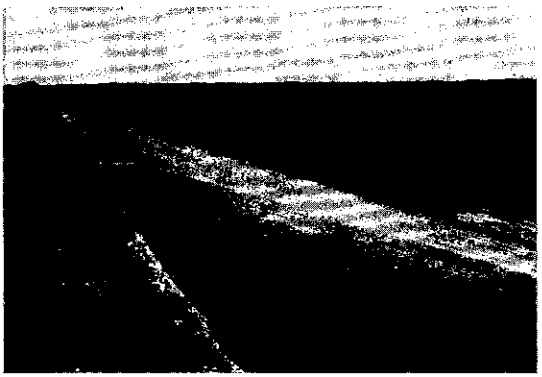

Figure A-15. Finished anchor trench-concrete.

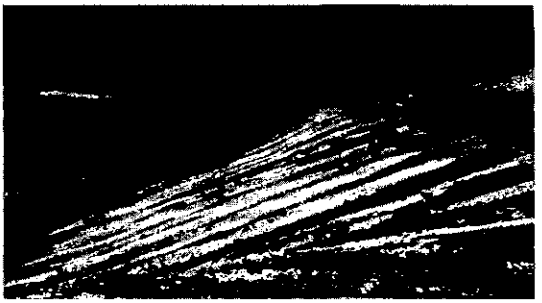

Figure A-18. Bentonite applied to a soil where spreading was uneven.

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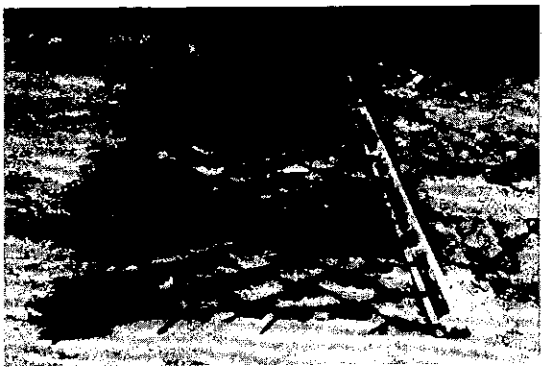

Figure A-19. An iron "rake" used to blend bentonite and native soil.

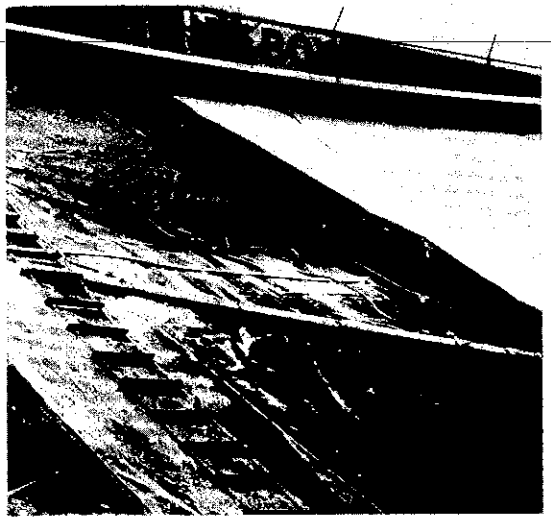

Figure A-20. Support board for working on steep incline.

Figure A-21. Unsuccessful seaming with a solvent adhesive in cold temperatures.

Figure A-22. Excessive accumulation of liner material.

Figure A-23. Patching compounds applied to concrete panel joints.

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Figure A-24. Field seams parallel to side slope toe.

Figure A-26. Plastic dowels being used to pull liner panels.

Figure A-27. Field generator.

Figure A-25. Large wrinkle at edge of liner panel.

Figure A-28. Removing wrinkles from panel.

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Figure A-29. This seam wrinkle will require removal.

Figure A-30. Repair of seam wrinkle.

Figure A-31. An impoundment being utilized while liner replacement continues.

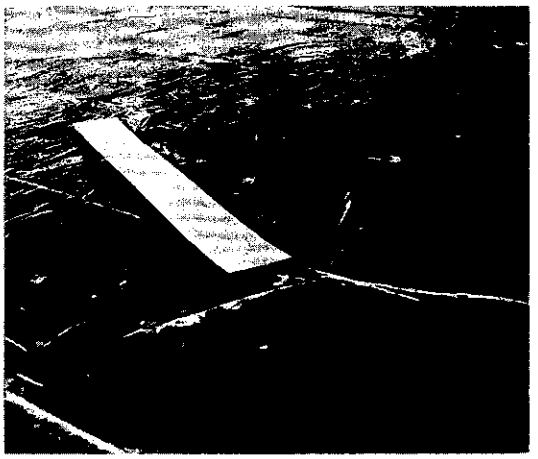

Figure A-32. Seaming board.

Figure A-33. Knee pad used by field crews.

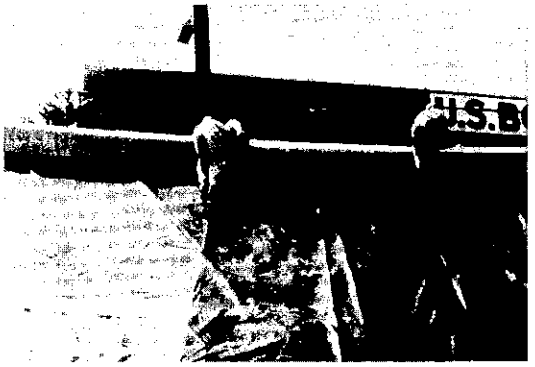

Figure A-34. Material overlap.

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Figure A-35. Use of a chalk line to mark a liner for removal of excess material.

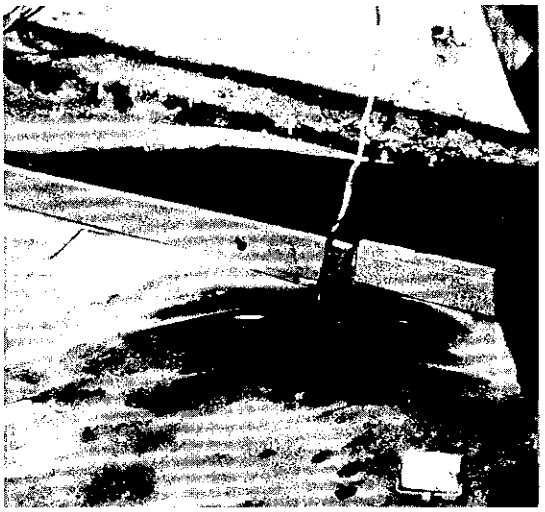

Figure A-36. Field constructed boot for a liner penetration.

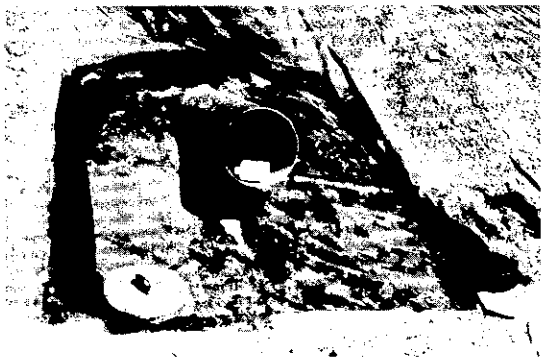

Figure A-37. Pipe penetration being prepared for installation of a "boot".

Figure A-38. Completed boot installation.

Figure A-39. Liner pad around a concrete penetration.

Figure A-40. Pad prior to locating steel batten strips.

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Figure A-41. Placement of steel battens around concrete penetration.

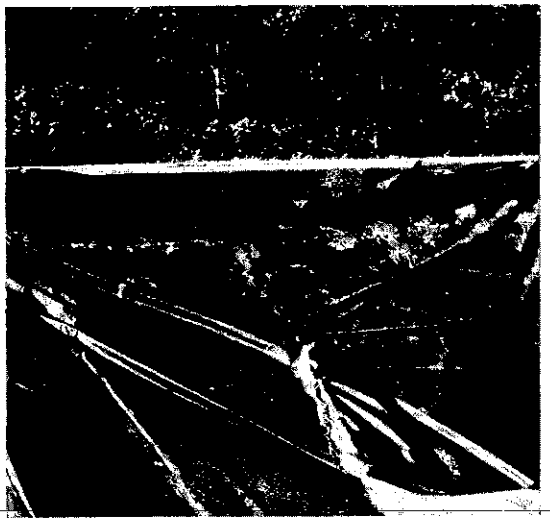

Figure A-44. Wind damage.

Figure A-42. Liner panels used to prevent wind damage.

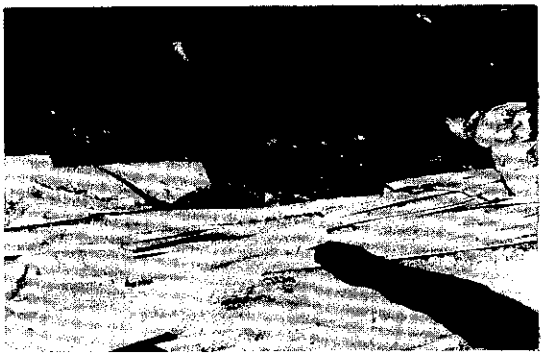

Figure A-45. Wind damage.

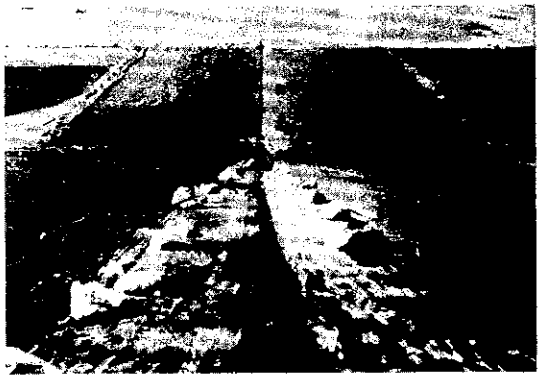

Figure A-43. Use of sandbags along a seam.

Figure A-46. Wind damage

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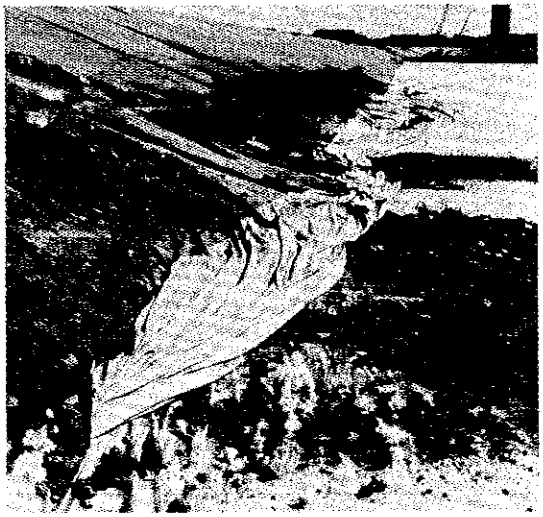

Figure A-47. Stretching of material by wind.

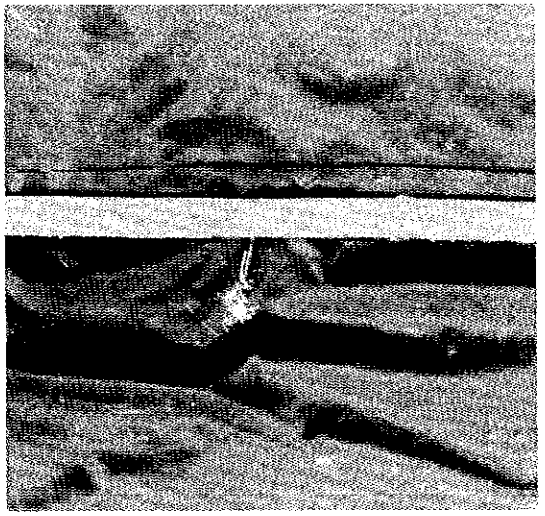

Figure A-50. Batten strip to secure liner to concrete subgrade.

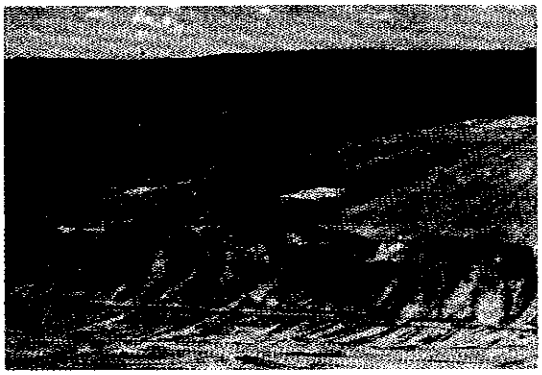

Figure A-48. Wafting effect on a liner not secured by a soil cover.

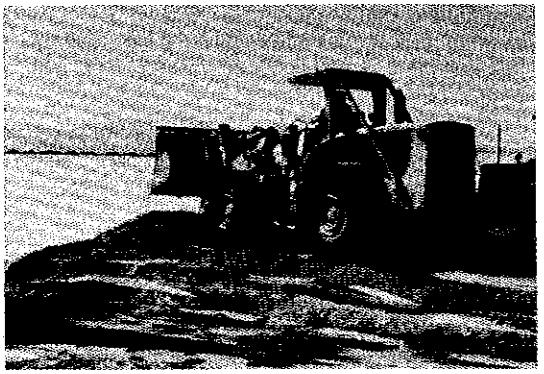

Figure A-51. Rubber-wheeled vehicle used for placing soil cover.

Figure A-49. Use of cover material in place of sandbags.

Figure A-52. Large dump truck placing soil cover.

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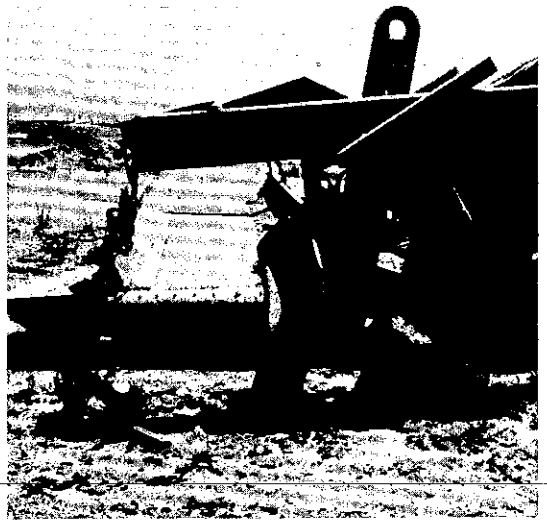

Figure A-53. Equipment to place soil cover.

Figure A-54. Equipment to place soil cover.

Figure A-55. Results of sun aging and degradation.

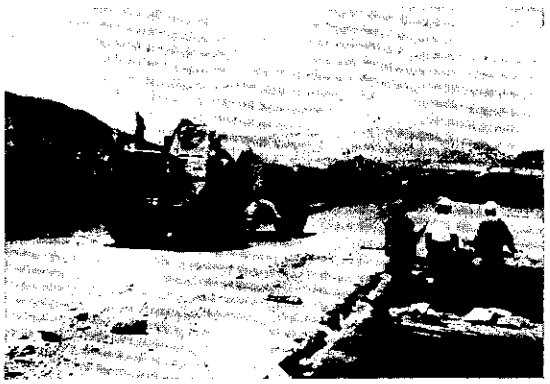

Figure A-56. Dust control on haul roads.

Figure A-57. "Blocking".

Figure A-58. Repair of "Blocking".

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Figure A-59. Blistering from solvent evaporation.

Figure A-60. Patch over field seam.

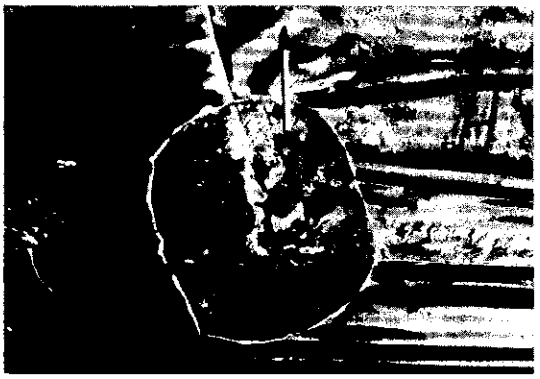

Figure A-61. Patch over field seam.

Figure A-62. Multiple patching should be avoided.

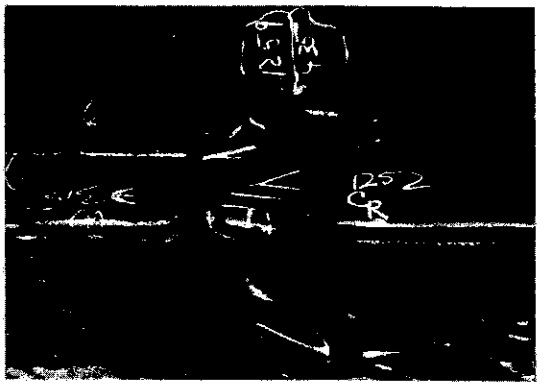

Figure A-63. Planned quality control inspection.

Figure A-64. Exposing edge of liner for expansion.

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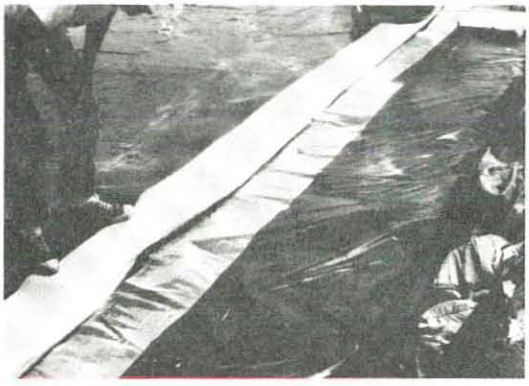

Figure A-65. Flap to be used for future expansion of liner.

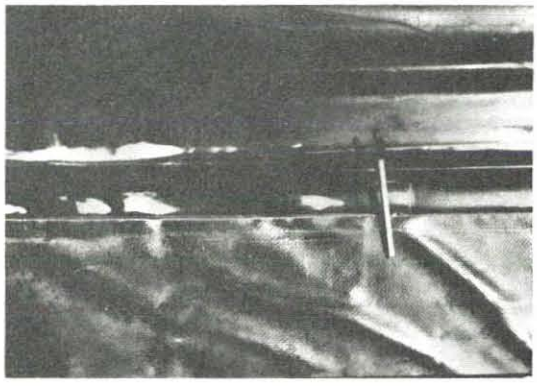

Figure A-68. Two materials "married " together for cost effective design.

Figure A-66. Flap sealed into place (shown of left).

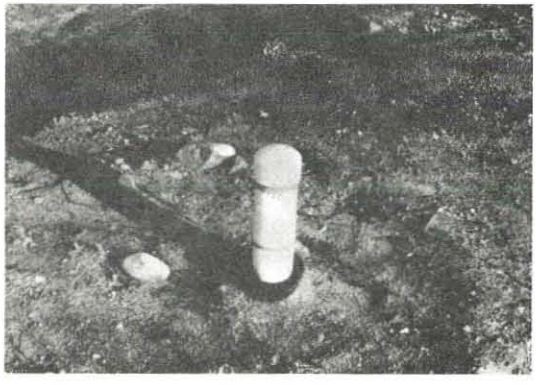

Figure A-69. Monitoring well casing

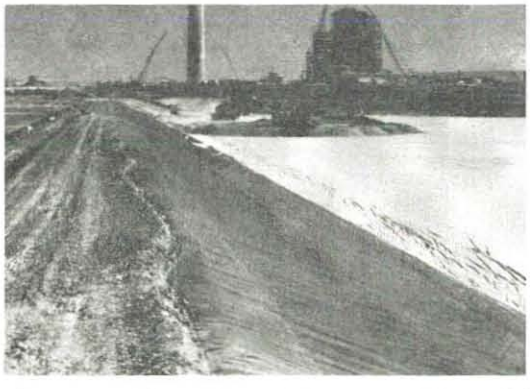

Figure A-67. Shows the use of two liner materials.

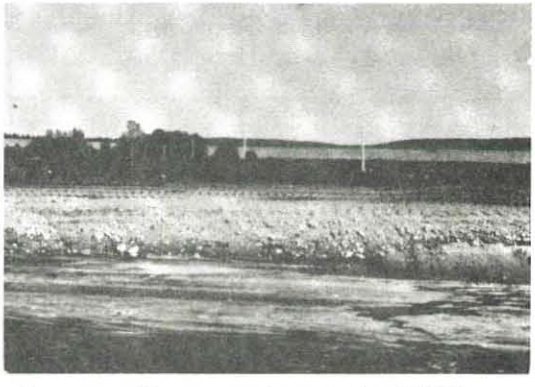

Figure A-70. Completed landfill cover.

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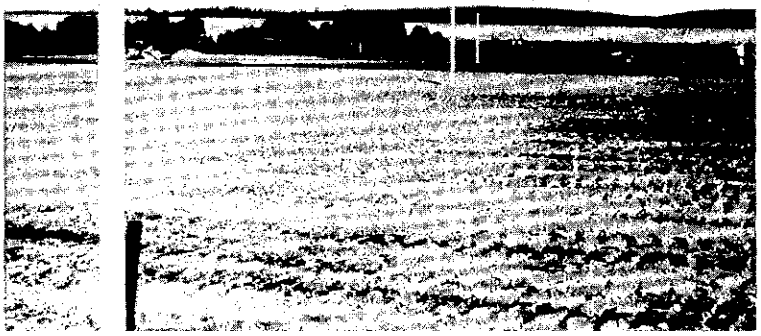

Figure A-71. Surface cover for a landfill showing gas vent pipes.

Figure A-72. Surface runoff diversion dam shown in upper left hand corner.

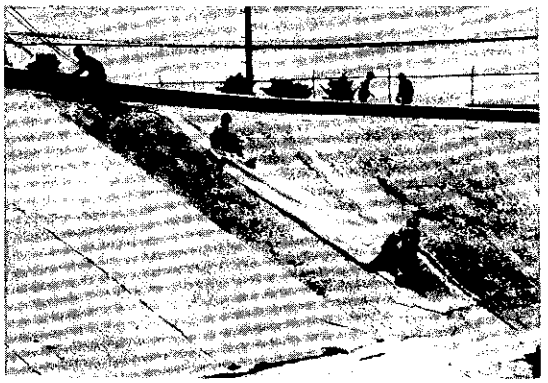

Figure A-74. Placement of filter fabric over differential settling crack in concrete.

Figure A-73. Shows use of a membrane and soil liner.

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APPENDIX B

BRIEF DESCRIPTIONS OF ASH
DISPOSAL PRACTICES

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BRIEF DESCRIPTIONS OF ASH DISPOSAL PRACTICES

Bull Run Steam Plant

The Bull Run Steam Plant is a 950 MW single-unit coal-fired power plant owned by the Tennessee Valley Authority located on the Clinch River near Oak Ridge, Tennessee. The power plant was brought on line in 1965 and burns 7,500 to 8,000 tons (6,800 to 7,200 metric tons) per day of bituminous coal from Kentucky and Tennessee. The coal is burned in a Combustion Engineering wet-bottom boiler. Exhaust gases pass through American Standard Precipitators and out a single 1,400 ft (426 m) stack. Fly ash removal is 99+ percent efficient. The Bull Run Steam Plant was visited to observe a simple once-through ash slurry water system.

Bottom ash from the Combustion Engineering wet-bottom boiler is quenched and sluiced to an ash dumping area. It used to be sluiced to a 15-acre (6.07 ha) bottom ash pond; however, this pond has been taken out of service and the bottom ash is now discharged to the fly ash pond.

Fly ash is removed from the precipitator hoppers, slurried, and pumped through a combination of steel and fiberglass pipes to the disposal area. Presently, the power plant is replacing the steel pipe with fiberglass pipe. The ash is then discharged into a 200-acre (80.9 ha) dual cell series pond. The ponds are separated by an ash levee with a skimmer system to catch cenospheres (hollow floating fly ash particles) before they enter the secondary pond (see Figure B-1). The secondary pond discharge passes through three corrugated metal pipe discharge structures equipped with an underflow weir to provide additional protection from floating matter, including cenospheres. The effluent then enters the Clinch River. Current discharges are analyzed weekly and are acceptable under present NPDES requirements.

Labadie Plant

Labadie Power Plant is a four-unit, 2,400 MW coal-fired power plant owned by Union Electric Company and located near Labadie, Missouri. The plant currently consumes 14,400 tons (13,000 metric tons) per day of southern Illinois bituminous coal. Low sulfur coal may be required in the future to reduce sulfur emissions. The coal is combusted in tangentially fired boilers. Exhaust gases are passed through Research-Cottrell electrostatic precipitators and three 700 ft (213 m) high stacks. Labadie Power Plant was selected as a case study to describe a means of reducing the ash pond discharge to a pH between 6 and 9 as required by NPDES.

Figure B-2 indicates the general power plant ash pond arrangement. All water wastes, i.e., ash slurries, blowdown water, pyritic refuse slurry, acid wash

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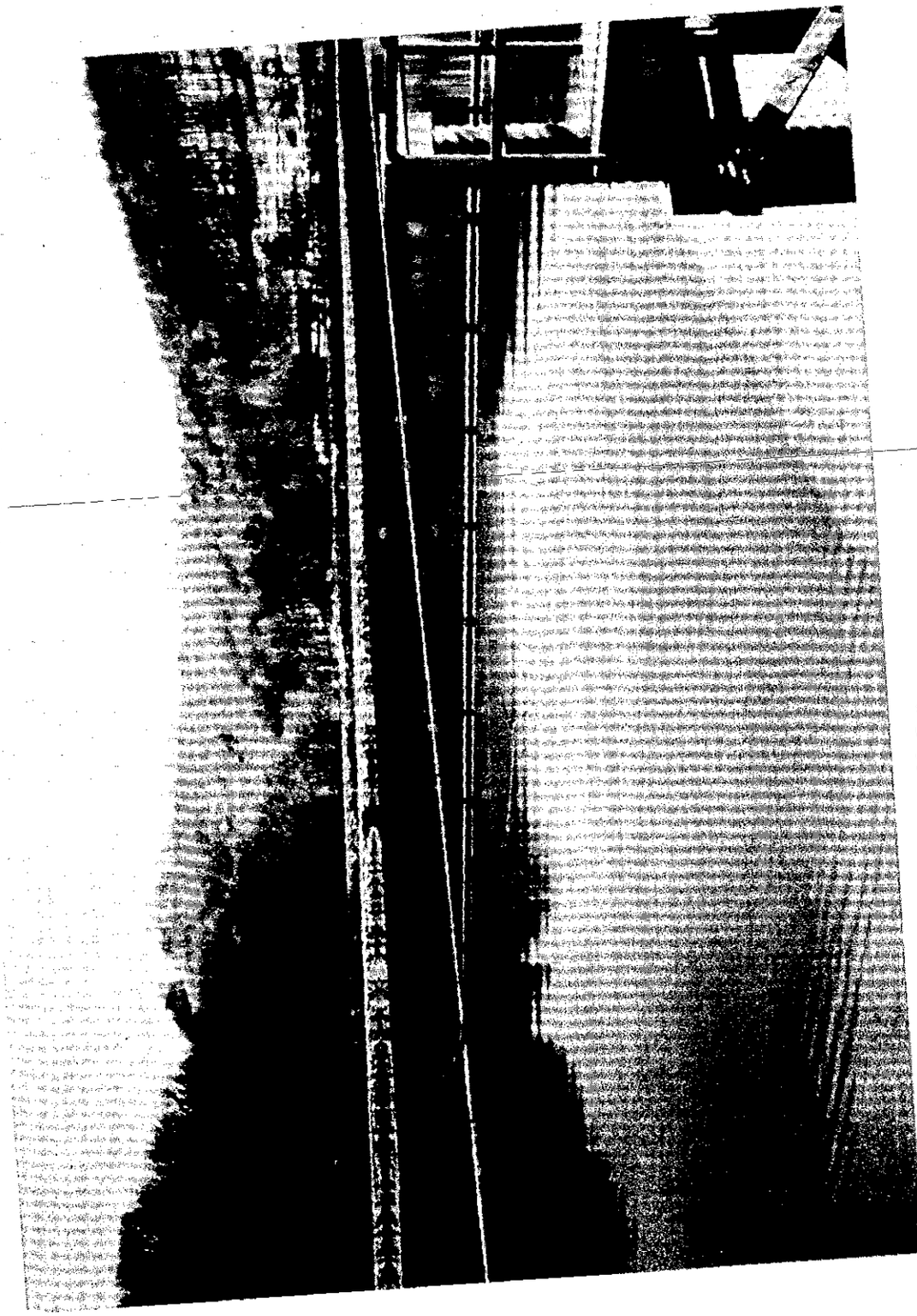

Figure B-1. Ash Levee and Skimmer, Bull Run

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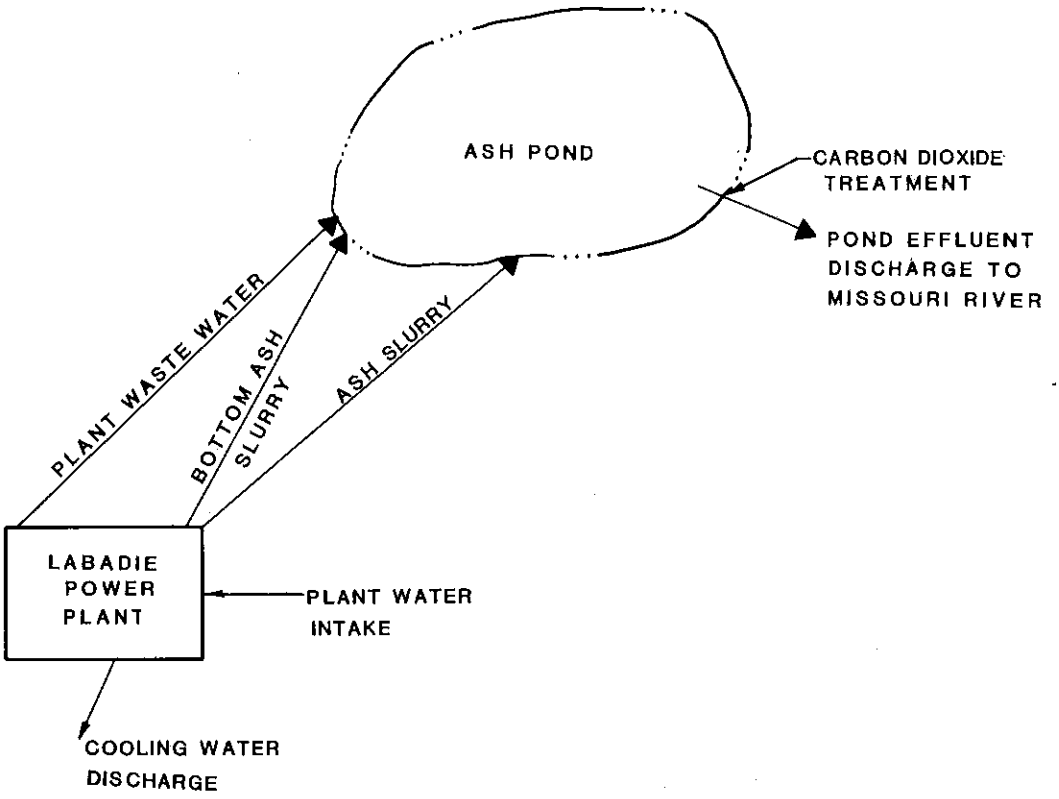

Figure B-2. Ash Disposal Schematic, Labadie

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water, neutralization water, etc., are pumped to the pond. Fly ash and bottom ash slurries are discharged to separate areas of the pond to maintain some degree of segregation. In this manner, the bottom ash can be excavated and utilized as anti-skid material (see Figure B-3). The fly ash, bottom ash, and pyrite refuse settle as they exit the discharge pipes. Pond effluent is discharged by pump to a one-half mile (0.8 km) long discharge canal which enters the Missouri River. The fly ash slurry pH is approximately 11 to 12 as discharged into the ash pond. However, by mixing this slurry with the other plant water, the resultant pond pH is in the range of 9.5 to 10. Labadie accomplishes compliance with their NPDES permit, i.e., maintaining a pH of between 6 and 9, by bubbling carbon dioxide gas through the pond discharge.

The addition of the carbon dioxide is accomplished by a constant feed system that is activated by the ash pond effluent discharge pump on-off control. When the pump is turned on, the carbon dioxide is bubbled into the pump intake. The pump acts as a mixing device to assure even and complete mixing. In addition, the discharge piping permits a sufficient detention time for the carbon dioxide to react, so when the discharge reaches the effluent canal its pH is less than 9.

Rush Island Plant

Rush Island Plant has two 600 MW coal fired units for a plant capacity of 1200 MW, is located near Rush Tower, Missouri, and is owned by Union Electric Company. The plant utilizes Combustion Engineering tangentially fired dry-bottom boilers to fire a mixture of bituminous coals obtained by both long-term and short-term contracts. The exhaust gases are passed through Lodge-Cottrell electrostatic precipitators and a 700 ft (213 m) high dual dive stack. Bottom ash and fly ash are sluiced to the pond through separate lines. Their discharges are at separate corners of the pond which provides a reasonable degree of segregation. Rush Island was selected as a case study to illustrate embankment/excavation pond construction. This method of construction is quite common where on-site material is acceptable.

The ash pond is a 96.4-acre (39.0 ha) impoundment, shown in Figure B-4. Originally, the ash pond site was a gently sloping area that ran from the river bank to the base of a series of bluffs overlooking the Mississippi River. Material was removed from this area to raise the power plant above the 500-year flood level. Additional material was also removed from this area to construct the ash pond embankment. These materials consisted of silts and sandy silts with some clay. The embankments were constructed with 3 horizontal to 1 vertical slopes and a

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Figure B-3. Bottom Ash Excavation, Labadie

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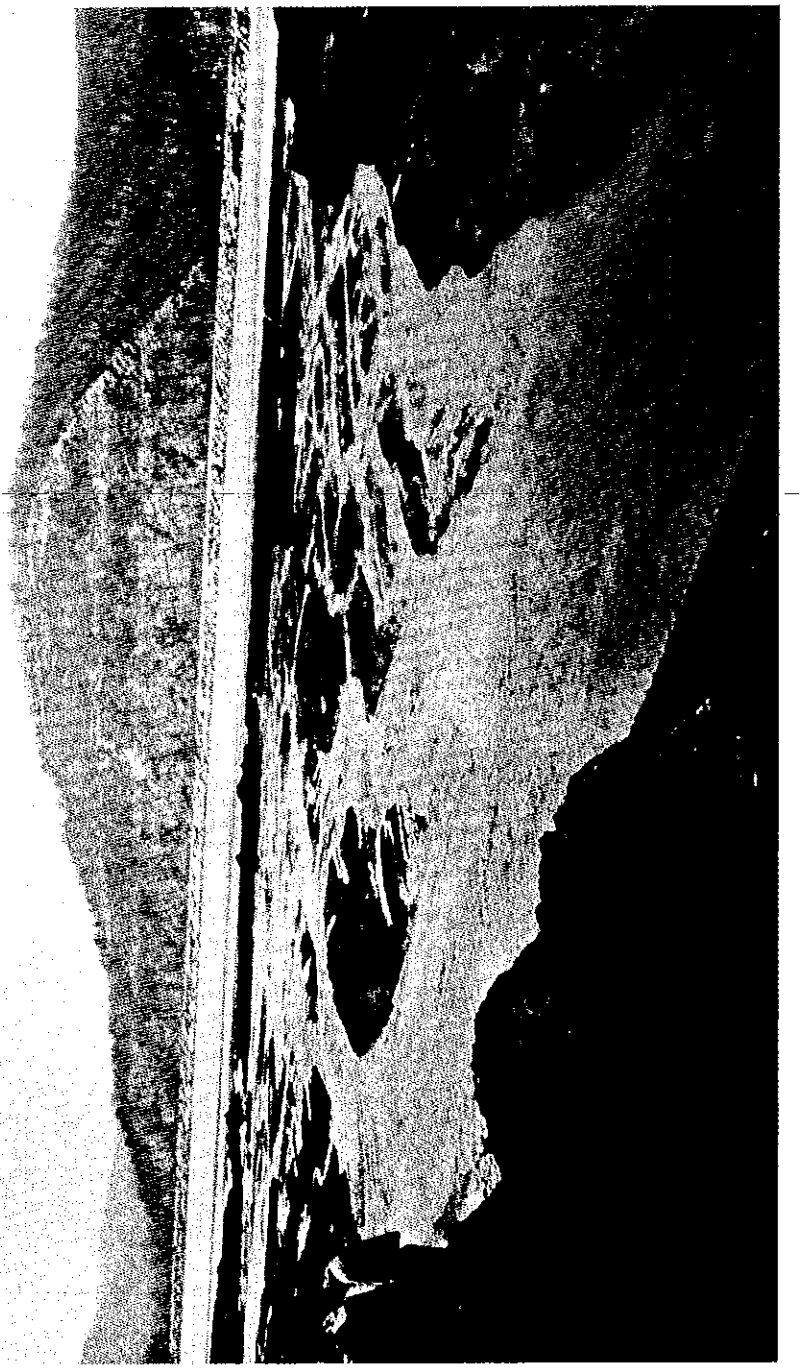

Figure B-4. Rush Island Ash Disposal Basin

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maximum height of 50 ft (15.2 m). After construction, the slopes were seeded and rip-rap placed on the lower outside embankment areas to provide slope protection from flooding.

Bottom ash and fly ash are discharged into the pond at different points to permit excavation and use of the bottom ash. Pond effluent is treated with carbon dioxide in a manner similar to Labadie. As water enters the discharge structures, CO_2 is injected by jets installed in the riser pipe (see Figure B-5). Mixing is accomplished in the outlet pipes leading to the discharge channel.

Brunner Island Power Plant

Brunner Island is located along the Susquehanna River in York Haven, Pennsylvania. It is owned by Pennsylvania Power and Light Company. The plant has three combustion engineering tangentially fired wet bottom boilers which have a total maximum generating capacity of 1485 MW. A maximum of 12,500 tons (11,300 metric tons) of central Pennsylvania bituminous coal are burned each day. The average ash content of the coal is 14.4 percent.

Fly ash is collected by electrostatic precipitators supplied by Research-Cottrell-Buell (Units 1 and 2) and Joy-Western (Unit 3) with 90 to 98+ percent removal efficiency for Units 1 and 3, and 99.5 percent efficiency for Unit 2. A fabric filter supplied by Joy-Western will be added to Unit 1 particulate removal equipment and the old precipitators will be by-passed and gutted. A Lodge-Cottrell precipitator will be added to Unit 3 particulate removal equipment. In addition, SO_3 injection systems have been installed on Units 1 and 3. The older ash ponds were constructed with an above ground dike system so that pond level was at plant grade. However, newer ponds were built so that pond level lies above the 1972 Agnes Hurricane flood level. Fly ash is slurried to a disposal pond along with bottom ash. Pyritic refuse is sluiced to a separate disposal area.

This plant was visited because it uses sulfuric acid to reduce the pond effluent pH. As shown in Figure B-6, acid is added to the effluent water as it leaves the pond. The effluent pH normally varies between 5 and 9. Acid is added at the pond discharge only when it is necessary to bring the pH to an acceptable value (less than 9). Mixing is accomplished by turbulence in the discharge structure.

Sunbury Power Station

Sunbury Power Station is a four unit 362 MW (net) coal-fired power plant owned by the Pennsylvania Power and Light Company and located in Sunbury, Pennsylvania, on

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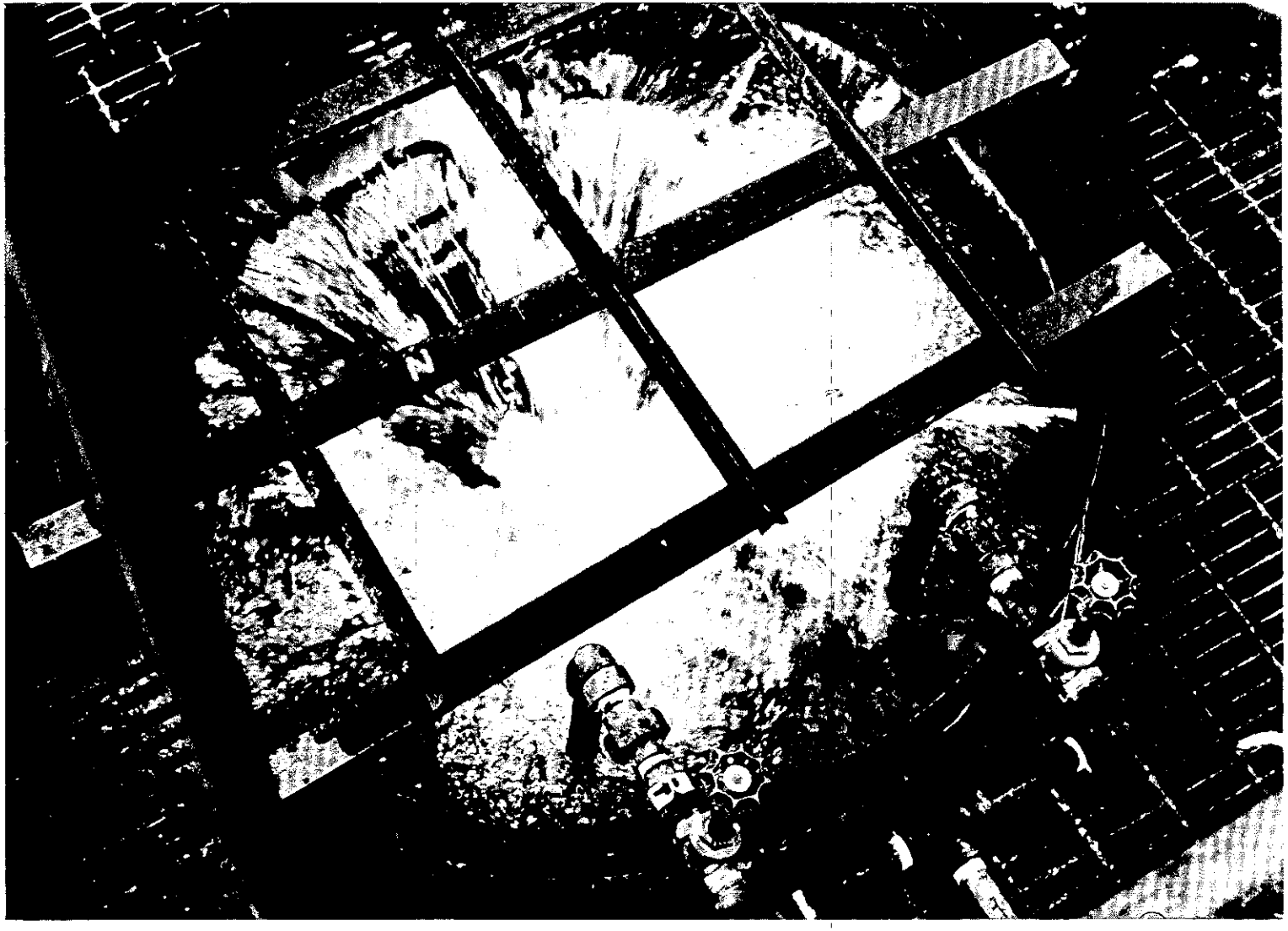

Figure B-5. Treatment of Ash Pond Effluent With Carbon Dioxide, Rush Island

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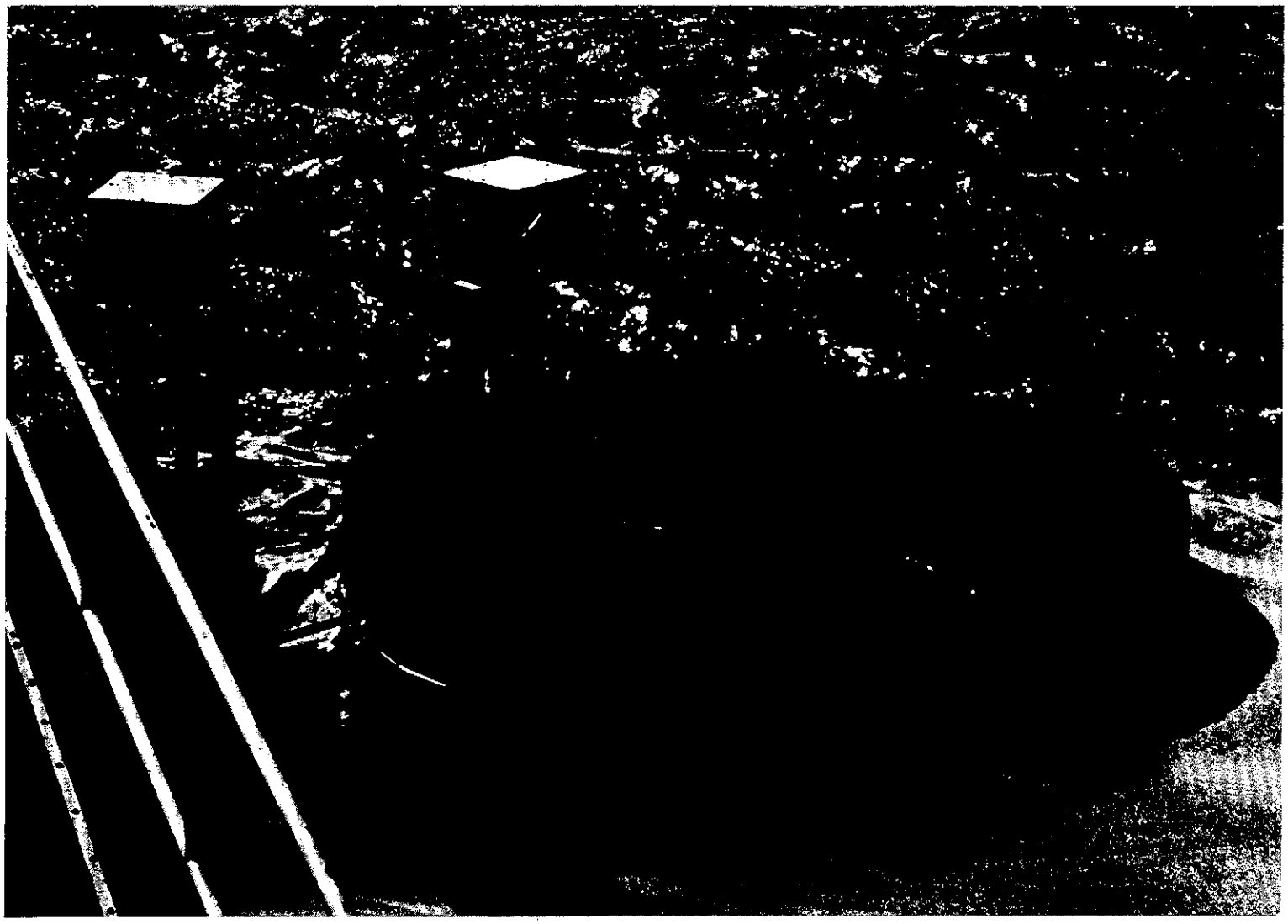

Figure B-6. Treatment of Ash Pond Effluent with Acid, Brunner Island

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the Susquehanna River. The plant steam supply consists of six Foster-Wheeler dry-bottom boilers. The steam from the five boilers feeding Units 1 (75 MW), 2 (75 MW), and 3 (94 MW), is collected in a common header and is used to operate the three turbine units. Unit 4 (128 MW) is a standard boiler-turbine combination. Boilers 1 through 4 burn a mixture of anthracite coal (sulfur content less than one percent) and coke (sulfur content of six to eight percent), whereas Boilers 5 and 6 burn a bituminous coal with 1-1/2 to 2 percent sulfur. The plant consumes approximately 4,100 tons (3,700 metric tons) of coal and coke per day, which is obtained from the eastern and central Pennsylvania area. Sunbury Power Station was selected as a case study because it uses lime as an ash pond treatment method due to the low pH of the ash pond water. This low pH is due to the use of the anthracite coal, coke and possibly the type of bituminous coal presently being burned. Another feature of the plant is its use of both electrostatic precipitators and bag-houses for particulate control.

Units 1 and 2 have Joy-Western baghouses whereas Units 3 and 4 have Buell and Research Cottrell precipitators in parallel. The exhaust stream from Units 3 and 4 is split such that 30 percent of the exhaust gases is routed through the Research Cottrell System and the remaining 70 percent is routed through the Buell system. The gas streams from the units are then exhausted through a pair of 300 ft (91 m) high stacks. The baghouse presently provides 99+ percent removal efficiencies, whereas the precipitators provide 98+ percent removal. To improve the precipitators' removal efficiencies, SO_3 conditioning has been installed on Units 3 and 4.

Bottom ash is collected from the boilers and slurried to a 25-acre pond near the plant, shown in Figure B-7. This is a dual pond with a small primary pond and a larger secondary pond. Bottom ash is excavated from the first pond to be marketed for anti-skid material and sand blasting operations. It is currently marketed to Bethlehem Steel Corporation for sand blasting ship hulls. Due to the acidity of the slurry, a lime solution is injected into the slurry pipe line near the plant to produce an effluent which is acceptable under their NPDES permit. If, however, there should be some system breakdown or failure, the ash pond discharge structure can be boarded up, using stop logs, to prevent pond discharge. This allows the addition of chemicals to alleviate the pond water problems. After the water has been treated, the discharge structure can then be opened up and normal discharge continued.

Fly ash, produced at a rate of approximately 200,000 tons (181,400 metric tons) per year, is sluiced to a pond located approximately 1.6 kilometers (one mile) from the

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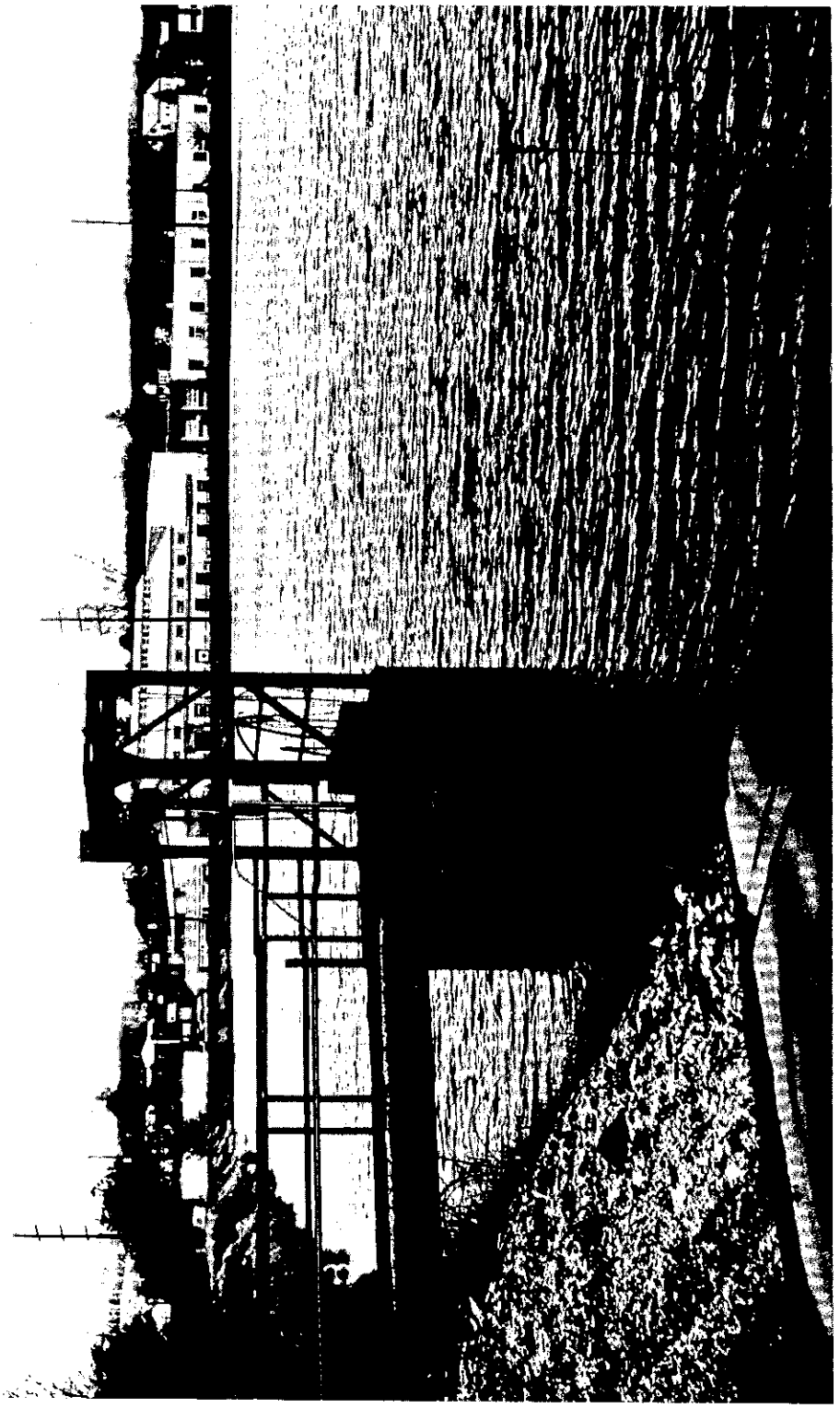

Figure B-7. Bottom Ash Pond, Sunbury

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plant. As with the bottom ash slurry, the acidity of the fly ash slurry requires the addition of a lime to reduce acidity prior to discharge to the pond.

Kingston Steam Plant

The Kingston Steam Plant is a 1700 MW coal-fired power plant located near Kingston, Tennessee, and owned by the Tennessee Valley Authority. The plant consists of four 175 MW units and five 200 MW units, all of which were placed on line in 1954 and 1955. Presently, the entire output from this plant is utilized by the Oak Ridge Atomic Energy Installation. Bituminous coal is delivered from Kentucky and Tennessee mines via trains and trucks. Twelve thousand to 16,000 tons (10,800 to 14,500 metric tons) of coal are fired daily in the balanced draft, dry-bottom boilers. The exhaust passes through mechanical collectors and two sets of electrostatic precipitators operated in series to provide 99+ percent particulate removal, then out 1,000 ft (300 m) high stacks.

Bottom ash and pyritic refuse are slurried along with the fly ash to a series of both old and new ash disposal ponds. The ultimate effect of this arrangement is that the slurry is discharged into a canal, located within a former ash pond, which discharges to the newer 250-acre (101.2 ha) settling pond. This new pond incorporates a discharge channel equipped with a skimmer arrangement. Water ultimately passes through an underflow weir discharge structure and into the plant cooling water intake channel. The skimmer arrangement is used to keep censopheres from entering the discharge. Currently, a private contractor is collecting these cenospheres for sale.

Figure B-8 is a schematic delineating the cooling water and ash handling distribution about the power plant. This discharge arrangement is a cross between a once through system and a total recirculation system. The advantages of this system are that the environmental effects of the ash pond discharge are reduced prior to discharge to the receiving water, and that the problem of soluble salt buildup is negated since this is not a true closed loop system.

As described above, the ash slurry is discharged into a canal which ultimately leads to the primary settling pond. However, due to the low flow velocity through this section, a substantial amount of bottom ash settles out and becomes an obstruction to the incoming slurry. To solve this problem, a dragline has been placed in operation to remove this accumulation of bottom ash (see Figure B-9). The bottom ash is then stockpiled on the sides of the canal where it dewaters. These piles are a source of bottom ash which is utilized locally for roadbase, aggregate replacement, etc.

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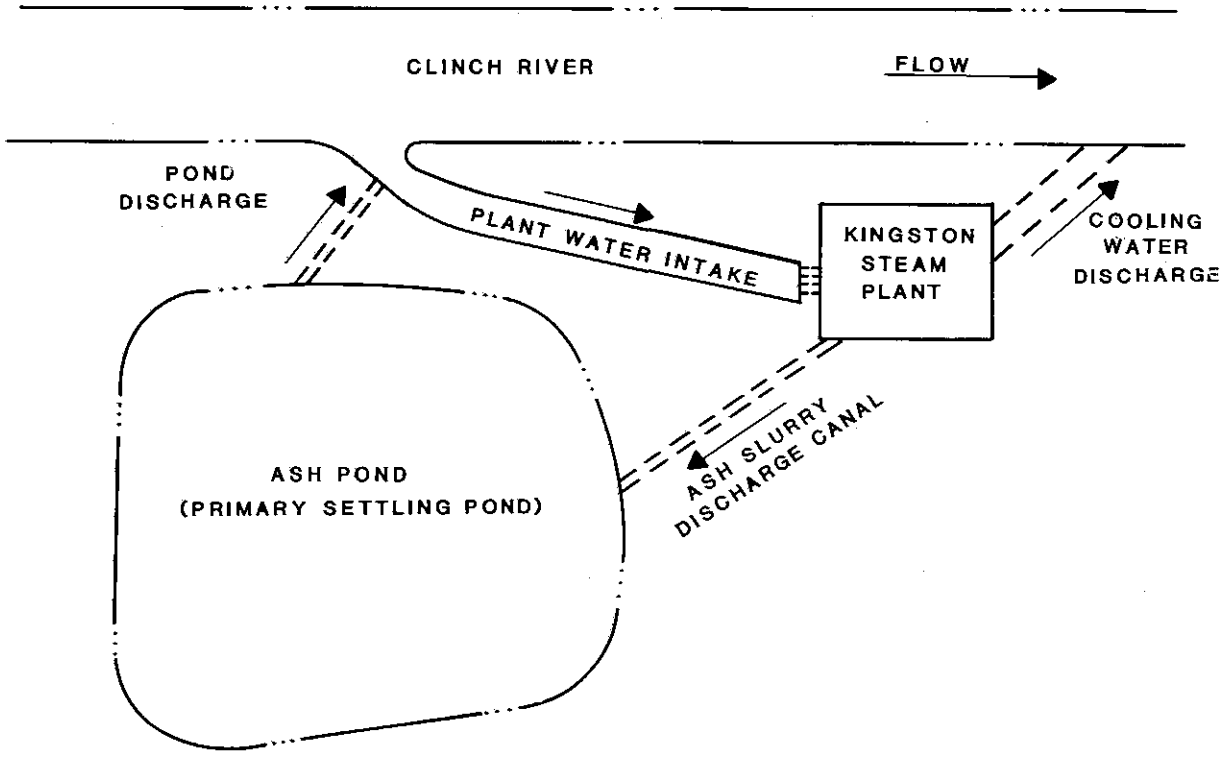

Figure B-8. Schematic of Kingston Steam Plant Water Distribution

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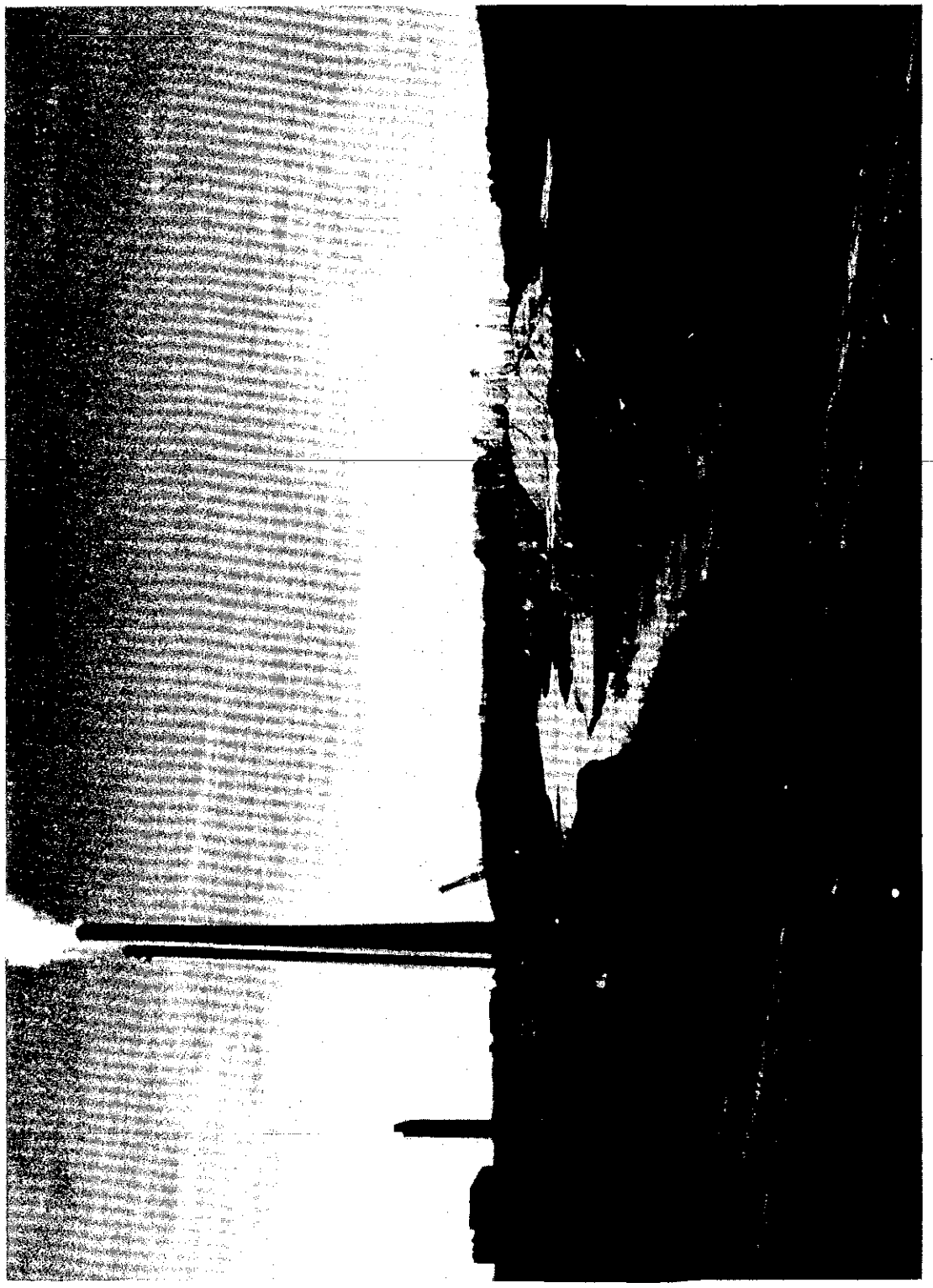

Figure B-9. Bottom Ash Excavation, Kingston

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Plant McDonough

Plant Jack McDonough is owned by Georgia Power Company, has a generating capacity of 490 MW, and is located near Atlanta, in Smyrna, Georgia. It burns approximately 3,800 tons (3,450 metric tons) per day of bituminous coal from Kentucky and Tennessee. The coal has an average ash content of 10 percent and a heating value of 12,000 Btu/lb (27,900 kj/kg). The plant has two 245 MW units, each of which has wet-bottom boilers. Plant Atkinson, a 240 MW oil fired generating station, is located adjacent to Plant McDonough. This ash disposal system is of note because it has a sluice water return line from the ash ponds to the ash pumping area, and because the pond construction is representative of side-hill embankment.

Fly ash at Plant McDonough is collected by Buell electrostatic precipitators which are 99+ percent efficient. The fly ash is moved to either storage silos for use in concrete, or to a mixing area where it is sluiced with bottom ash to disposal ponds. Presently, approximately 35 percent of the fly ash generated is used for concrete. In the future, bottom ash will be separated and sluiced to a holding pond for dewatering and sale.

As shown in Figure B-10, the wet disposal system is primarily a two pond series operation. The ash slurry enters Pond 3 for initial settling. Pond 3 discharges into Pond 4 through a channel. Pond 2 is currently empty and will be used for bottom ash dewatering. Supernatant from that operation will be pumped to Pond 3. Pond 1 is abandoned and has been covered with soil and seeded. Effluent from Pond 4 can be returned to the plant by gravity flow through a 24 in (61 cm) line or mixed with cooling water and discharged to the river. Approximately 50 percent of the ash pond effluent is recycled.

The pond embankment is shown in Figure B-11. Pond 3 has an average depth of 20 ft (6.1 m) and Pond 4 has an average depth of 30 ft (9.1 m). Ash is presently being dredged from Pond 3 to Pond 4 to increase slurry retention time in Pond 3 and prolong its life. The system as a whole has an estimated remaining life of 18 years.

Montrose Station

Montrose Station is a three-unit 510 MW coal-fired power plant located near Clinton, Missouri, and is owned by Kansas City Power and Light. The power plant consists of three Combustion Engineering boilers with dry bottoms that consume an average of 5,000 tons (4,500 metric tons) of coal per day. Unit 1 was brought on line in 1959, Unit 2 in 1960, and Unit 3 in 1974. The power plant is a mine mouth operation

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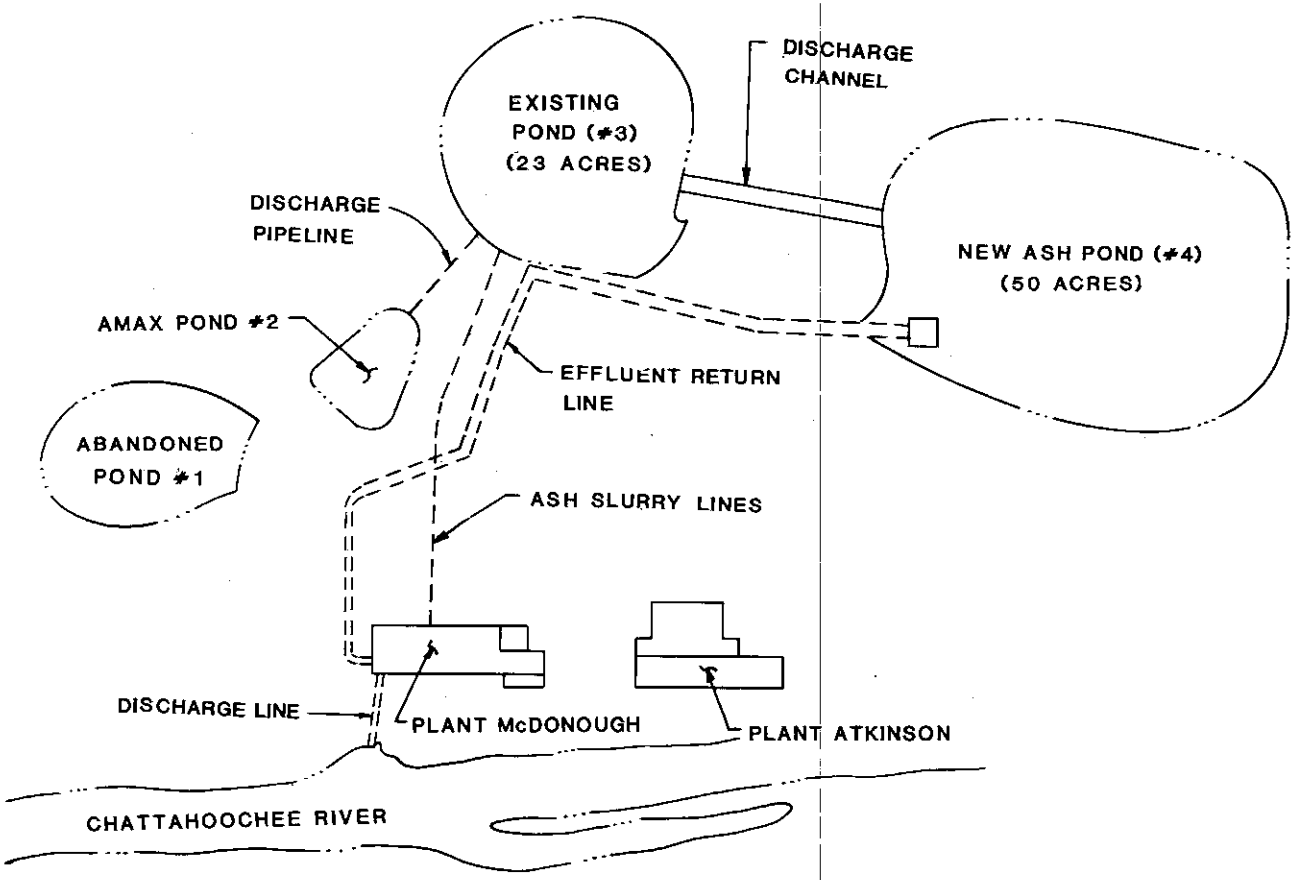

Figure B-10. Ash Disposal System, Jack McDonough

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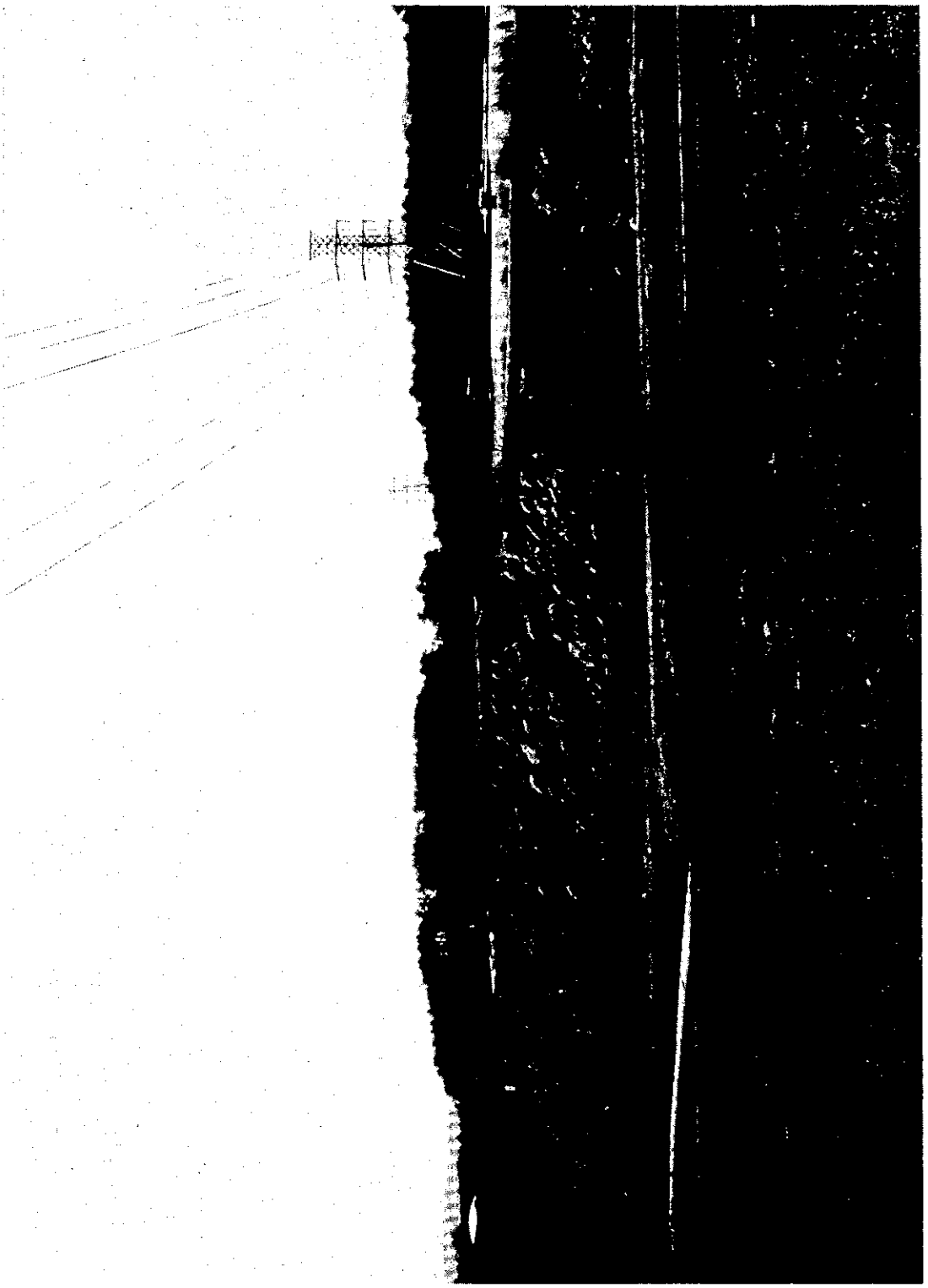

Figure B-11. Ash Pond Embankment, Jack McDonough

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which acquires subbituminous coal from a Peabody Coal Company mine. The coal has an average ash content of 30 percent and is a blend of washed and unwashed coal with an average sulfur content below six percent. Montrose power station was visited to examine its complete recirculation of bottom ash slurry water and its use of a private railroad to transport ash.

Bottom ash is removed from the boilers, slurried with the pyritic refuse, and dewatered in dewatering bins. The supernatant from the dewatering bins is then recirculated to the boilers and reused for bottom ash transport. Salt buildup or other recirculation problems have not yet been encountered. The bottom ash-pyritic refuse is subsequently loaded onto side dump railroad cars and transported to the ash disposal area.

Fly ash is collected from the precipitator hoppers and transferred to a storage silo. The ash is then either marketed or placed in side dump railroad cars as shown in Figure B-12. If the ash is being disposed of, the railroad cars are hauled to the Peabody Coal Mine. Here, the fly ash is deposited in the stripped area, covered with spoil material and revegetated. The use of the railroad and side dump cars, Figure B-13, for ash transport imposes restrictions on disposal operations. Because of their limited right-of-way the railroad tracks have to be moved periodically to avoid long disposal hauls of the ash. On-site spreading equipment is needed on a full time basis to spread the ash after it is dumped. In addition, the on-site equipment must be capable of cleaning out ash stuck in cars and of lifting derailed cars back on the track. If the ash does not discharge when the car is tipped, the car will tip off of the track.

Naughton Power Plant

The Naughton Power Plant is a 688 MW coal-fired power plant located near Kemmerer, Wyoming, and owned by Utah Power and Light. This plant utilizes subbituminous coal from the Sorensen Mine, located adjacent to the power plant, which is 8-9 percent ash and 0.4 to 0.7 percent sulfur. This coal is fired in three Combustion Engineering tangentially fired pulverized coal wet-bottom boilers. Flue gasses are passed through Research-Cottrell electrostatic precipitators. The Naughton Power Plant was visited due to its conversion from single cell ponds to two cell series ponds and to observe a method of constructing pond embankments using self-hardening ash.

Bottom ash is removed from the boilers, quenched, and slurried together with the pyritic refuse. Fly ash is removed from the precipitator hoppers and either marketed or sluiced together with the bottom ash-pyritic slurry to the ash

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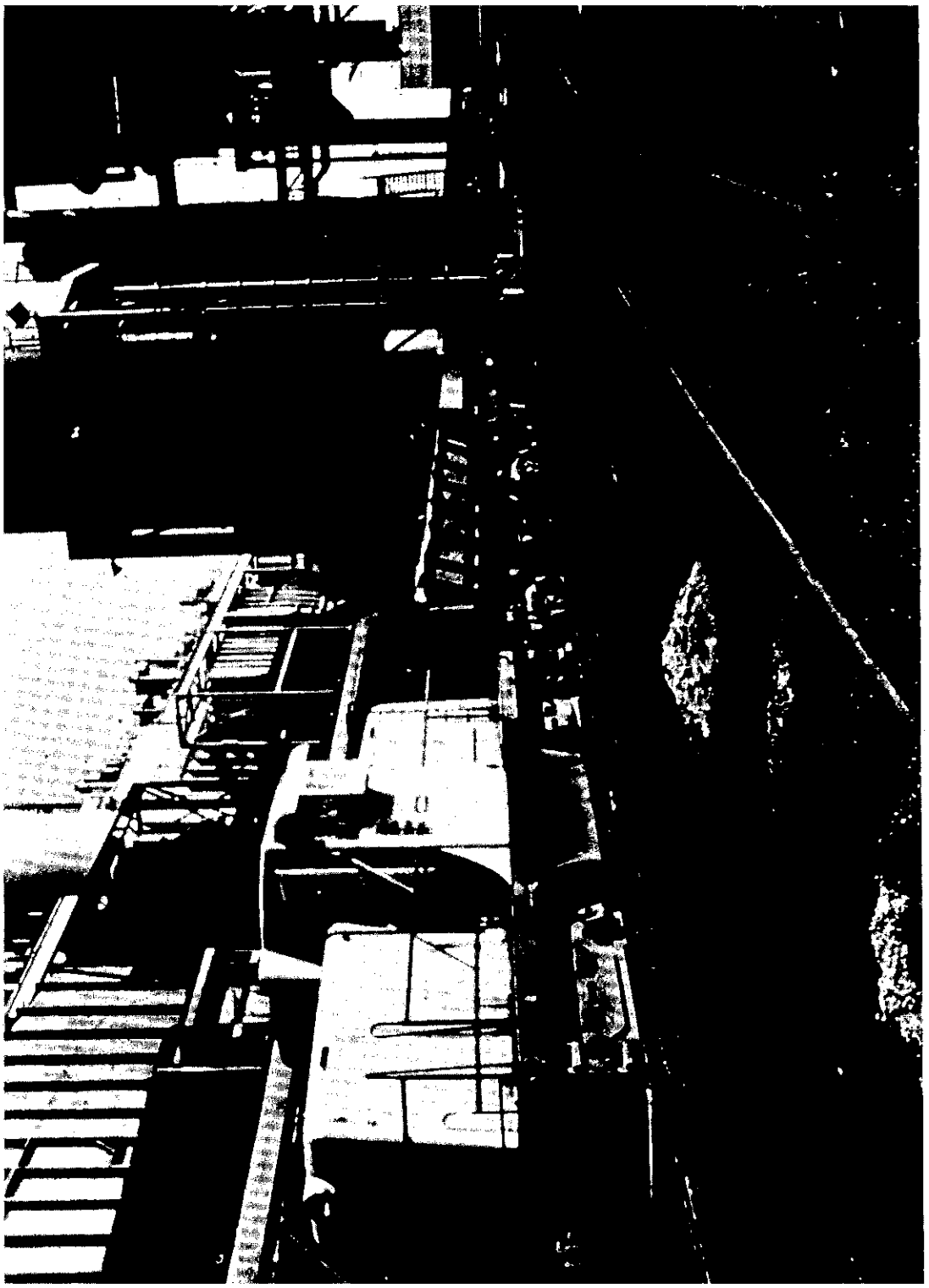

Figure B-12. Ash Loading, Montrose

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Figure B-13. Ash Dumping, Montrose

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disposal ponds. Units 1 and 2 (367 MW) orginally discharged to a single 20 acre (8.1 ha) pond, the effluent from which exceeded NPDES suspended solids requirements. They now discharge to a 26-acre (10.5 ha) two stage pond with a 6-acre (2.4 ha) primary area as a sediment trap and 20-acre (8.1 ha) secondary area for final clarification prior to discharge. A schematic of this pond is shown in Figure B-14. The 320 MW Unit 3 discharges into a similar two stage pond with 6-acre (2.4 ha) and 30-acre (12.1 ha) primary and secondary areas.

The ponds are divided by a soil dike between the primary and secondary areas, such that there is no more than a two foot difference in water level between the areas (see Figure B-15). The difference in water level is controlled by the primary area discharge structure. Ash entering the primary area is settled, and the supernatant is discharged to the secondary area. As the depth of ash in the primary area approaches the top of the dike, the dike is raised. The ability to raise the dike is due to the self hardening property of the ash. Since the ash behind the dike sets up, it exerts little thrust, thus allowing the dike to be raised with little fear of structural failure.

Clifty Creek Power Plant

Clifty Creek Power Plant is a 1284 MW coal-fired power plant located near Madison, Indiana. Although privately owned through a consortium of power companies, the electrical output of this plant is dedicated to the Department of Energy, Portsmouth Gaseous Diffusion Plant in Portsmouth, Ohio. Coal from Southern Indiana and Western Kentucky Mines is presently supplied to the plant by barges. Ash is removed from the exhaust gases by electrostatic precipitators. New precipitators were completed in 1979. Plant ash yearly production, 55 percent fly ash and 45 percent bottom ash, is approximately 243,000 tons (220,000 metric tons) of bottom ash and 297,000 tons (269,000 metric tons) of fly ash. The Clifty Creek Power Plant is of interest due to its use of floating, flexible, plastic pipe to control the placement of ash within the disposal area. This method can achieve excellent ash disposal distribution within a pond with minimal effort by the plant personnel.

Bottom ash is slurried to two bottom ash ponds. Because increased precipitator efficiency will require more storage capacity, one of the bottom ash ponds may eventually be converted to a fly ash disposal pond. Then all bottom ash will be slurried to one pond. This is possible due to an original oversizing of the bottom ash ponds and subsequent marketing of the bottom ash.

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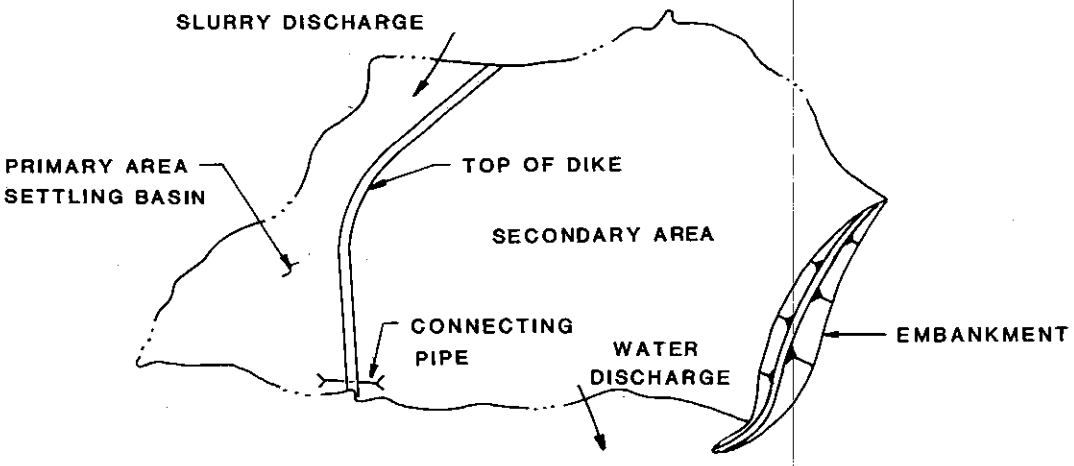
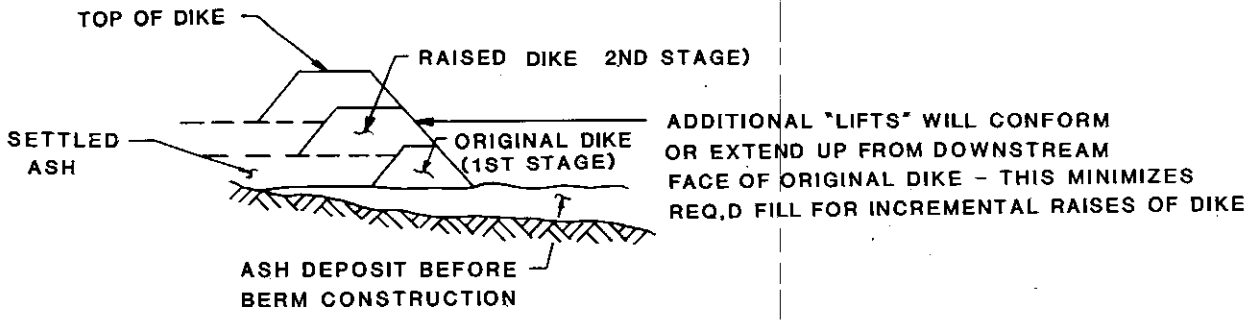


ASH POND 1



TYPICAL BERM SECTION

Figure B-14. Schematic of Ash Disposal Pond, Naughton

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Figure B-15. Dividing Berm, Naughton

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Fly ash is collected dry from the electrostatic precipitators. It is then slurried and pumped to the fly ash disposal area. During the use of the present fly ash pond, full utilization of the volume became a problem due to its long narrow geometry. Fly ash settled out near the sluice line discharge and would not fill the entire pond. This problem was alleviated by extending the slurry lines with polyurethane heat welded plastic piping with flotation collars, as shown in Figure B-16. Piping was extended through the pond and terminated at a floating platform positioned by guy wires to the shore. Present operation consists of moving the floating platform via guy wires to a predetermined position. Once sufficient amounts of fly ash have been deposited, the platform is moved to another position. This method requires minimal manpower and negates the need for either motorizing the platform or utilizing a boat when the pipes are moved. When the existing pond is full, piping will be installed to the converted bottom ash pond.

Marshall Station

Marshall Station is a 2025 MW coal-fired power plant located on Lake Norman, near Terrell, North Carolina, and owned by Duke Power Company. Lake Norman is a 100,000 acre (40,470 ha) impoundment created by Cowans Ford Dam, a Duke Power Company hydroelectric project. Also located on Lake Norman is Plant McGuire (a nuclear power plant). A third plant is possible based on cooling water availability. Marshall Station consists of four units which were brought on line in 1961, 1962, 1969, and 1970. Bituminous coal is brought to the plant by unit trains from Kentucky and Tennessee. Particulate removal on units one and two is accomplished by mechanical collectors followed by electrostatic precipitators. This combination provides a 99+ percent particulate removal. This performance is enhanced by chemical injection. Units three and four each have two electrostatic precipitators in parallel with particulate removal performance of 99+ percent. Marshall Station was visited to observe its method of maximizing its ash pond capacity by dredging.

Bottom ash is removed from the boilers, quenched, and slurried together with the pyritic refuse to the ash disposal area. Fly ash is collected from the precipitator hoppers and either marketed by Amax Resource Recovery or sluiced with the bottom ash-pyritic refuse slurry to the ash pond.

The ash pond is a 268-acre (108.5 ha) impoundment created by an earthfill dam across an unnamed stream. The maximum pond depth is approximately 75 feet (22.9 m) at the dam. Initial disposal capacity was 19,000,000 yd^3 (14,535,000 m^3) of ash. In addition to the plant water, the ash disposal pond must also handle runoff from the drainage basin contiguous to the ash pond. Although not large in comparison to

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Figure B.16. Floating Slurry Lines, Clifty Creek

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the size of the pond, this drainage area does contribute substantial quantities of stormwater runoff, decreasing pond settling time and, therefore, total effective ash storage volume. This complicates not only ash placement, but final pond closure since this runoff volume must be diverted when the pond is abandoned. As initially designed, the ash slurry discharge was near the point of pond discharge causing poor distribution of ash in the pond. In addition to preventing full utilization of the impoundment volume, it also threatened to violate the ash pond discharge requirements. A barrier was constructed to prevent ash entering the discharge structure and a canal constructed such that a greater percentage of the pond would be utilized. However, even this flow rerouting still did not permit its full utilization. This was due, in part, to the irregular shape of the pond. To maximize the disposal potential, a dredge is now being used to transfer ash from the main ash deposition areas to backwater areas (see Figure B-17). This shifting of ash permits full use of all the available storage volume within the embayments that would otherwise remain unfilled under previous ash disposal operations. The use of a dredge to redistribute the ash was selected due to the ownership of a dredge within the power company. Since the dredge is somewhat portable, it can be transferred between jobs, if required.

Navajo Station

The Navajo Station is a 2400 MW coal-fired power plant managed by the Salt River Project and located near Page, Arizona. The plant burns subbituminous coal which is mined at the Kayenta Mine located on the Black Mesa, 78 miles (125 km) from the plant. After stripping operations, the coal is moved by conveyor to a coal storage silo, where it is loaded onto the Black Mesa and Lake Powell Railroad and transported to the plant. The coal, which has an average ash content of 10 percent and a sulfur content of 0.51 percent, is fired in Combustion Engineering wet-bottom boilers. Under full load about 24,000 tons (21,820 metric tons) of coal are burned per day. Exhaust gases are routed through Joy Manufacturing hot side electrostatic precipitators operated in parallel, then through one of three 750 ft (229 m) high stacks. The Navajo Station was visited to observe trucking dry ash to a canyon disposal site in an arid environment.

Bottom ash is removed from wet-bottom boilers, quenched, and slurried along with the pyritic refuse to dewatering bins where the supernatant is decanted. This supernatant is passed through a secondary settling operation prior to return to the bottom ash quenching/slurry operation, completing the water recycle loop.

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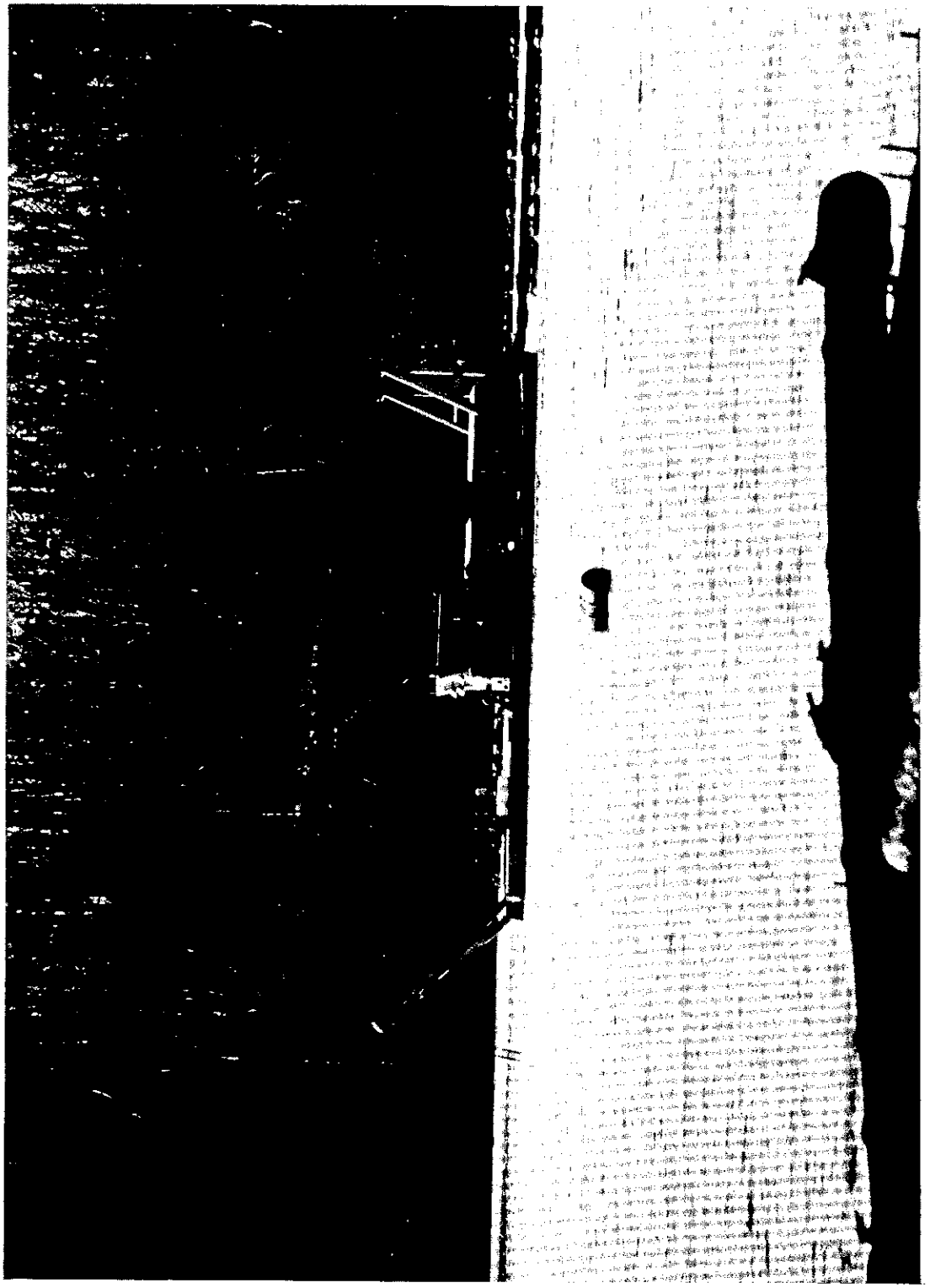

Figure B-17. Ash Dredge, Marshall

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Fly ash is transported from the electrostatic precipitator hoppers by a pneumatic system to storage silos. Here, air is bubbled through the ash to fluidize it. This is done to minimize caking and agglomeration problems due to the high free lime in the fly ash. Ash which is being marketed is loaded into tank trucks. Ash which is sent to disposal is mixed with water in a dustless unloader and placed in 60 ton (54 metric ton) off-road, end-dump trucks along with the dewatered bottom ash-pyritic refuse for transport to the disposal site.

The Navajo ash disposal area is a canyon located approximately two miles from the power plant and designed to contain approximately 41,460,000 yd^3 (31,716,900 m^3) of ash when completed. The ash disposal area is designed to be filled with ash that is placed in 2 ft (0.6 m) layers and compacted by machine tracking. The high free lime of the fly ash serves to cement the ash into a solid mass, further consolidating the fill. Due to current utilization of the fly ash as a concrete filler, the majority of ash transported to the site is the bottom ash-pyritic refuse mixture. Studies are being conducted to assess the possibility of bottom ash utilization, which would require the separate disposal of the pyritic refuse. The compacted fly ash has a permeability of 17 feet/year (1.6×10^{-5} cm/sec). Fill side slopes are maintained at a 3 horizontal to 1 vertical slope. As areas within the disposal areas are completed they are covered with 2 feet (0.6 m) of sandy soil (see Figure B-18).

No revegetation is attempted, other than to allow native species to volunteer. This is due to the arid climate, less than 7 in (18 cm) of precipitation per year, which makes any revegetation difficult. However, the end purpose of a vegetative cover, i.e., erosion control, is adequately fulfilled by the two foot sand cover which provides protection from severe dusting. In addition, when heavy rain occurs, the site has been designed to contain the disposal area runoff from a 100-year storm. All of the runoff will be collected and evaporated; consequently, no sediment discharge occurs.

Front Street Station

Front Street Station is a 110 MW coal-fired power plant located in Erie, Pennsylvania. The plant is owned by the Pennsylvania Electric Company and was originally brought on line in 1921; however, the existing Units 7 and 8 date from 1942 and Units 9 and 10 from 1952. Bituminous coal from western Pennsylvania is delivered to the plant and burned in water tube, drum type, dry-bottom boilers which provide steam to condensing and one back pressure turbines. The exhaust gases are routed through Research-Cottrell electrostatic precipitators and discharged through short stacks.

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Figure B-18. Sand Cover on Exterior of Ash Fill, Navajo

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Coal consumption at the plant varies due to its current use as a cycling station; however, maximum coal consumption is approximately 1,000 tons (900 metric tons) per day at peak capacity. Ash production is currently on the order of 39,000 tons (35,400 metric tons) per year. Front Street Station was visited to observe the use of fly ash as a means of restoring disturbed areas. Since the plant is located on the shore of Lake Erie in downtown Erie, the ash must be trucked to an off-site disposal area approximately 7 miles (11.3 km) from the plant.

Bottom ash is removed from the boilers, slurried, and dewatered in settling ponds. After settling, bottom ash is then excavated and piled on the sides of the ponds for final gravity dewatering. It is then loaded into dump trucks and transported to the ash disposal area. Fly ash is removed from the precipitator hoppers and transferred to a storage silo. It is then mixed with water to prevent dusting and transported, along with the bottom ash, to the disposal areas by tandem, end-dump trucks (Figure B-19).

The ash disposal area, as shown in Figure B-20, is a sand and gravel pit. This area, which is about 42 acres (17.0 ha) in size and has a capacity of about 316,000 tons (287,000 metric tons) of ash, was designed, permitted, and placed in operation in 1977. The site has been prepared for the ash by providing a PVC liner and subsurface drain system to intercept groundwater flow and isolate it from the ash. In addition, a bottom ash drainage blanket has been placed under the entire site so that the majority of the water percolating through the ash would be collected for subsequent treatment, if required. The ash is currently placed in an uncompacted state. Four monitoring wells were installed to monitor ground water quality in compliance with Pennsylvania regulations.

Due to the site's proximity to a highly traveled highway, it is likely that it could be used as light commercial or industrial property once the site is brought to grade and closure completed. Siting studies for the ash disposal project considered a number of properties. This site was selected because the cost of land near Erie is rather high and, by utilizing a disturbed area for ash disposal, the power company has been able to minimize its capital expenditure, even though site preparation costs are high. In addition, by proper site planning, the disposal area property is available for future resale at a higher value, thus providing a return on investment for the power company.

Waukegan Station

The Waukegan Station, located near Waukegan, Illinois, is an 800 MW coal-fired

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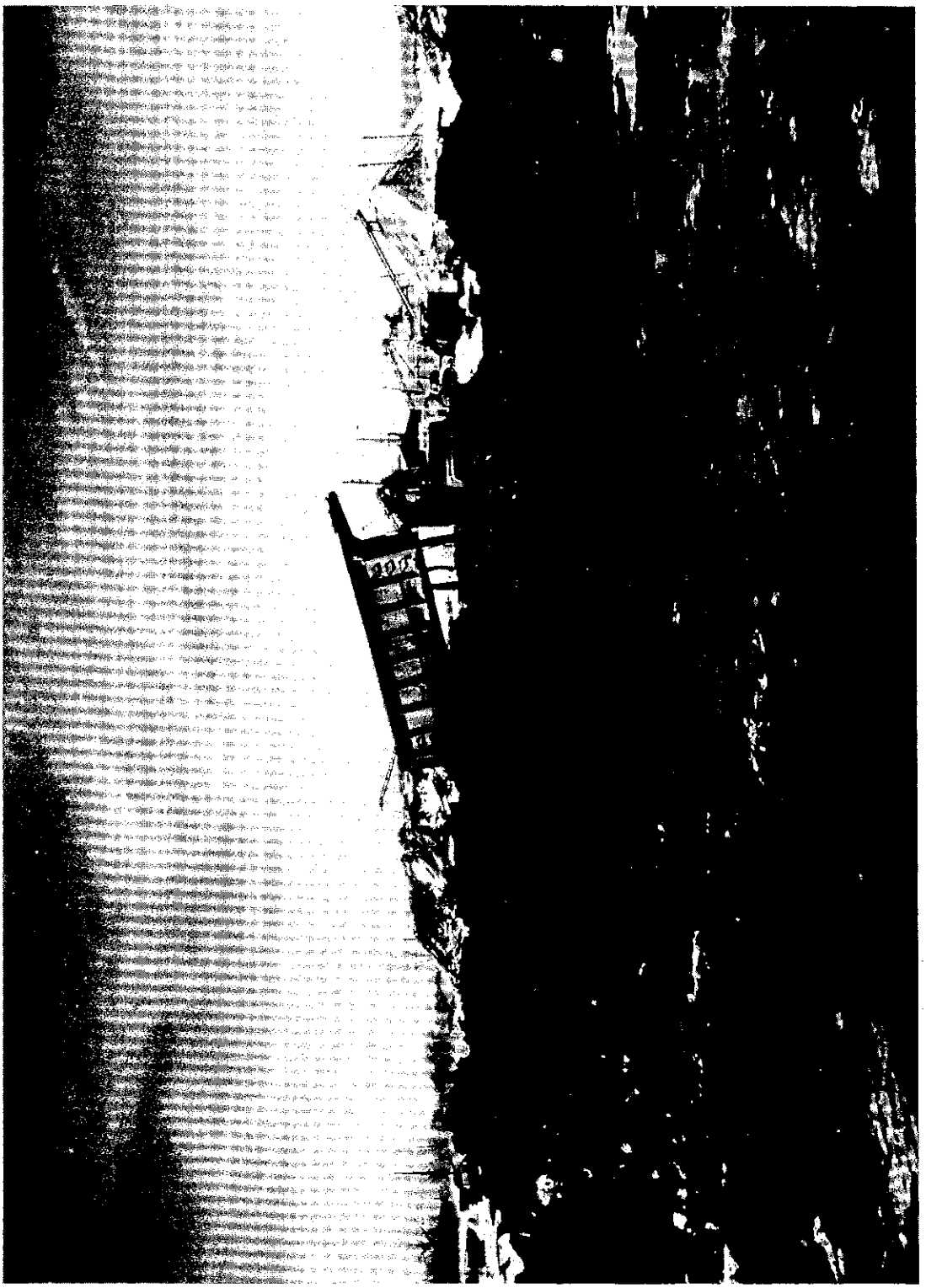

Figure B-19. Ash Placement, Front Street

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Figure B-20. Front Street Ash Disposal Area

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power plant owned by Commonwealth Edison Company. The power plant has five older units which have been retired, and now consists of three units, one with a cyclone boiler and two with pulverized coal-fired, dry-bottom boilers. The plant consumes 5,000 tons (4,500 metric tons) per day of western subbituminous coal with a 10 percent ash content and 0.4-0.5 percent sulfur content. Exhaust gases are passed through either Research-Cottrell (Unit 6), P. C. Walter (Unit 7), or Koppers (Unit 8) electrostatic precipitators. Units 6 and 8 utilize SO_3 injection to enhance particulate removal. Overall fly ash removal is approximately 98 percent. Although the plant is owned by Commonwealth Edison Company, American Admixtures Corporation (AAC) is responsible for the ash disposal. The 37-acre (15.0 ha) ash disposal area is the Newport landfill, owned by AAC and located near Zion, Illinois, approximately one-half mile (0.7 km) south of the Wisconsin Border. Fly ash disposal at the Newport landfill site incorporates the American Admixtures FAS™ System, which is a proprietary system. The Newport landfill site was visited to observe the use of a stabilization process in the disposal of ash from western coal.

Bottom ash is collected and slurried at a rate of 100 tons (91 metric tons) per day and dewatered in dewatering bins. The bottom ash is then sold or trucked to the ash disposal area for use as access road base material.

Fly ash, 500 tons (450 metric tons) per day, is transferred from the precipitator hoppers to silos where it is pneumatically transferred to sealed tankers and sold or trucked to the disposal area, depending upon the demand for fly ash. The fly ash must be maintained dry since it is a reactive ash which will set up if subjected to moisture. Moisture in the tankers must be avoided since handling would be difficult and the heat of hydration may result in vaporization of the water and excessive internal pressure in the tanker. Once at the site, the fly ash is either temporarily stored in the tankers or transferred to a storage silo. Prior to disposal, it is mixed into a thick slurry (25-50 percent water content as a percent of dry fly ash) with proprietary admixtures added when required for stabilization. The resultant slurry is then pumped into a clay-lined cell, shown in Figure B-21, where it proceeds to harden into a product similar to soft shale. The purpose of the mixtures is to increase pumpability and strength and decrease permeability so that leachate movement is prevented. Ultimately, the disposal area is to be covered with the original clay/topsoil mixture which has been retained. It is expected to be used for agricultural purposes after closure. Monitoring wells have been installed by others beyond the perimeter of the area to evaluate leachate movement according to Illinois EPA permits.

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Figure B-21. Ash Disposal Area, Waukegan

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Allen S. King Plant

The Allen S. King Plant is a 581 MW coal-fired power plant owned by Northern States Power Company and located near Oak Park Heights, Minnesota. The plant utilizes a Babcock and Wilcox Universal Pressure cyclone fired boiler to burn 5,100 tons (4,625 metric tons) per day of subbituminous and bituminous (Montana and southern Illinois) coal and petroleum coke. The gases are passed through Research Cottrell electrostatic precipitators which have a 95+ percent fly ash removal efficiency. The Allen S. King Plant was visited to observe a current method being used to establish the magnitude and quality of leachate from a dry fill.

Bottom ash (slag) is slurried, dewatered, and placed in the bottom ash placement area. Fly ash is pneumatically transferred from the precipitator hopper to a storage silo where it is mixed with water in a dustless unloader, placed into dump trucks, and hauled to the placement area. There the ash is end dumped and spread with a dozer. Approximately 96,000 tons (87,300 metric tons) of ash were placed in this manner in 1978.

The Allen S. King ash placement area is presently serving as a fly ash leachate monitoring study area. Both monitoring wells and test cell have been constructed to analyze in-place leachate generation and its impact on the groundwater system.

Figure B-22 shows the test cells as installed at the ash placement area. To analyze various leachate generation conditions both "acidic" fly ash from the Allen S. King Plant and "alkaline" fly ash from the High Bridge plant were utilized. In addition, two ash densities will be studied. Two test cells were placed by end-dumping only; the other two cells were placed and compacted. To determine the amount of rainfall occurring, i.e., percolating through the ash, a rainfall gage has been installed.

The test cells were installed in the fall of 1978. However, when leachate collection begins, it will be measured and tested monthly for quantity and quality (pH, dissolved oxygen, alkalinity, total dissolved solids (TDS), sulfate, chloride, phosphorus, barium, boron, cadmium, arsenic, manganese, nickel, zinc, aluminum, iron, magnesium, and selenium).

In addition to the leachate generation study, the ash placement area is currently being monitored for groundwater changes. As shown on Figure B-23, four 4-1/2 in (11.4 cm) PVC groundwater monitoring wells have been installed. One upgradient monitoring point will provide background samples. Three downgradient wells are

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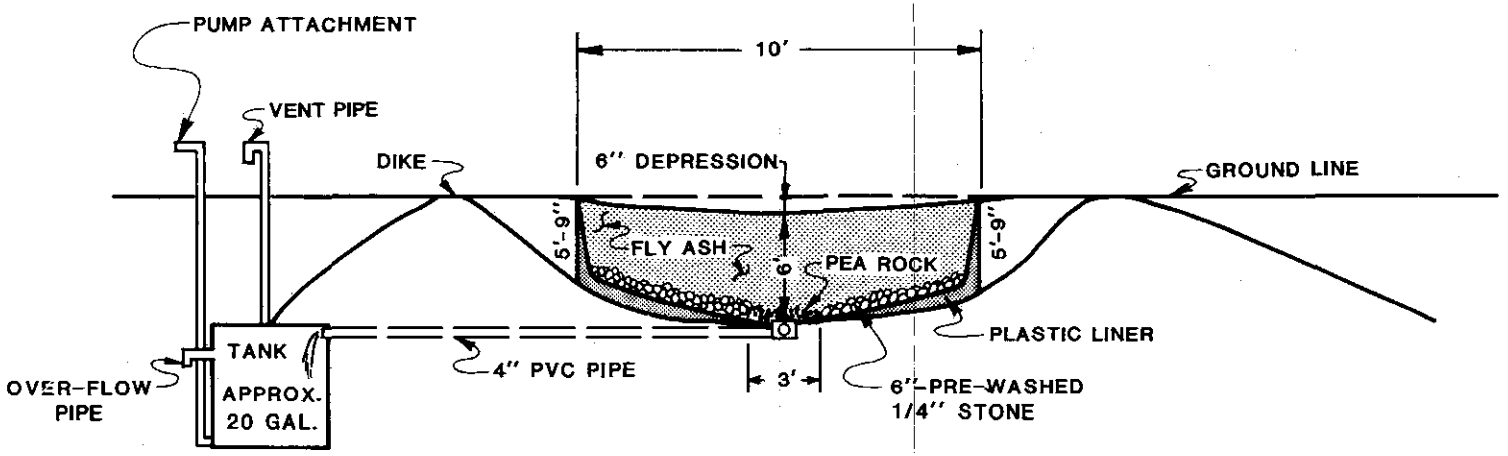

Six inches of Pea Rock, 3'-0" wide over 4" drain pipe
fill rest of area with 1/4" washed stone.

Figure B-22. Fly Ash Test Cells, King

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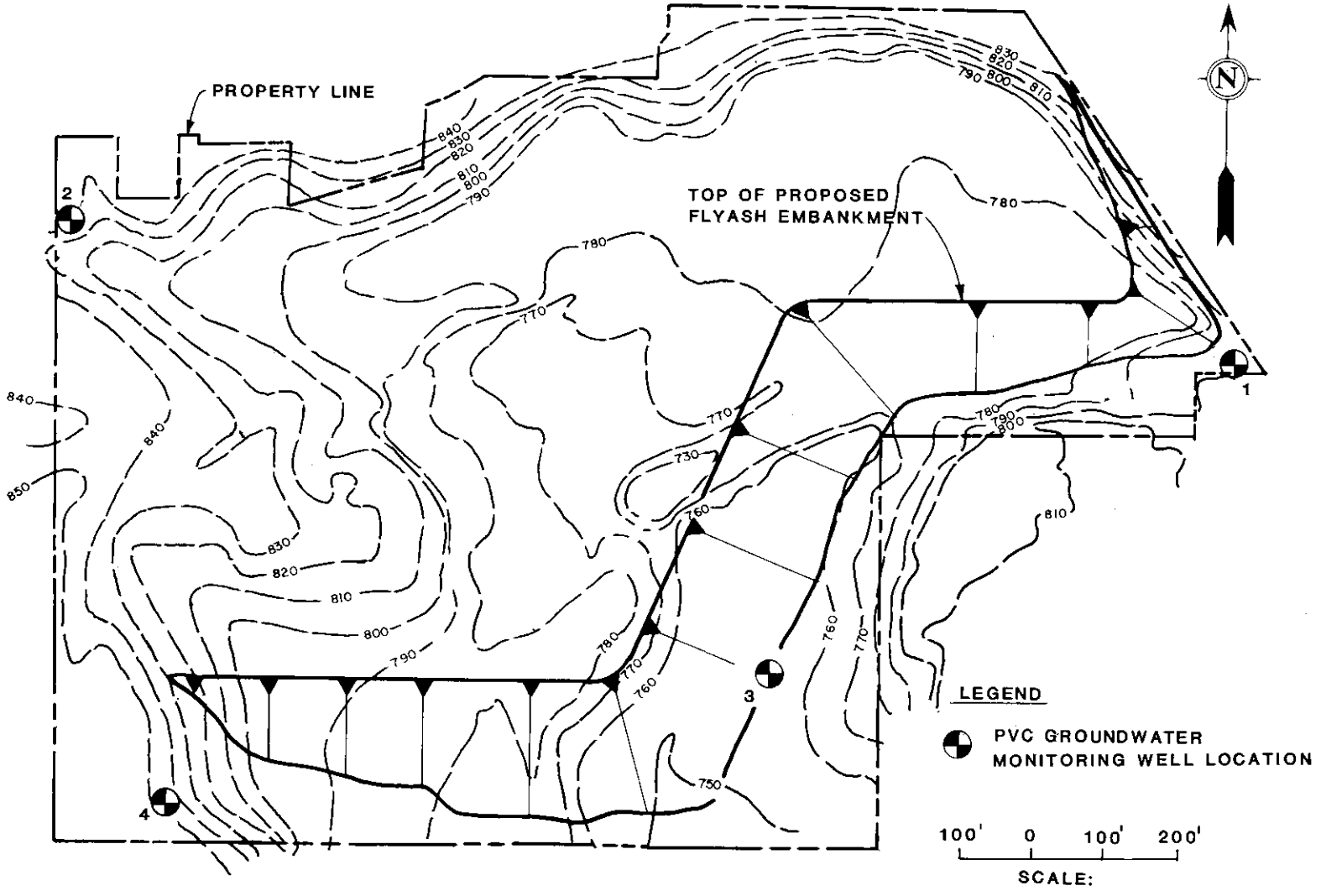

Figure B-23. Ash Storage Area, King

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being utilized to determine the impact of the site on the groundwater system. Sampling of the groundwater monitoring points will be performed quarterly to determine total dissolved solids (TDS), sulfates, manganese, boron, and pH. Boron has been specified as an indicator metal, i.e., if the boron concentration changes by more than 50 percent, the fly ash leachate is assumed to have entered the groundwater system. If this occurs, then a metals analysis will be performed to determine cadmium, copper, hexavalent chromium, lead, mercury, nickel, zinc, arsenic, silver, selenium, and iron concentrations.

Powerton Station

The Powerton Station, located at Pekin, Illinois, is a 1800 MW plant owned by Commonwealth Edison. The plant had been burning 12,000 tons (10,900 metric tons) per day of bituminous Illinois coal with an average ash content of 10 percent and a sulfur content of 3 percent. However, subbituminous western coal with a sulfur content of 0.24 to 0.53 percent is now being burned to help control sulfur emissions. The boilers are the cyclone type, and produce 42 percent fly ash and 58 percent boiler slag. This disposal site was visited due to the use of a constructed site liner and because they are currently using the completed surfaces of the site for growing agricultural products.

Fly ash is collected by electrostatic precipitators and pneumatically conveyed to two 1,500 ton (1,360 metric ton) storage silos. It is either sold for use in road materials, pozzolanic or bituminous pavements, or sent to the disposal area. Boiler slag is sluiced to a dewatering bin, dewatered, then trucked to the disposal area or sold for various commercial purposes.

American Admixtures Corporation places all ash and slag requiring disposal in the Mahoney landfill. The disposal site is located in a low lying area, a portion of which is within the floodplain of Lost Creek. The soil profile for the site indicates that large sand and gravel deposits underly two to seven ft (0.6 to 2.1 m) of silty clay. In order to minimize the flow of leachate into the groundwater, the Illinois EPA required the installation of a site liner. The liner used is 8 in (20 cm) of pozzolanic concrete (as shown in Figure B-24). A new site to be located adjacent to the existing site will have a 5 ft (1.5 m) thick pozzolanic concrete liner. The pozzolanic concrete is a mixture of lime, fly ash, and boiler slag aggregate which is sold commercially for roadbase and similar applications. Samples from 9 monitoring wells within and around the disposal site are analyzed for total residue, sulfate, iron, and chlorides.

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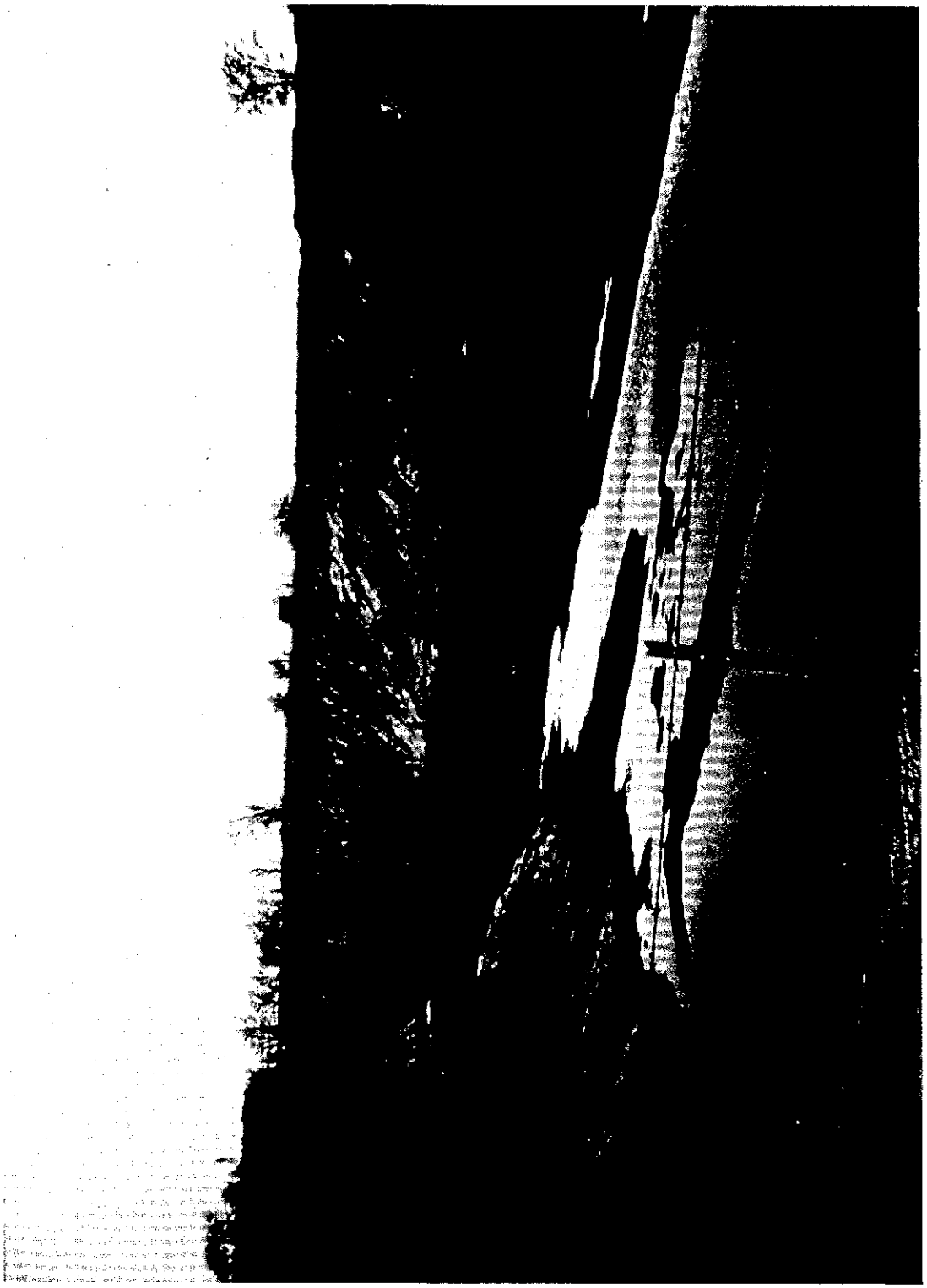

Figure B-24. Site Liner, Powerton

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Fly ash and boiler slag used in the pozzolanic concrete are stockpiled in a damp condition prior to mixing. Fly ash sent to disposal is placed in the fill by end dumping from open end dump trucks and spread and compacted by a dozer. The fill has a maximum height of 30 ft (9.1 m) and side slopes of 2 horizontal to 1 vertical. When a section of the landfill reaches final grade, it is covered with 18 in (46 cm) of silty clay and 6 in (15 cm) of imported topsoil, then seeded with a mixture of grasses. As shown in Figure B-25, some portions of the completed fill have been seeded with winter wheat to assess the possibility of using the closed site for agricultural purposes. The completed portion of the site has now been harvested for the first time and the wheat sold.

Coal Creek Power Plant

The Coal Creek Power Plant near Underwood, North Dakota, is jointly owned by the Cooperative Power Association (56%) and the United Power Association (44%). Lignite from the nearby Falkirk mine is burned in both 550 MW units. The boilers are Combustion Engineering pulverized coal, dry-bottom, balanced draft boilers. The plant has an expected life of 35 years, which is also the expected life of the lignite reserve. With both units at peak capacity, the plant will burn approximately 21,000 tons per day of lignite that has a heat value of 5800-6800 Btus/lb. and 9% ash. Coal Creek was visited to observe lignite ash disposal.

Bottom ash is sluiced to a disposal pond, Figure B-26. Effluent is currently recycled from the pond back to the plant for use as bottom ash sluice water. A second pond is under construction and is approximately four times larger than the pond currently in use. The ponds were lined with two feet of clay with a permeability of 1×10^{-6} cm/sec. These ponds encompass an estimated 400 acres, and are designed to store ash through the life of the plant.

Fly ash is collected by cold-side Wheelabrator Fry electrostatic precipitators and transported to silos by a pneumatic pressure system. Fly ash is also being used in a lime/fly ash SO_2 scrubber. Fly ash is trucked from the silos to the mine for burial during mine reclamation, or loaded into trucks or rail cars for sale.

Centralia Power Plant

The Centralia Power Plant is located in southwest Washington near Centralia, and is jointly owned by Pacific Power and Light (48%) and several smaller interests, including other power companies and cooperatives. The plant has two 665 MW generating units made by Combustion Engineering that have been operating since 1972. Subbituminous coal is strip mined nearby and trucked to the plant. The plant burns

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Figure B-25. Reclaimed Area, Powerton

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Figure B-26. Bottom Ash Disposal Pond, Coal Creek

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an average of 19,000 tons of coal per day. The ash content is 15-17 percent and the heat content is about 8,000 Btu/lb. Centralia was visited to observe mine disposal of subbituminous ash.

Bottom ash is sluiced from the boiler hoppers approximately 300 feet to dewatering bins by a United Conveyor closed loop system. Water is returned to the system through a settling tank and a surge tank. Additional make-up water is supplied from recycled wastewater. Bottom ash removed from the bins is stockpiled for future sale or sent to the strip mine for disposal.

Fly ash is collected by two sets of precipitators. The first set is from Koppers and removes 99% of the ash. Lodge-Cottrell precipitators were added in series to meet particulate emission standards. Overall removal efficiency of the series of precipitators is 99.96 percent. Fly ash is handled in-plant by a United Conveyor pressurized pneumatic system and transported to storage silos. From the storage silos, fly ash is either loaded dry into Pozzolanic Inc. carriers, or unloaded through rotary unloaders into trucks for transport to the mine disposal area. Pozzolanic Inc. carriers are either rail cars especially adapted for ash transport, or bulk tank trucks.

Fly ash sold to Pozzolanic Inc. is used for bulk concrete replacement material and also as a pozzolan. Pozzolanic Inc. unloading facilities include an air classifier and bagging facility. Bottom ash is sold to a trucking firm, which sells the ash for use in road base and driveways.

Ash that is not sold is mixed with the strip mine spoils during reclamation, Figure B-27. At an active pit, over 250 feet of overburden was being removed to reach coal seams varying from 10 to 30 feet in thickness. Ash placed in the mine is end-dumped and spread by rubber-tired dozers. The ash is then buried during the reclamation process. Ash and other waste products, such as coal cleaning wastes, are mixed with the lower soil horizons during the reclamation procedure. Final reclamation includes the placement of topsoil, seeding, and the planting of saplings.

Big Brown Plant

The Big Brown Power Plant is situated near Fairfield, Texas and is equally owned by three power companies: Texas Power & Light, Dallas Power & Light, and Texas Electric Service, all members of Texas Utilities. The two 575 MW units burn approximately 20,000 tons of pulverized lignite per day, which is strip mined about four to six miles away by Texas Utilities. The lignite contains approximately 15

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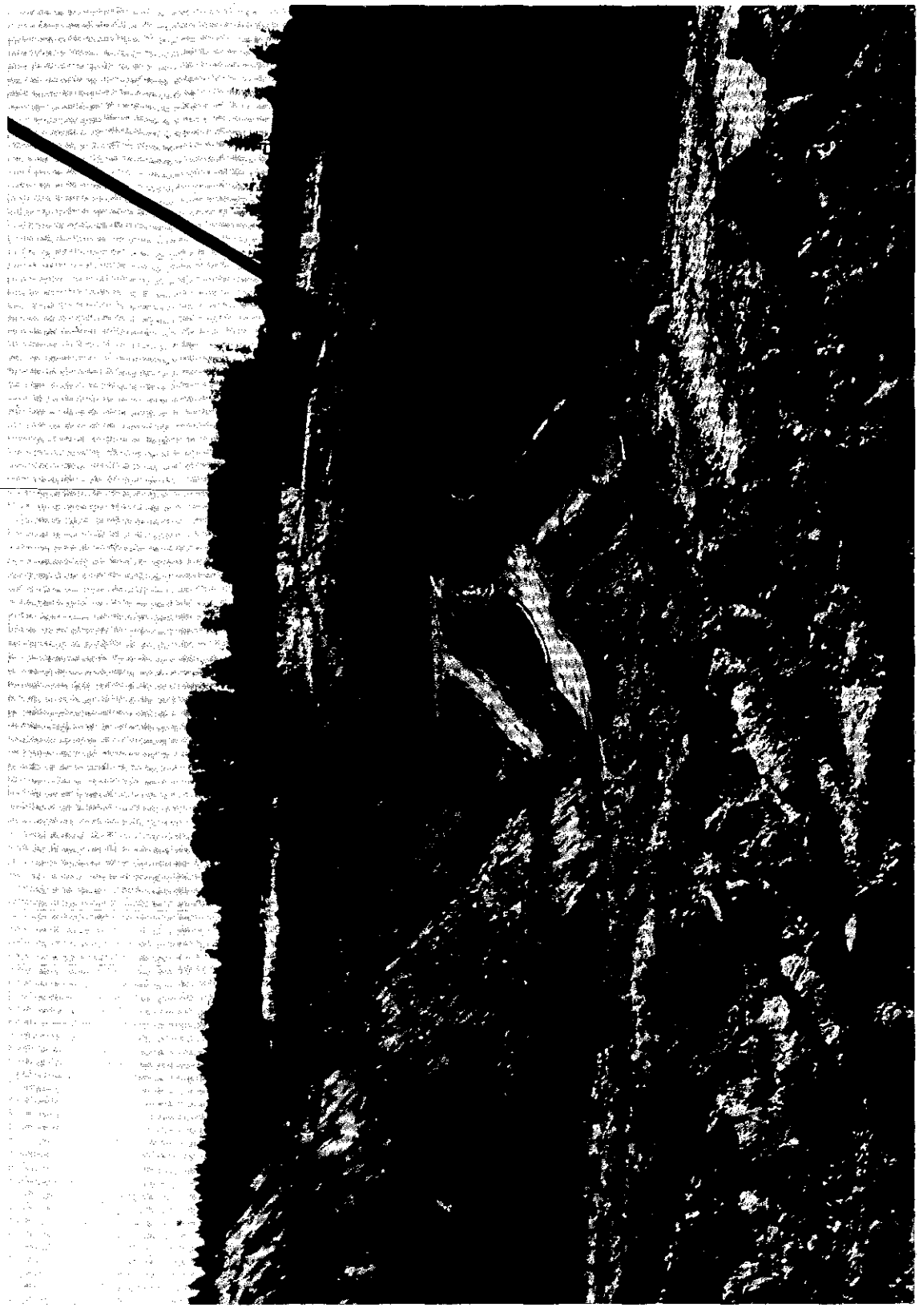

Figure B-27. Ash Disposal in Strip Mine, Centralia

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percent ash content and approximately 6,800 Btu/lb. Both boilers are Combustion Engineering, tangentially fired, supercritical, dry-bottom models. Water from Lake Fairfield, 2,500 acres, is used for cooling. Boiler make-up water is obtained from wells located adjacent to the plant. Big Brown was visited to observe lignite ash disposal and treatment of recycled bottom ash sluice water.

Bottom ash is quenched as it leaves the boiler and, after crushing, is pumped by jet pumps to disposal ponds located an estimated 2,500 feet from the plant. The bottom ash disposal system has two dewatering ponds which are used on an alternating basis. The bottom ash delta formed near the point of slurry discharge is moved out into the pond with a dozer. Bottom ash excavated from the ponds is either trucked to strip pits for disposal or used on plant and strip mine roads as an aggregate replacement. The typical fill/excavation cycle for the ponds is three months. Bottom ash pond effluent is 100 percent recycled. After passing through a skimmer discharge structure, the effluent is treated with sulfuric acid to reduce the pH to between 6.0 and 9.0. Approximately 3,000 gallons of acid are used each month. The recycled water then flows by gravity through 24-inch diameter pipes to a high pressure pumping system for reuse. Make-up water is supplied from plant discharges, including auxiliary boiler blow-down, area runoff, and service water make up (wash-down water).

Fly ash is collected by Research Cottrell precipitators, which have been rewired for double power and also use an Appolo additive to enhance collection. After collection, fly ash is pneumatically conveyed to two storage bins and a silo located an estimated 1,500 feet from the plant by a United Conveyor Handling System. The storage bins are owned by TUGCO and operated by General Portland Cement; the silo is owned and operated by Texas Utilities. One General Portland storage bin is used to store ash for subsequent transfer by tank trucks, Figure B-28, to a rail line for shipment to a central bulk cement plant. The other General Portland storage bin stores ash which is used for grouting, and mixed with a proprietary additive prior to shipment. The Texas Utilities silo is a transfer station in the fly ash disposal system. Fly ash transferred to this silo is unloaded into off-road scrapers through United Conveyor dustless unloaders, (10 percent moisture added), and hauled to certified disposal sites. Approximately 1728 tons of fly ash per day require disposal.

Leland Olds Station

The Leland Olds Station is owned by the Basin Electric Power Cooperative, and located near Stanton, North Dakota. The plant has two units. Unit 1, rated at 216

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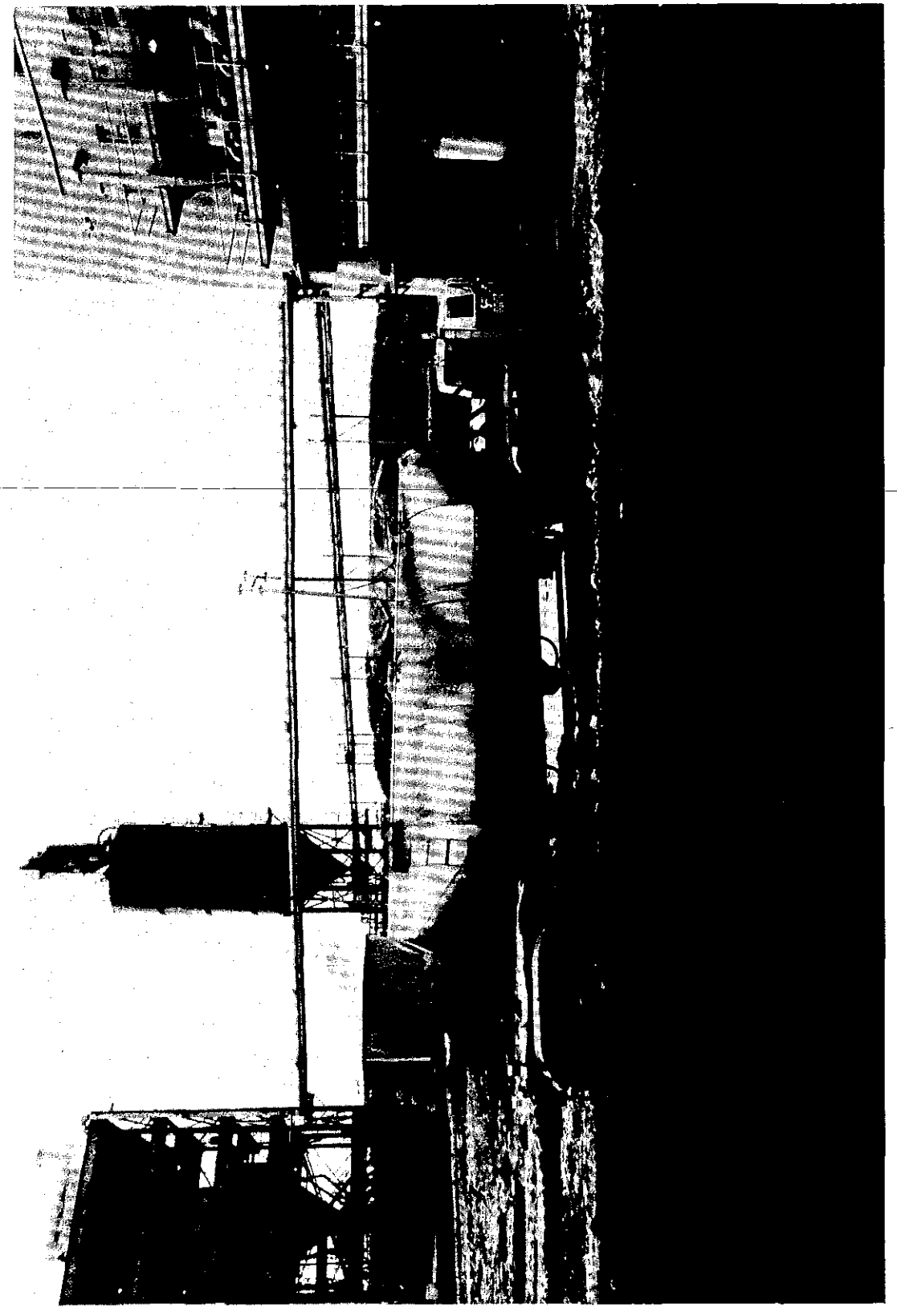

Figure B-28. Fly Ash Loading, Big Brown

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MW, burns pulverized lignite in a Babcock and Wilcox boiler. Unit 2 has a Babcock and Wilcox cyclone boiler rated at 440 MW. The bottom ash to fly ash ratios for the units are 35:65 and 67:33, respectively. Lignite for the station is strip mined at the adjacent GlenHarold mine; it contains about 10 percent ash and 6,000-7,000 BTU/lb, as received. Maximum lignite consumption is 13,000 tons per day. Leland Olds was visited to observe wet lignite ash disposal.

Both units have cold side electrostatic precipitators. Unit 1 has a Research Cottrell precipitator and Unit 2 has a Joy Western precipitator. Both precipitators operate at 99.9 percent efficiency, and achieve particulate removal in compliance with the state opacity regulations.

The Leland Olds Station uses a wet ash disposal system. Fly ash is collected by vacuum, sent to a hydrovactor, and then slurried by gravity to the ash ponds which are located some 2,500 feet east of the power station. Bottom ash, after grinding, is sluiced by jet pump to the disposal ponds. The fly ash and bottom ash are sluiced together to the same pond. The fly ash, which is self-hardening, has a tendency to clog pipes and restrict slurry transport. High-pressure water cleaning has proved effective in cleaning individual pipe joints.

The ash disposal ponds function in a series arrangement. At present, there are four ponds. Three ponds are now in use. Pond 4 is out of service until ash is excavated. The surface area of the first pond is approximately 50 acres, the second 40 acres, the third 3 acres, and the fourth 70 acres. The ash slurry from Units 1 and 2 enters the first pond where the coarse ash settles. Supernatant is drawn off into the second pond for further settling, and the third pond acts as a polishing pond for water prior to pumping back to the plant. (B-29)

Water from the ash ponds is recycled to the plant where it is mixed with cooling water, and either discharged into the Missouri River or recycled in the sluicing system. Plant cooling water is handled on a once-through basis from the Missouri River, through the plant, and back into the Missouri River. The pond supernatant is diluted to avoid solids build-up in recycled water, and to dilute any high concentrations of chemicals in the pond discharge.

Hunter Power Plant

The Hunter Power Plant near Castle Dale, Utah, is owned by Utah Power & Light. The two 410 MW units burn approximately 6,800 tons of pulverized subbituminous coal per day from a nearby surface mine owned by Utah Power & Light and operated by the

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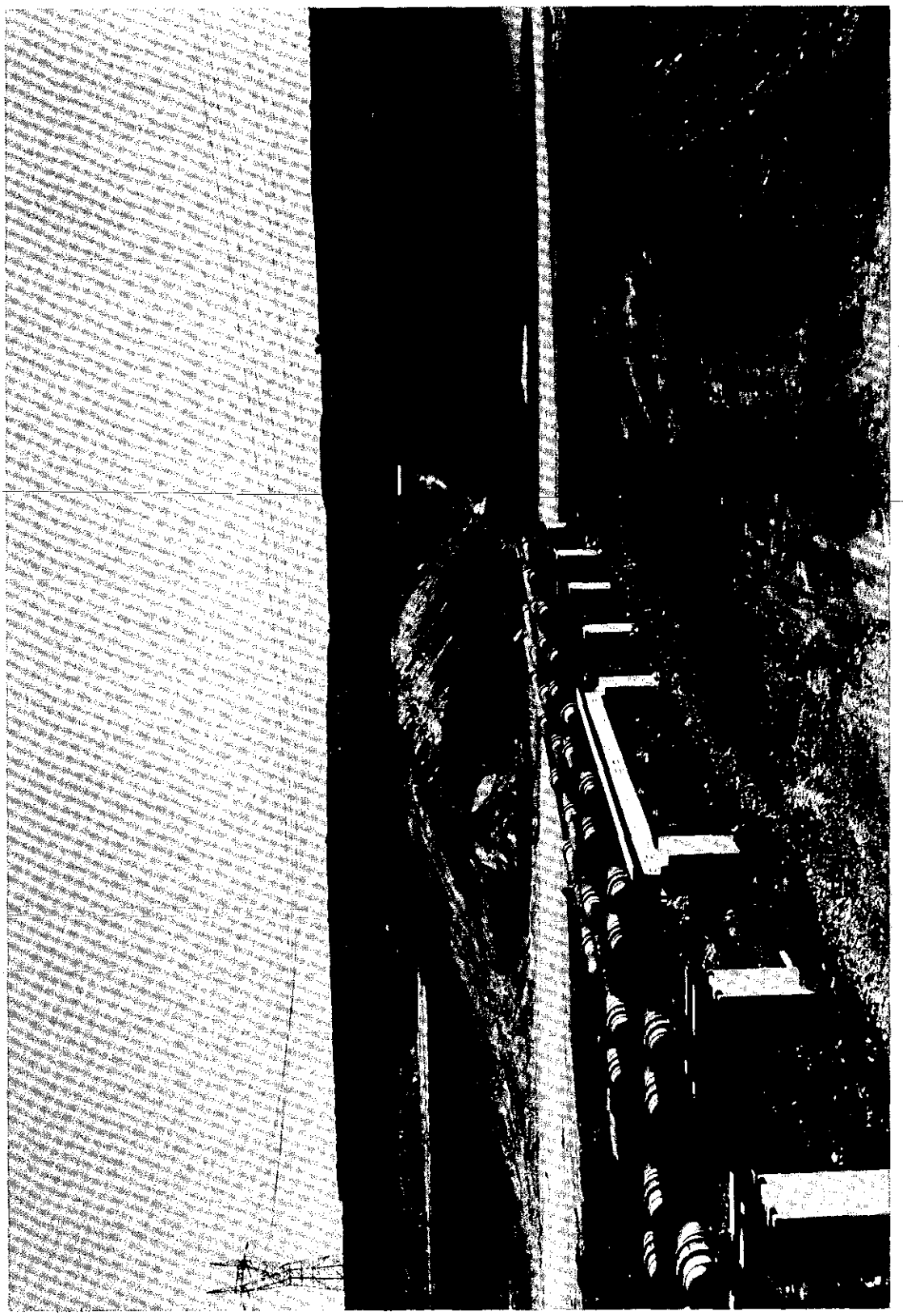

Figure B-29. Ash Disposal Pond, Leland Olds

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Emery Mining Corporation. The coal contains approximately 13.5 percent ash and is delivered to the plant by truck. The boilers are Combustion Engineering pulverized coal, dry-bottom, controlled circulation boilers. Water for the plant comes from reservoirs that are approximately ten miles east of the plant. The Hunter Plant was visited to observe subbituminous ash disposal in a flat topographical setting.

Fly ash is collected by Buell cold-side electrostatic precipitators and transported by a United Conveyor pnuematic pressure system to silos. There is one silo for each generating unit and they are located approximately 1000 feet from the collectors. From the storage silos, fly ash is loaded into 35 and 40 ton off-road dump trucks, both end and belly dump. A private contractor hauls the ash and operates the disposal site which is located 2-1/2 miles from the plant, Figure B-30. Approximately 700 tons of fly ash per day require disposal.

Bottom ash, economizer ash, and pyrites are handled wet and sluiced together to dewatering bins located approximately 500 feet from the boilers. There is one set of dewatering bins for the two units. One bin fills each day and the bins are on an alternating daily basis for dewatering and filling. Bottom Ash is trucked from the dewatering bin to the same disposal site as used for fly ash. The trucks used for bottom ash transport are the same as used in fly ash transport.

Bottom ash sluice water operates in a total recycle system. Make-up water to the sluicing system comes from plant wastewater and boiler blowdown. The plant has no discharge; evaporation ponds are used to dispose of boiler blowdown and wastewater.

Jim Bridger Power Plant

The Jim Bridger Power Plant, located 30 miles east of Rock Springs, Wyoming, is jointly owned by Pacific Power and Light (67%) and Idaho Power Co. (33%). The plant has four 510 MW generating units with Combustion Engineering, dry-bottom, pulverized coal boilers. Subbituminous coal from Bridger Mine, adjacent to the plant, is burned at a peak consumption of 24,000 tons/day. The coal has an ash content of approximately 10 percent. The Bridger Plant was visited to observe strip mine disposal of subbituminous ash.

Water is pumped to the plant from the Green River, located approximately 40 miles to the west of the plant. This water is used for cooling and process makeup water. Plant wastewater is discharged to an evaporation pond. Some of the water is later pumped into an irrigation system.

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Figure B-30. Ash Placement, Hunter

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Bottom ash is sluiced to dewatering bins by United Conveyor Equipment. The bottom ash sluicing water is recycled for each unit. A unit running at full capacity takes five to six days to fill a bottom ash dewatering bin. Some problems with plugging of bottom ash dewatering bin screens by fines have occurred. A vacuum truck is used to remove fines from the screens and also to clean the sludge from bottom ash clarifiers.

Fly ash is collected from Flakt cold-side electrostatic precipitators. A United Conveyor pressurized fly ash system is used to transfer ash from the precipitator to the silo, which is located 400 to 500 feet from the boiler. Ash unloaded from the silos and the dewatering bins is taken to the strip mine by 60-ton, end-dump, off-road trucks, Figure B-31. Ash is hauled 24 hours per day, 5 days per week. Bottom ash and fly ash are trucked separately. A problem with freezing of the ash in the trucks occurs during the winter, which diminishes effective truck capacity. Fly ash was observed by plant personnel to be self-hardening and, when mixed with water, will harden into a solid mass. Coupled with freezing temperatures in the winter, this property makes fly ash difficult to unload from the trucks. Transport distance to the mine disposal site is approximately seven miles. A portion of the ash is sold to Pozzolanic Inc. for use as bulk concrete replacement material and also as a pozzolan.

Cherokee Power Plant

The Cherokee Power Plant of the Public Service Company of Colorado is located in suburban north Denver, adjacent to industrial and residential areas. The plant has four generating units, Unit 1 (100 MW), Unit 2 (110 MW), Unit 3 (150 MW), and Unit 4 (350 MW). The average daily coal consumption for the entire plant is 7,500 tons. Typical fly ash to bottom ash ratio is 70 to 30. The coal is sub-bituminous from the Fresh Water seam with an ash content of 10 percent and a heat rate of 10,000 Btu/lb. The Cherokee Plant was visited to observe sub-bituminous ash disposal in a metropolitan area.

A variety of particulate removal devices are used at the plant. Typically, each unit has mechanical and electrostatic particulate removal equipment. In addition, Units 1 and 4 have particulate scrubbers, and Units 2 and 3 have Buell bag houses. Sulphur captured with particulates creates an acidic scrubber effluent, pH approximately 2, which is neutralized with lime. This neutralization process creates a sludge which is slurried to dewatering ponds along with bottom ash. Approximately 500,000 cubic yards of ash are produced each year by the plant. Typically, there

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Figure B-31. Ash Placement in Strip Mine, Jim Bridger

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are 1,500 pounds of ash in a cubic yard, which indicates that 375,000 tons of ash are produced per year.

The in-plant ash handling system incorporates a wide variety of ash handling equipment from United Conveyor and Allen-Sherman-Hoff. In general, heavier ashes including bottom, air heater, economizer, and mechanical cyclone ash are handled wet. Scrubber ash and mill rejects are also handled wet.

Electrostatic precipitator ash and bag house ash are handled dry. Dry ash is transferred pneumatically to 2 silos, which are located approximately 150 feet from the boilers. Units 1, 2, and 3 are vacuum pneumatic systems, and Unit 4 has a pressure system.

There are three ash settling ponds. Ash is allowed to settle, and the effluent is pumped to two polishing ponds. Water from the polishing ponds is recycled to the plant for later use in the sluicing system. The dewatering ponds are used on an alternating basis. Typical time for ponds to fill is four to six weeks. Dewatered ash is excavated and trucked to the dry landfill, which was once a gravel quarry.

Ash transport to the disposal site and site operation are done by a private contractor. Fly ash is trucked from the storage silos to the disposal site in 20 ton, end-dump trucks.

Placement of ash entails end-dumping and spreading of the ash, Figure B-32. A rubber-tired dozer works in combination with two or three trucks during an eight-hour shift. Hauling is done on a continuous basis. The haul distance from the plant to the site is approximately one mile. The general plan of operation is to fill the gravel pit from the periphery working towards the center. The site covers an estimated 100 acres, and typical fill depth is approximately 40 feet. There is some revegetation of the site. The estimated life of the site and the duration of the hauling contract is ten years.

The landfill is lined with bentonite and will be eventually developed as an office complex and warehouse building site. Site lining was required by county solid waste disposal regulations. No monitoring of the groundwater is done. Industrial and light commerical property are adjacent to the disposal site.

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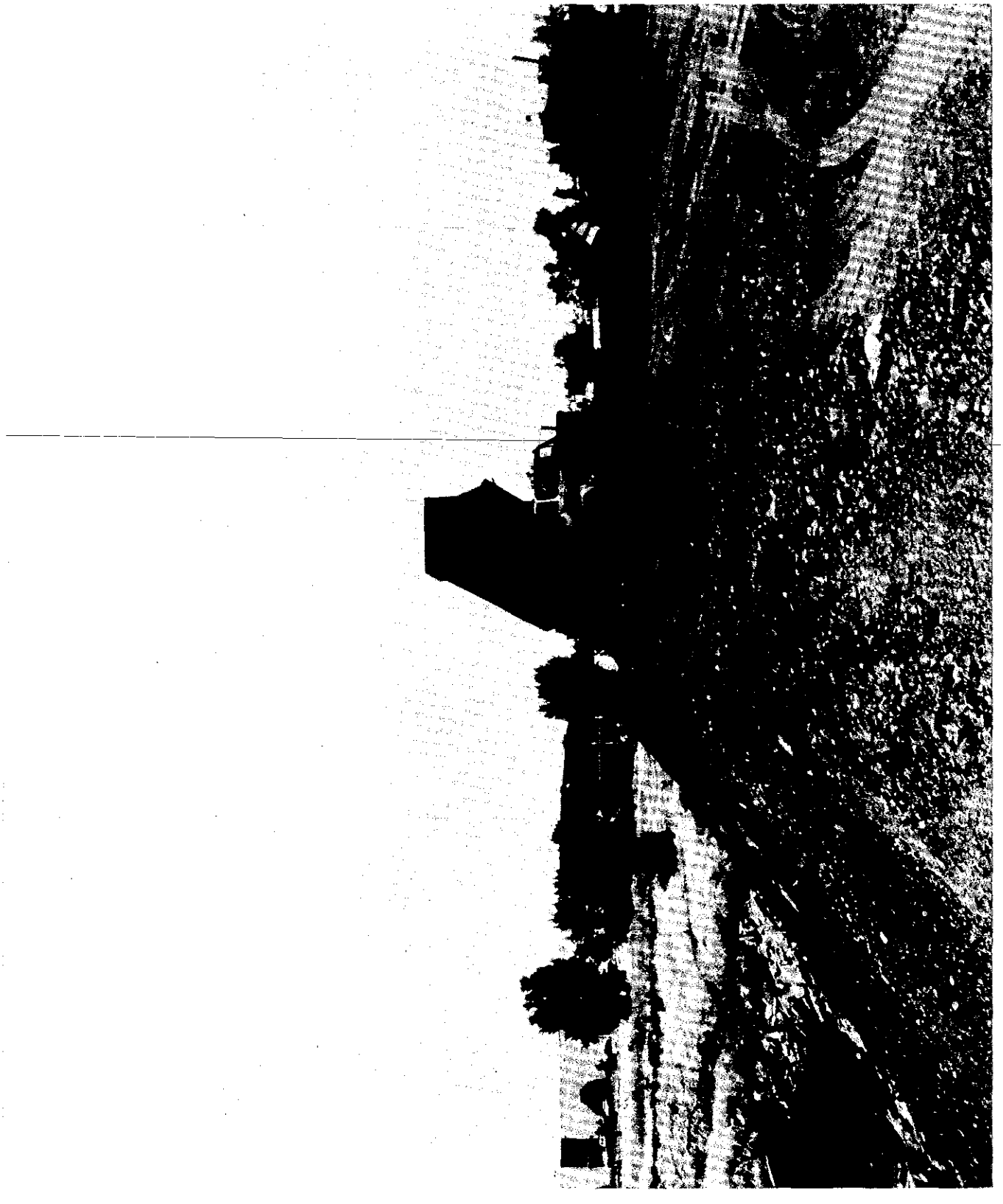

Figure B-32. Ash Disposal, Cherokee