Coal Ash Disposal Manual

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Research Project 1404-1

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ABSTRACT

Of the approximately 70 million tons of fly ash, bottom ash, and boiler slag produced by United States utilities in 1978, only 24 percent was used. The rest was placed in storage or disposal areas. This manual was developed to provide reference information for ash disposal. It is intended to aid in the selection and operation of ash disposal systems with respect to cost considerations and current governmental regulations by furnishing specific disposal criteria, where available, and by outlining methodologies for decision making and cost estimating. Specific topics covered include site selection methodology; ash physical and chemical properties; current disposal philosophies; possible governmental regulations affecting new ash disposal sites; conceptual design of ash disposal systems and estimates of ash quantities; case studies of existing ash disposal sites; monitoring; site reclamation; and cost estimating. References covering these topics and ash disposal site design are included.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This document is one of a series of manuals published by the Solid Waste By-Products Disposal Subprogram on the disposal of utility waste by-products. It serves as a companion to the FGD Sludge Disposal Manual, FP-977. This manual, developed under Research Project (RP) 1404, provides the utility industry with a sound methodology that will permit confident selection of the methods and facilities for the storage and/or disposal of coal ash. The material covered in this manual encompasses four principal categories: (1) data on the chemical and physical properties of coal ash and a description of current ash disposal practices; (2) information on site-selection methods, environmental monitoring, and site reclamation; (3) a review of proposed and promulgated federal regulations on solid waste disposal and an analysis of their impact on ash disposal; and (4) computational methods for estimating waste quantities, waste characteristics, leachate production rates, and new plant system costs. The manual applies to new plants and does not include provisions in the cost development methodology for retrofitting premiums. Thus, the costs that are developed herein may be substantially lower than those for retrofitting wet or dry disposal systems at existing power plants. A manual that will describe methods and cost for upgrading existing disposal systems is being prepared under RP1685-2 for publication in early 1981.

PROJECT OBJECTIVE

The objective of this manual is to provide the industry with detailed information about design features, equipment selection, and specific procedures for evaluating factors necessary in selecting an optimal ash disposal system for new plants. It is intended for use by utility designers and managers in the preliminary identification, cost analysis, ranking of candidate ash disposal sites, and system selection. A continuing objective of the EPRI Solid Waste By-Products Disposal Subprogram is to maintain and update the manual series with regard to the evolving requirements of the Resource Conservation and Recovery Act (RCRA), the Clean Water Act (CWA), and other relevant regulations; advances in waste disposal technology; and changing costs or economic factors. For this reason, this manual is in a loose-leaf format, which will allow easy insertion of updated material from future EPRI projects. Already a project is underway (RP1685-3) to develop the second edition of this manual.

PROJECT RESULTS

This manual presents a systematic and objective methodology for evaluating candidate ash disposal sites and methods. It provides background information and references on existing practices, regulatory constraints and trends, as well as ash properties and system costs. The cost estimating procedures are illustrated in a carefully described base case in conformance with the EPRI Technical Assessment Guide. Adjusting factors from the base case for some site-specific considerations are included.

Coal ash disposal systems are usually categorized as either wet or dry. A significant conclusion reached is that for the range of factors considered, and using investor-owned, regulated utility financing, dry disposal is in general considerably less expensive than wet disposal. The cost disadvantage in wet systems is primarily the result of the large capital costs associated with pond construction.

Certain features of the base case should be noted when applying the cost estimation methodology:

- The data on ash pond effluents composition and ash leachates contained in the manual are based on a limited number of samples and thus may not be representative of either the range or the average for such values for the industry as a whole.
- The base case estimate assumes that all bottom ash is sold or used off-site at no cost to the utility. Therefore the costs for such disposal must be added for any case where this assumption does not apply.
- The systems described and costed are not intended to meet proposed or future RCRA requirements for either the dry or wet disposal systems. Neither do they provide for costs of rainfall runoff or effluent treatment systems for meeting current effluent limitations under the Clean Water Act. Cost estimates provided in Section 9 should be modified by the manual user to meet any such limitations.

This manual contains a questionnaire (see yellow-colored pages) to be completed by the users, to provide EPRI with a feedback mechanism so that subsequent editions will be even more responsive to industry needs. The questionnaire return date is given as May 1, 1980; however, questionnaires received after that date will also be welcomed. Comments and suggestions will be incorporated to the extent possible.

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ACKNOWLEDGMENTS

This manual represents the combined efforts of many individuals. GAI Consultants, Inc., wishes to acknowledge the written contributions of the following individuals in the preparation of this manual: A. M. DiGioia, Jr., R. J. McLaren, M. P. Bahor, F. L. Creamer, D. R. Lenhardt, H. C. Pedersen, R. E. Pepperman, L. R. Taylor, and W. A. Wood, and also to J. E. Niece and S. W. Waters for their review and editorial comments. We also wish to express our gratitude to the utility companies for the time and assistance offered in allowing us to visit their power plants and disposal sites in gathering the background data necessary for the manual. Finally, we would like to thank Mr. Dean Golden of EPRI for his valuable suggestions and guidance.

CONTENTS

ILLUSTRATIONS

TABLES

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 fly ash and bottom ash. The manual has been prepared to aid utility design personnel in the selection and location of optimal disposal systems. This 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 two other EPRI publications, FGD Sludge Disposal Manual FP-977 and Fly Ash Structural Fill Handbook, RP-1156 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 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 the promulgation of federal regulations covering solid waste disposal 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, and 3, Current Disposal Philosophies, 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 possible variations in disposal schemes which are presented in the manual. Ash disposal essentially entails the transport of ash from the collection points at the power plants to disposal areas for placement. Wet systems commonly use pipelines to move the ash from the plant to the pond area. Dry systems commonly use trucks to transport ash, although rail, barge, or conveyor systems may be feasible in some cases. Disposal areas can be either prepared sites or sites needing reclamation, such as mines or quarries. Wet disposal areas are usually ponds and dry disposal areas are generally landfills.

CONTENTS

Section 1, Site Selection Methodology, presents detailed information about the selection of an optimal disposal site and includes a discussion of disposal system types and the physical, engineering, regulatory, environmental, and economic factors influencing site selection. Usually the initial step in selecting a disposal site is to decide whether it will be operated as a wet site or a dry site. It can also be operated as a combination of the two. An alternate approach to site selection which is less common is to begin searching for candidate sites and postpone the decision of whether to go with a wet or dry system until after an initial site inventory is conducted. In either case, the characteristics of wet and dry systems are reviewed early in the site selection process. Next, candidate sites are inventoried. This process starts with a look at the overall physical constraints such as site size, proximity to the power plant, suitable topography, etc. These criteria are relatively inflexible in that they are not easily altered. 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 physically satisfactory are more closely scrutinized to determine what engineering development is required to create a usable disposal area. These engineering criteria are usually somewhat

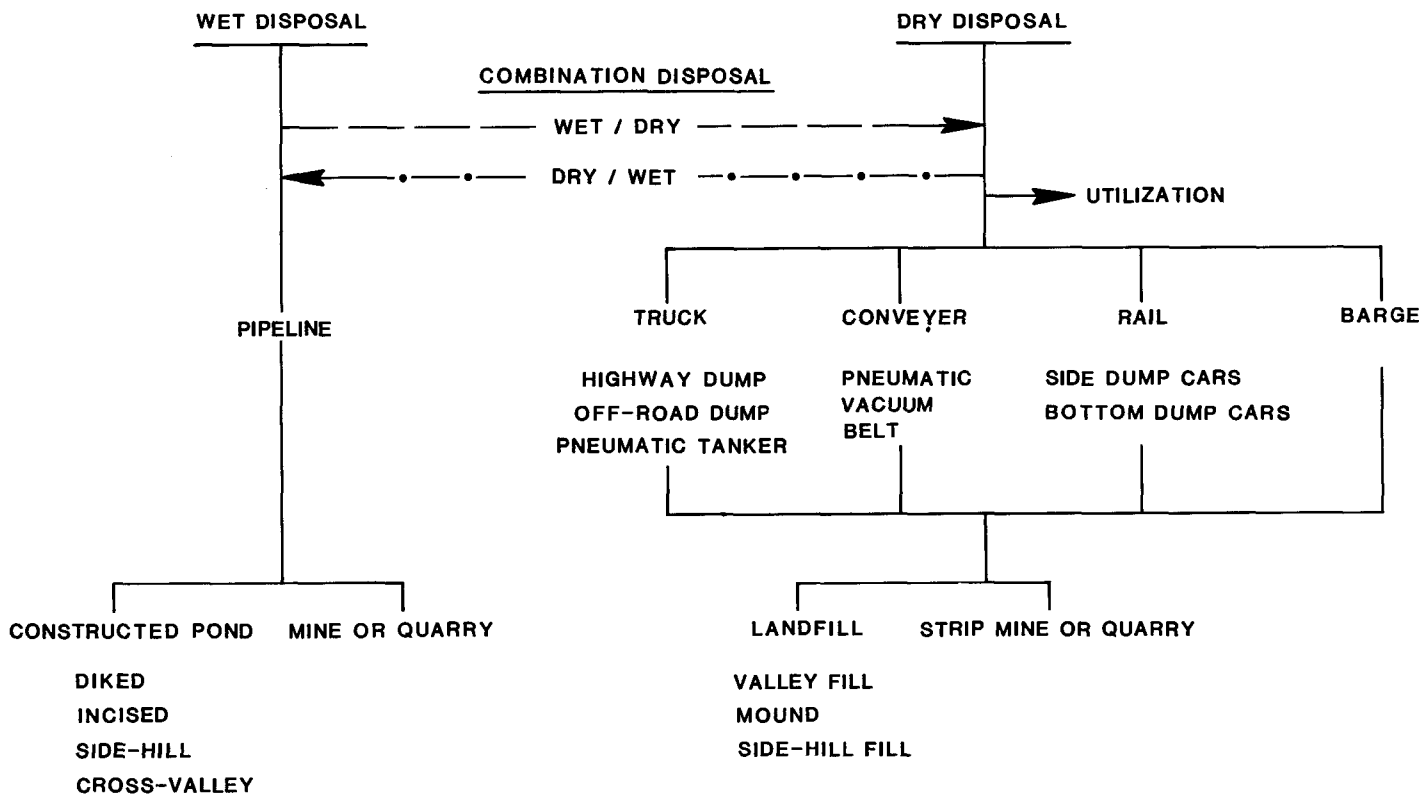

Figure S-1. Variations in Ash Disposal Schemes

flexible in that most problems can be solved, but at some development cost. Factors such as access road construction, surface water control, 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 also relatively inflexible constraints. While problems of this nature can often be overcome through cooperation with the appropriate agencies or government 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 usually flexible constraints that 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 solve 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. The matrix results in a useful comparison with the economic ranking to select sites which will minimize both cost and adverse environmental impacts. A case study of a typical site selection process using this method is included.

Section 2, Properties of Power Plant Ash, presents information on the physical, chemical, and engineering properties of ash and its leachate. In the past, most ash disposal was in wet systems where the ash was sluiced to a pond with little or no subsequent handling. Little characterization of its physical or chemical properties was necessary. However, as environmental regulations and concerns have become increasingly important considerations in ash disposal site design, 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 overall increase in interest in the physical and chemical characteristics of fly ash and fly ash leachate.

Section 2 discusses the chemical and physical characteristics of fly ash from the standpoint of origins in the coal and the effects of methods of combustion, ash collection and handling. Ranges of typical values for parameters of interest are included.

The original purpose of Section 3, Current Disposal Philosophies, was to summarize current disposal systems, determine where they might be deficient when compared to EPA criteria, and describe what remedial measures are necesssry to bring existing systems up to standards. The delay in implementation of RCRA has left some questions unanswered in regard to necessary remedial measures. Section 3 is divided into three parts:

- A review of current disposal practices.
- A discussion of the Clean Water Act of 1977 with regard to ash disposal.
- A discussion of the requirements of the Resource Conservation and Recovery Act of 1976 (RCRA) with regard to ash disposal.

The review of current disposal practices is presented on a regional basis. In some regions, wet disposal is dominant, while in others dry disposal in landfills is the most prevalent practice. Factors which may influence the choice of a disposal method are presented. The Clean Water Act of 1977 is having considerable impact on ash disposal practices. Stringent discharge requirements have been issued for ash disposal sites under the National Pollutant Discharge Elimination System (NPDES) permitting program. The requirements for wet and dry sites are presented and their effect on future disposal sites discussed.

The discussion of requirements of RCRA should be of particular interest to many in the utility industry since it is likely to have a major impact on ash disposal practices in the future. Therefore, the details of the legislative history of RCRA, its current status, and anticipated future events, such as the date of final regulations, are included. An explanation of the regulations as now promulgated includes a discussion of hazardous and non-hazardous waste and the importance of distinguishing between the two.

For wastes which are classified as non-hazardous, RCRA regulations for siting, surface and groundwater protection, and other requirements are discussed. For those wastes which are classified as hazardous, RCRA requirements for siting and surface and groundwater protection are also discussed along with the additional

requirements for security, record keeping, closure, etc. Under the regulations as currently drafted, fly ash and bottom ash which are not classified as a hazardous waste will be regulated by the states with programs consistent with these guidelines. Finally, a review of standard engineering practice used in the design of many current ash disposal sites is included for a comparison.

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. The 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.

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 in detail. Other sites which illustrate certain key features of interest to site design have also been presented. Example topics include revegetation procedures, groundwater monitoring systems, ash transportation and placement, etc.

Section 7, Monitoring, presents explanations of monitoring and monitoring well systems, including their costs. Topics that have been included are 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 specific 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 bezconducted 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 most 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 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 ash. To assist utility personnel in dealing with site retirement procedures in their area, this section gives specific guidance to effective and economical retirement and revegetation procedures as well as sources of additional information and assistance.

Section 9, Cost Estimating, presents cost estimates, the basis for these estimates, and the methods to be used in preparing a detailed cost estimate. Also included are cost curves which allow preliminary general level cost estimates which are not site specific. Economic comparisons are key factors in the decision process when choosing an ash 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.

A significant conclusion regarding the cost of wet and dry disposal systems is reflected in the cost curves in Section 9. For the range of parameters considered, and using investor-owned, regulated utility financing, dry disposal is generally considerably less expensive than wet disposal. The cost disadvantage in wet systems is primarily the result of the amortization of the large capital cost associated with pond construction.

QUESTIONNAIRE ON
COAL ASH DISPOSAL MANUAL, EPRI RP 1404-1

To users of the Coal Ash Disposal Manual:

The answers to this questionnaire will be used to update and improve the Manual. There are two sections to the questionnaire:

I Overall Comments

II Comments on Specific Sections

Your cooperation in answering all or any part of the questionnaire will be appreciated. Use additional sheets, if necessary.

Please return by May 1, 1980.

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Palo Alto, CA 94303

If you have any questions, please contact Dean Golden at (415)855-2516.

Note: If you receive your manual after April 1, 1980, please complete the questionnaire anyway. Your suggestions can be included in subsequent revisions.

I. Overall Comments

Format _____

_____

Appearance _____

_____

Contents _____

_____

Ease of Reference _____

_____

Other _____

_____

Answered By:

Name _____ Title _____

Company _____ Phone No. _____

II. COMMENTS ON SPECIFIC SECTIONS

Section 1 - SITE SELECTION METHODOLOGY

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 2 - PROPERTIES OF POWER PLANT ASH

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 3 - CURRENT DISPOSAL PHILOSOPHIES

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 4 - IMPACT OF RCRA ON NEW DISPOSAL SITES

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 5 - CONCEPTUAL DESIGN OF ASH DISPOSAL SYSTEMS

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 6 - CASE STUDIES

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 7 - MONITORING

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 8 - SITE RECLAMATION

Was information helpful? _____ Factual? _____
Comments: _____

Suggestions for improvements (deletions, additions, method of presentation, other): _____

Section 9 - COST ESTIMATING

Was information helpful? _____ Factual? _____
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Section 1

SITE SELECTION METHODOLOGY

INTRODUCTION

The selection of fly ash and bottom ash disposal sites is a complex problem entailing the development of engineering and environmental design criteria, and the evaluation of environmental impact, economic studies, 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 ash disposal sites which will achieve the goal of optimum balance of low cost and high environmental acceptability. The approach provides a means for documenting the decision making process and helps ensure adequate evaluation of all sites considered. In addition, this section also provides a brief description of wet, dry and combination disposal systems, including advantages and disadvantages.

In order to summarize and illustrate the disposal site selection methodology, a case history is included.

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. Additional information is available in Section 3 - Current Disposal Philosophies.

Wet Systems

Wet systems are designed to dispose of bottom and fly ash generated at the plant in the form of a slurry. The slurry is piped from the plant to the disposal area where the ash is contained in ponds which function as large-scale sedimentation basins. Upon entering the pond, the ash 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. 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. Increasing concern on the part of regulatory agencies about the possibility of ground water 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 can 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, FP-977 (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,
- Ash transportation and site operation are simpler and generally less expensive than those of dry disposal.

Disadvantages

- High site development costs,
- Larger quantities of leachate are generated than with dry systems,
- Larger disposal site volume is required than with dry methods,
- Value of fly ash for reuse is reduced,
- Operation is inflexible with regard to future changes,
- Use of land after site closure may be difficult and costly,
- Potential for spills of slurry,
- Cannot be used to transport self hardening fly ash over large distances.

Dry Systems

Dry disposal systems essentially entail the landfilling of ash conditioned with a sufficient amount of water to aid placement. 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 ground water, 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, FP-977 (1).

Transportation of dry ash is most commonly done by truck. It is sometimes moved by rail, and might also be transported by belt or pneumatic conveyors. For a more detailed discussion of transportation systems see the EPRI FGD Sludge Disposal Manual, FP-977 (1).

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. 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,
- Increased visual impact along transportation routes.

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 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.

In the case of bottom ash, many plants use a combination disposal system. The bottom ash is sluiced to a holding pond at the plant site where it settles. After the pond has been filled, the bottom ash is drained, excavated and transported to a dry disposal area where it can be used as drainage blanket material or placed along with fly ash. At newer plants, the bottom ash slurry is often dewatered in dewatering bins, loaded directly into trucks and then transported to a dry disposal area.

SITE SELECTION METHODOLOGY

General

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:

- Siting and design criteria development,
- Initial screening of prospective sites,
- Design, evaluation and selection,
- Final design.

Criteria Development. As shown in Figure 1-1, the development of ash disposal area siting and design criteria involves the following activities:

- Collect power plant ash data,
- Review applicable regulations.

The collection of power plant data involves securing information on ash properties, ash production quantities, production processes and operation procedures. Zoning ordinances, regional master plans, and local, county, state and federal solid waste disposal regulations are included in applicable regulations to be reviewed. It is common practice to review local and county regulations within a zone around the power plant in question. The areal extent of this zone cannot be generalized since it is power plant specific.

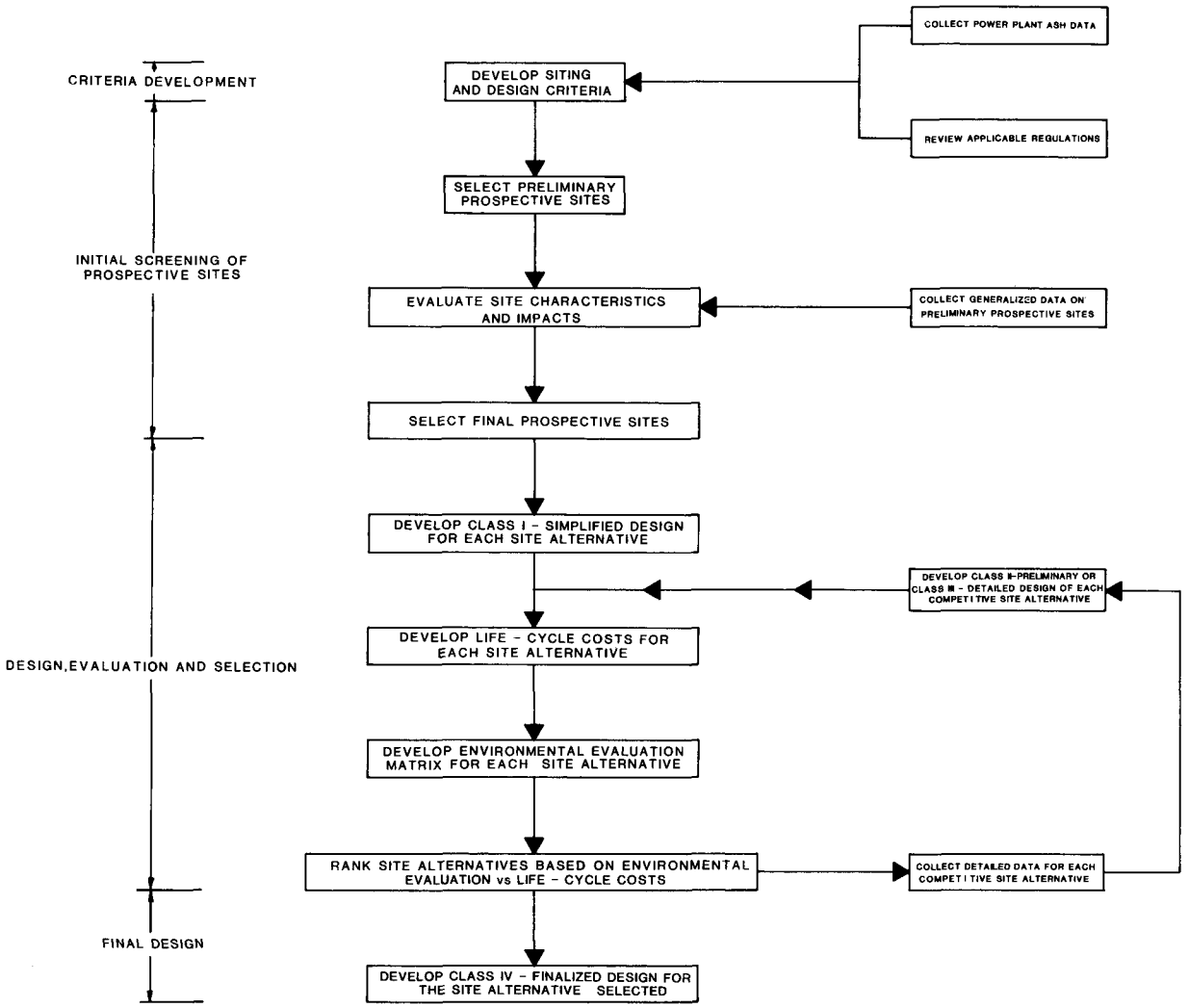

Figure 1-1. Disposal Site Selection Methodology

Based on the power plant ash data and applicable zoning, planning and solid waste regulations, siting and design criteria can be developed for prospective ash disposal sites located within a specified zone around the power plant.

Initial Screening of Prospective Sites. As shown in Figure 1-1 this phase involves the following activities:

- Select preliminary prospective sites,
- Collect generalized data on preliminary prospective sites,
- Evaluate site characteristics and impacts,
- Select final prospective sites.

The procedure for selecting initial preliminary prospective sites within a zone around the power plant vary from one utility to another. Some utilities maintain an inventory of potential sites. Others develop an inventory on an as-needed basis by reviewing topographic maps, property maps, etc. In any event, the selection of initial preliminary prospective sites is based on a review of the site inventory relative to the siting and design criteria developed under the previous phase. However, to screen the initial sites and select final prospective sites, generalized data about each preliminary prospective site should be obtained. This activity involves tasks such as collecting geologic, hydrologic and topographic data, conducting a site reconnaissance visit and evaluating community acceptability. Based on an evaluation of the generalized site data, final prospective sites can be selected from the list of preliminary sites.

Design, Evaluation and Selection. As outlined in Figure 1-1, this phase involves the following activities.

- Develop a Class 1 - Simplified Design for each site alternative,
- Develop life - cycle costs for each site alternative,
- Develop an environmental evaluation matrix for each site alternative,
- Rank site alternatives based on environmental evaluation versus life - cycle costs.

Based on the siting and design criteria and the data developed under the first two phases, a conceptual layout of the ash disposal area can be made at each site for wet and/or dry disposal alternatives. Using the technique outlined

under Section 9 - Cost Estimating, a Class 1 - Simplified life-cycle cost estimate can be made for the disposal alternatives feasible at each site.

The impact on man and his environment as a result of developing each site alternative can be gauged through the use of an environmental evaluation matrix. The matrix provides a rational method for evaluating the impact of developing, operating and abandoning each site on water quality, public health and safety, air quality, etc. While subjective in nature, this technique provides a uniform method of comparing sites environmentally through the use of a structured approach to impact evaluation.

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. Ideally, the objective of this ranking is to select the site of least cost and least adverse environmental impact. However, selection on this premise may not be straightforward. For instance, the least costly site might produce the greatest adverse environmental impact. A graph of life-cycle costs versus environmental impact, which is useful in comparison, can be drawn. However, final site selection is a judgmental decision based upon the best practicable presentation and evaluation of influencing considerations.

Many times a Class I - Simplified Design of the disposal areas may not provide sufficient information to differentiate among several apparently equal site alternatives. In this situation the following activities may be necessary to provide additional information to aid in ranking the competitive site alternatives.

- Collect detailed data for each competitive site alternative,
- Develop Class II - Preliminary or Class III - Detailed Design of each competitive site alternative,
- Re-evaluate life-cycle costs and environmental impact.

Final Design. The final step in the site selection procedure is to develop a Class IV - Finalized Design for the site alternative selected.

A detailed description of the specific activities involved in the four phases of the site selection procedure summarized on Figure 1-1 is provided below.

Collect Power Plant Ash Data

In order to design an ash disposal area, the following type of data is required.

- Physical, chemical and engineering properties of the ash,
- Quantities of ash,
- Production processes at the plant,
- Operating procedures at the plant.

The data indicated above should be collected for both the present situation as well as for a time period into the future for which the evaluation is being made. As indicated in Section 2 - Properties of Power Plant Ash, 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 are required for proper environmental design of the site while physical and engineering properties, such as in-place dry density, are needed to determine disposal volumes.

Review 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 zone variance or change. 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 can not 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.

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, NPDES, waterway obstruction, water rights, and possibly in the future, a RCRA permit could be required. A detailed description of RCRA requirements is provided in Sections 3 - Current Disposal Philosophies and 4 - Impact of RCRA on New Disposal Sites.

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 ground water 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 engineering and environmental siting and design criteria can be developed for the prospective disposal sites located within the zone under study around the power plant. Siting criteria may include items such as:

- Floodplain limitations,
- Earthquake considerations,
- Water supply implications,
- Critical habitat areas.

Design criteria may include items such as:

- Volume requirements,
- Allowable fly ash embankment slopes,
- Allowable cut slopes,
- Maximum ash lift thickness,
- Ground water quality monitoring requirements,
- Surface water quality effluent criteria.

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/NPDES
	(may be enforced by state)
	Wetlands Construction under Section 404 of CWA
	Possible RCRA Permit
	(may be enforced by state)
	Waterway Obstruction in Navigable Waterways
	(water withdrawal and intake structures)
	Water Withdrawal or Usage in Navigable Waterways

Select 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 will have an inventory of available ash disposal sites in the vicinity of each power plant. In other cases, the inventory may be kept by the department directly responsible for ash disposal activities or there may be no inventory at all. In any case, a review of USGS topographic maps, property maps, etc., for the zone under consideration can lead to an inventory of preliminary prospective sites. The selection of the sites will be based on the specific siting and design criteria developed previously. For example, only sites which can be developed to satisfy the design ash volume requirement should be placed on the preliminary site list.

Collect Generalized Data on Preliminary Prospective Sites

The collection of generalized data involves the following activities for

each site in the inventory of sites:

- 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,
- Ground water 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 useable areas within a site or may be indicative of future subsidence problems.

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),
- Transportation 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.

Evaluate Site Characteristics and Impacts

Based on the generalized 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 ash disposal sites. Some sites may be suitable for both dry and wet disposal alternatives and can be carried through the remainder of the selection process as supporting two 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 and routes,
- 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.

Select Final Prospective Sites

The evaluation of site characteristics and impacts relative to the suitability of each preliminary prospective site being developed for dry and/or wet disposal alternatives, 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.

Develop Class I - Simplified Design

A simplified layout 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.

Develop Life-Cycle Costs

Section 9 - Cost Estimating provides an outline of the method for doing a cost estimate for a Class I - Simplified Design. 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.

Develop Environmental Evaluation Matrix

Fly ash disposal necessitates the handling and placement of great quantities of material over an extended period of time. During the course of the disposal process, 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 fly 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 depending on the specific situation under study. For example, terrestrial ecology 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, $WF_{pc} = 1 - WF_{c/o} = 1 - 0.8 = 0.2$

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.

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

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 (± 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 - Simplified cost estimates (± 30 percent) it may be difficult to differentiate between sites; thus, as shown in Figure 1-1, it may be necessary to recycle through the following steps:

- Collect detailed data for each competitive site alternative,
- Develop Class II - Preliminary or Class III - Detailed 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 - Preliminary or Class III -Detailed Design of each competitive site could be performed depending on the degree of accuracy needed in cost estimates at this stage of the selection

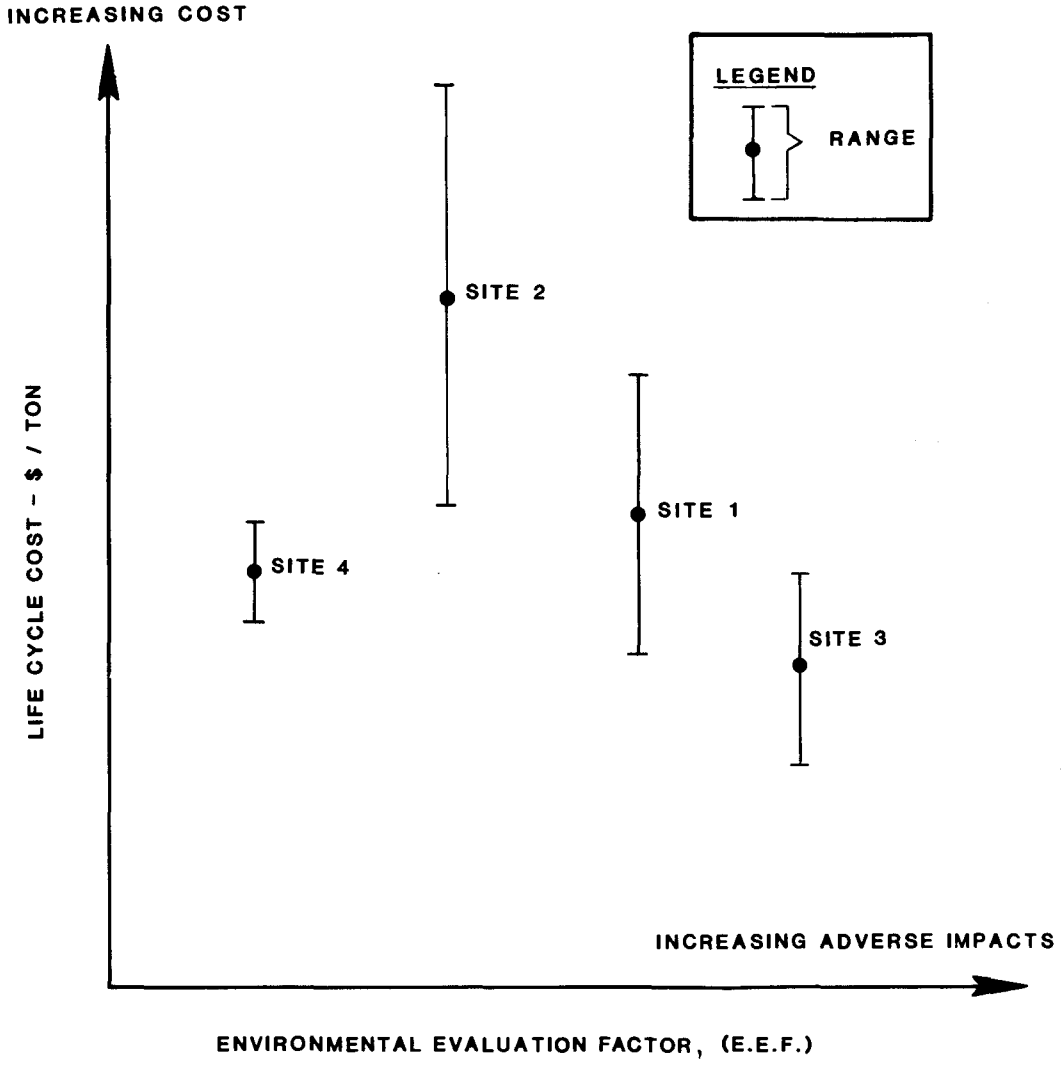

Figure 1-2. Schematic Relationship Between Life-Cycle Costs and Environmental Evaluation Factor (EEF)

process. Based on the more detailed designs, life-cycle costs and environmental impact can be re-evaulated and the sites ranked once again.

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 - Finalized Design performed. The final design may require additional site specific information such as test borings, test pits, the installation of a ground water quality monitoring system, etc.

CASE HISTORY

In this section, a case history of a typical ash disposal site selection study is presented in order to illustrate the methodology outlined in the previous portions of this chapter. 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.

Background

As indicated by Figure 1-3, the generating station is located in the North Central region of the U. S. along a major river and is bordered on the east by a railroad and highway, on the north by a small city, 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 maximum capacity; thus, a new site was required to handle ash from Units 1 through 5 along with anticipated ash quantities from Unit 6. Four potential ash disposal sites were identified

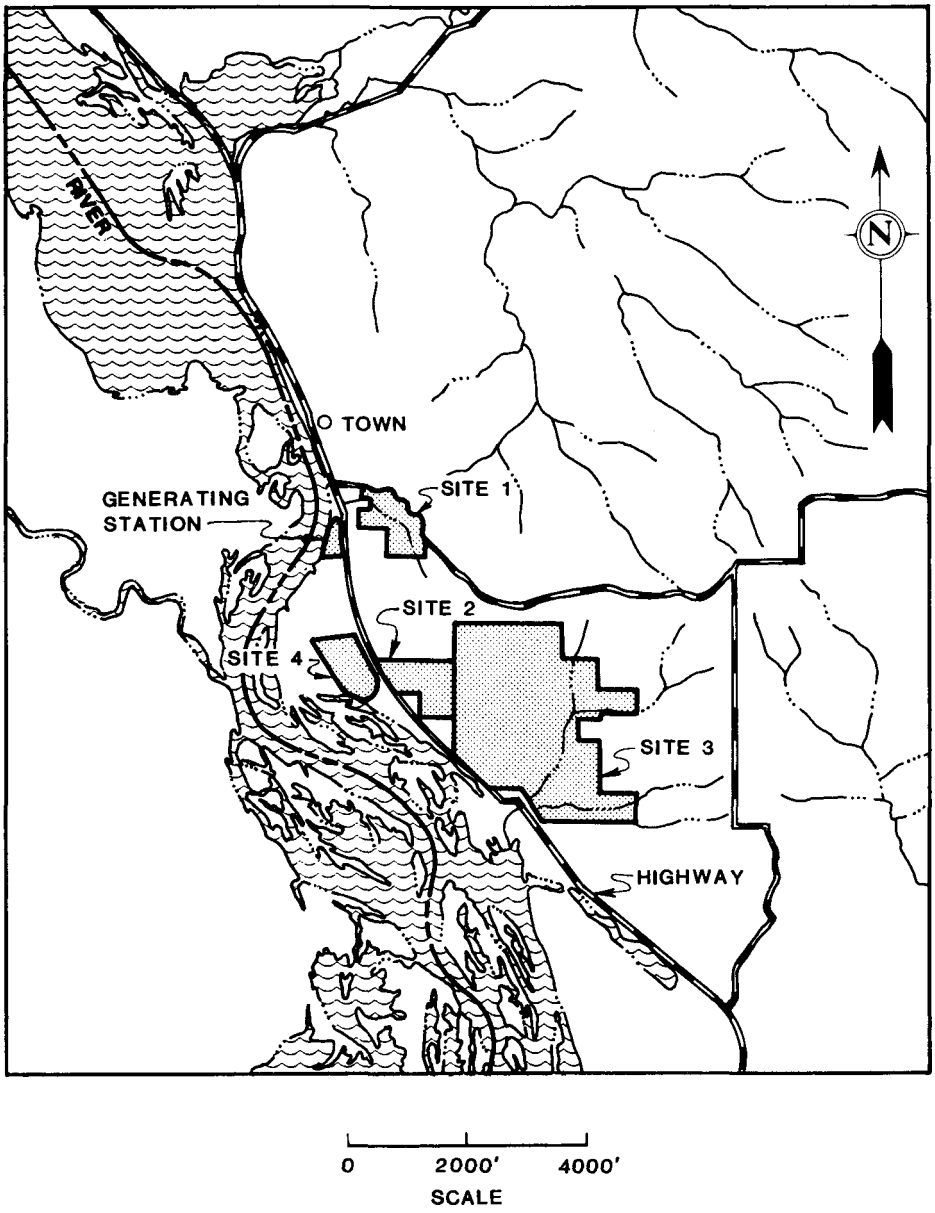

Figure 1-3. Case Study Site Location Map

by the utility. These sites are shown on Figure 1-3.

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 the end product of subbituminous coal combustion, there was a possibility that it might be self-hardening due to high lime content. This sort of reactive characteristic would severely limit the distance that fly ash could be sluiced, and would place restrictions on truck transport methods. Reactive fly ash will permit the addition of little or no water at the silo. For short haul distances, it may be possible to add a small amount of water which causes "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 fly ash through proper design and operating procedures. This can be done by sloping the surfaces of the disposal area to accelerate runoff and through the use of 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

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. Since the installation of liners does not affect the relative ranking of the sites, 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 in order to determine physical features, environmental setting, land use, and access. Table 1-2 summarizes the topography, geology, soils and hydrology of each site. Table 1-3 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. Both wet and dry disposal schemes were developed for each site, and possible operational difficulties were analyzed.

Site 1. Site 1 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) (see Figure 1-4). 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.

Table 1-2

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.

Table 1-3

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.

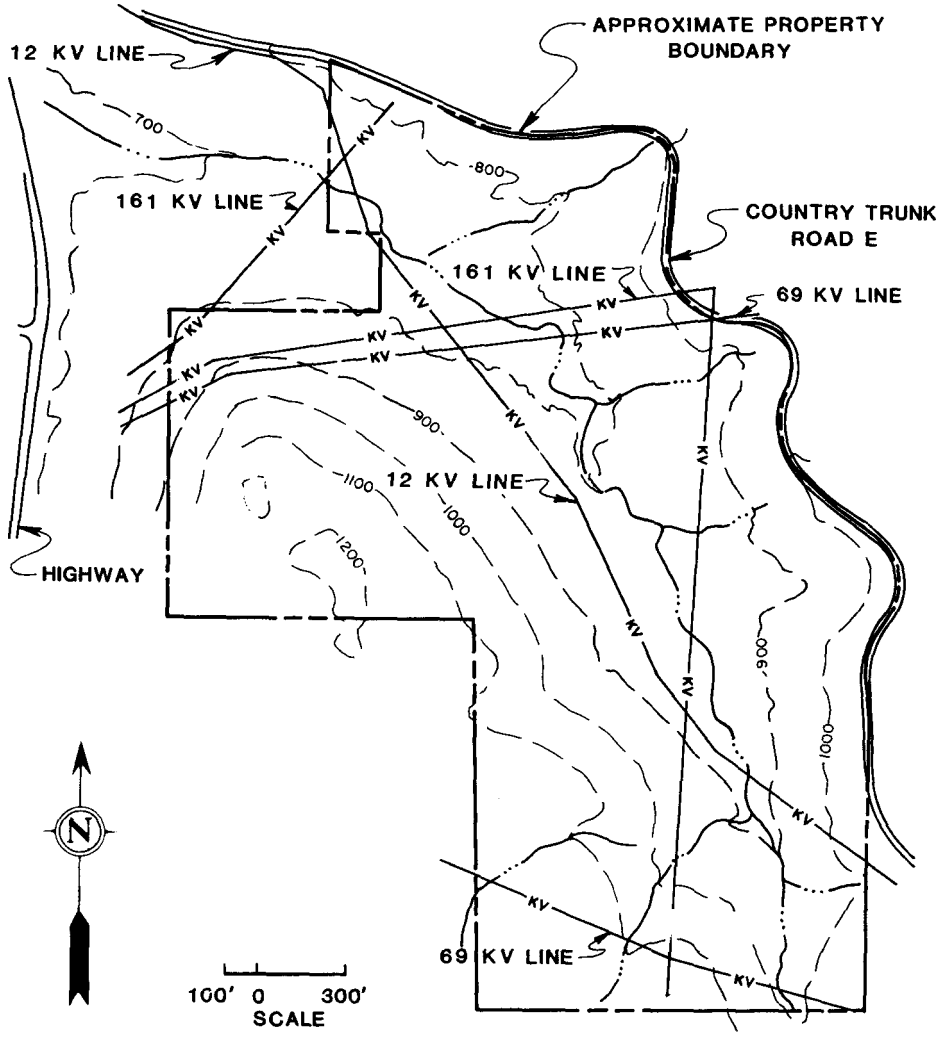

Figure 1-4. Case Study - Site 1 Existing Conditions

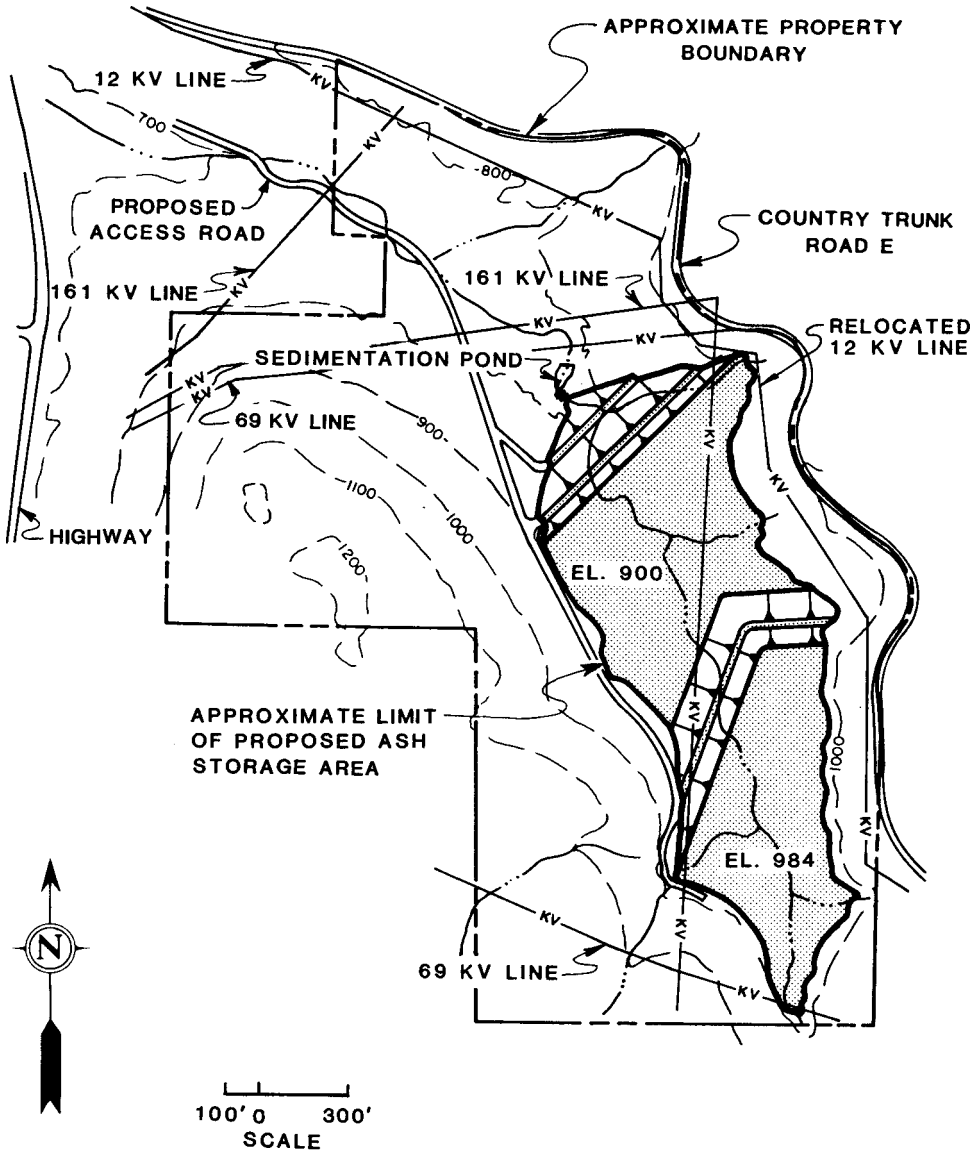

Figure 1-5. Case Study - Site 1 Conceptual Plan for Dry Ash Disposal Area

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,
- 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 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 is a narrow heavily wooded valley located one and one-half miles south of the power plant and east of the highway (see Figure 1-6), 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. Because of heavy woods, extensive clearing would be required on the entire site and diversion or by-pass systems would be required to handle upper watershed runoff. The location and visibility of the

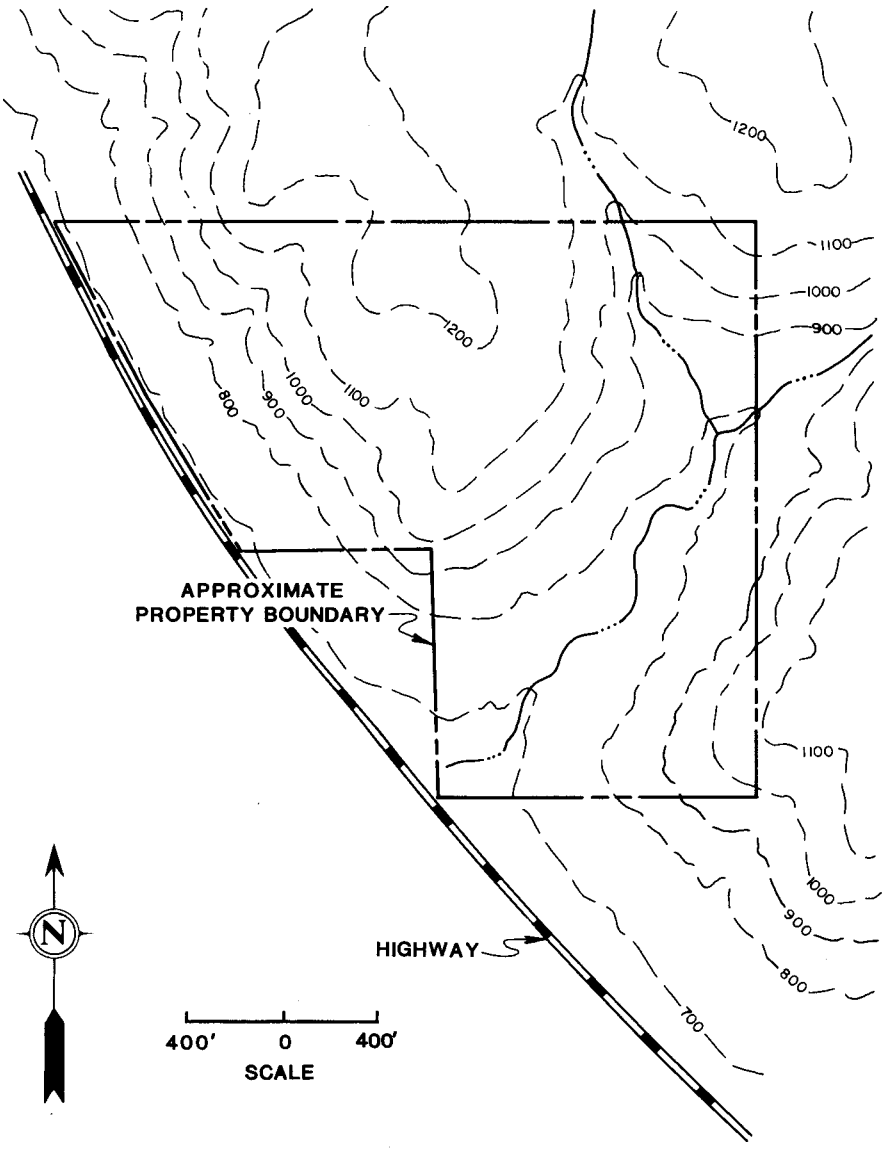

Figure 1-6. Case Study - Site 2 Existing Conditions

site would make the establishment of effective visual and audio screens difficult.

The dry disposal plan for Site 2, as shown on 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 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 down-gradient of the site. Access to the site is steep and would require considerable earthwork.

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 on 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

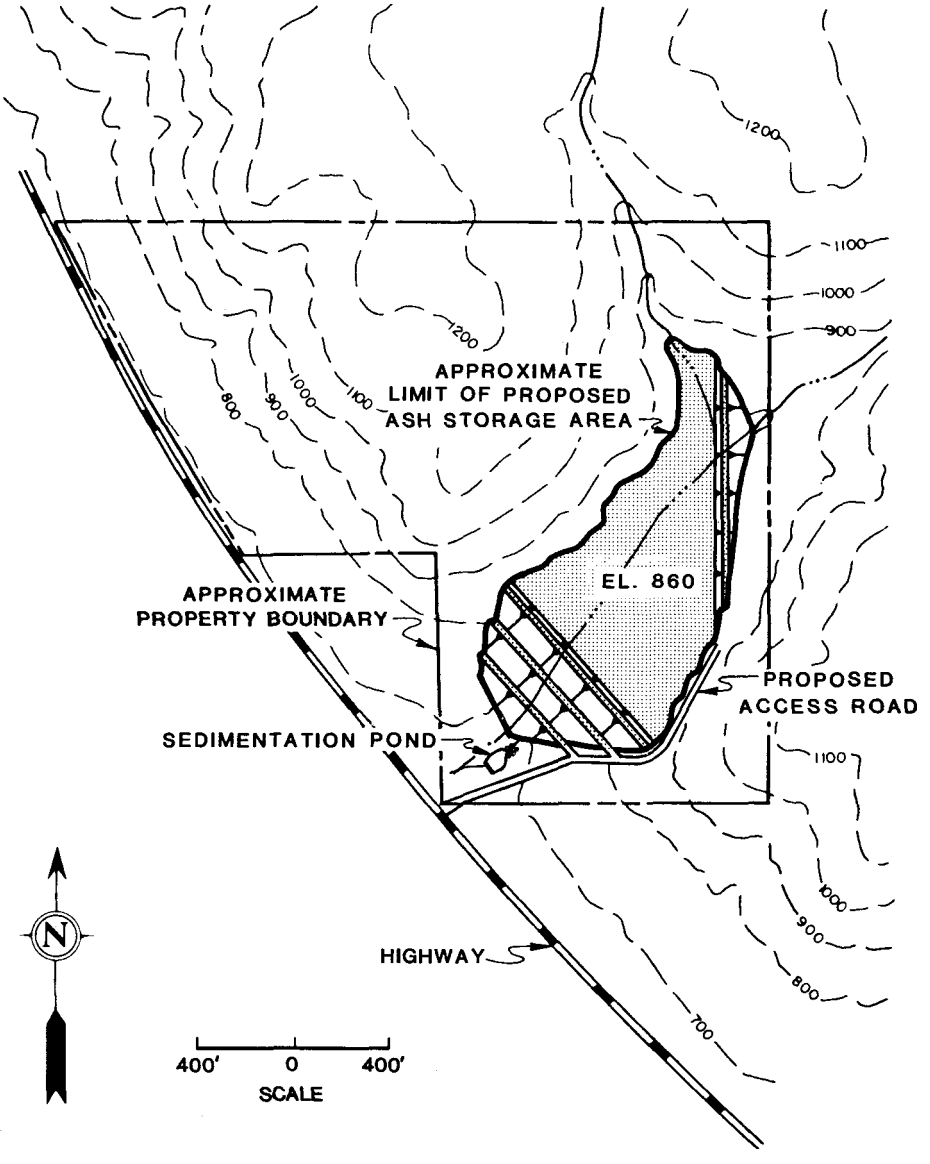

Figure 1-7. Case Study - Site 2 Conceptual Plan for Dry Ash Disposal Area

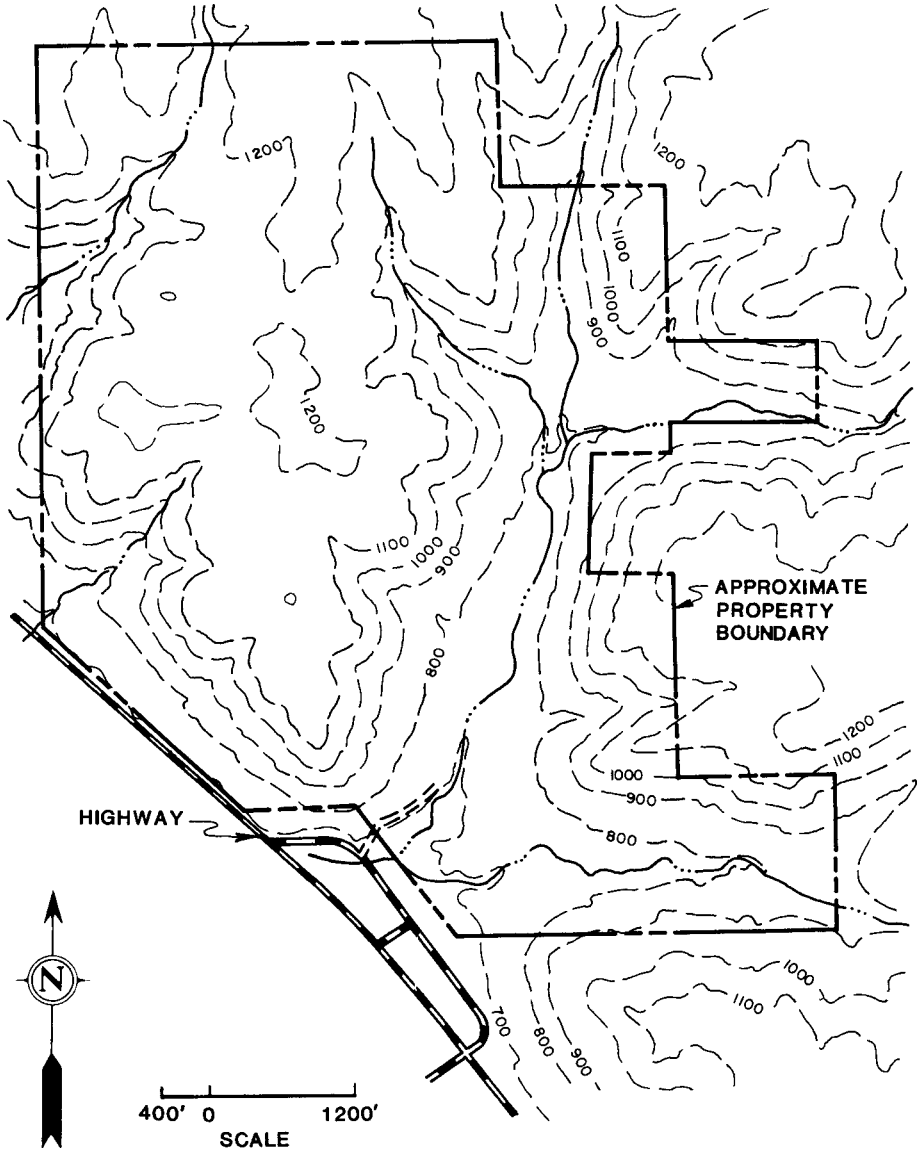

Figure 1-8. Case Study - Site 3 Existing Conditions

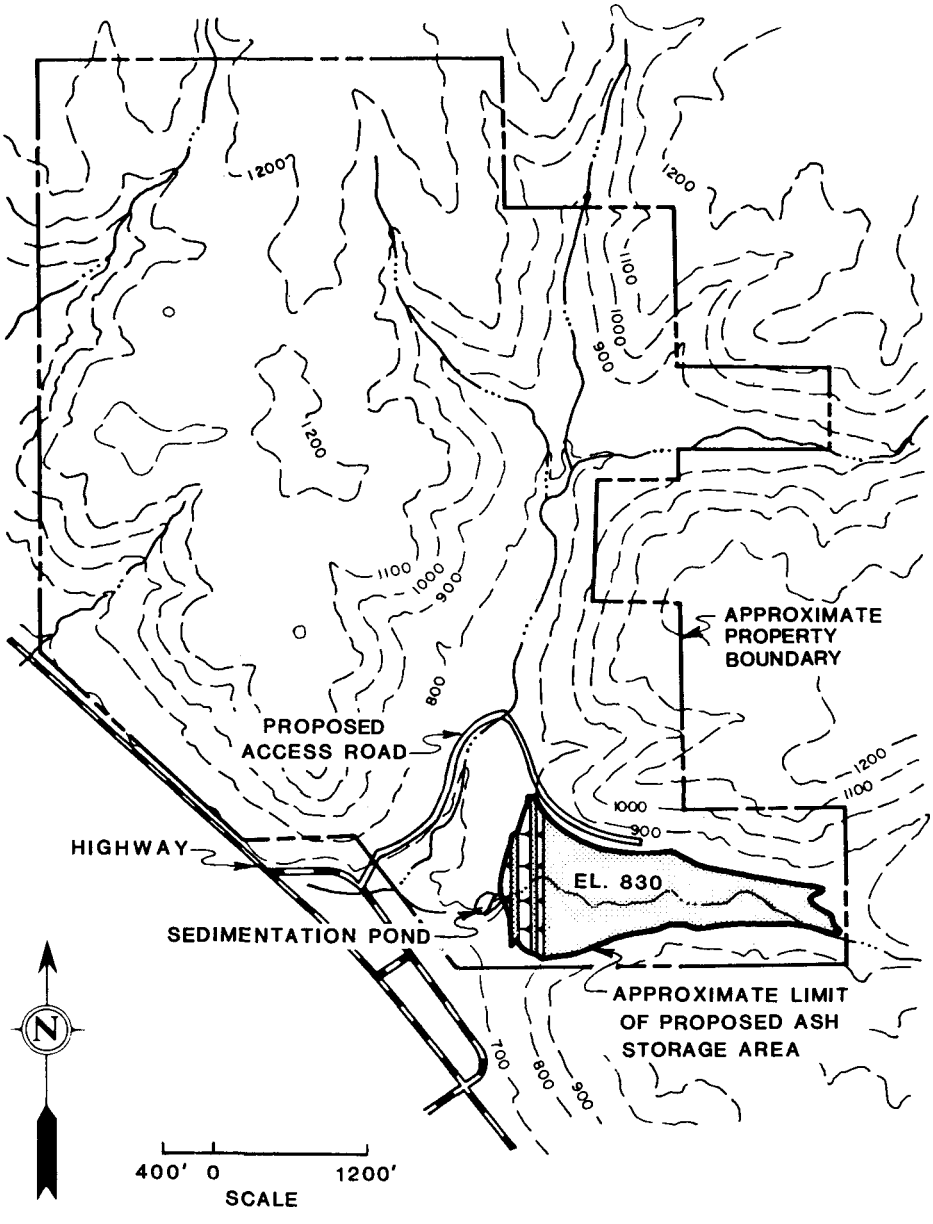

Figure 1-9. Case Study - Site 3 Conceptual Plan for Dry Ash Disposal Area

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 29-1/2 years of fly ash production.

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.

After completion of site preparation, the entire pond would be filled with water to the level of the outlet works. It was thought that outlet water would meet surface water quality standards due to dilution of sluice water before discharge. 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 fly ash reached the design level of the pond, excess surface water would be drained off and the surface covered with topsoil 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 proposed 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

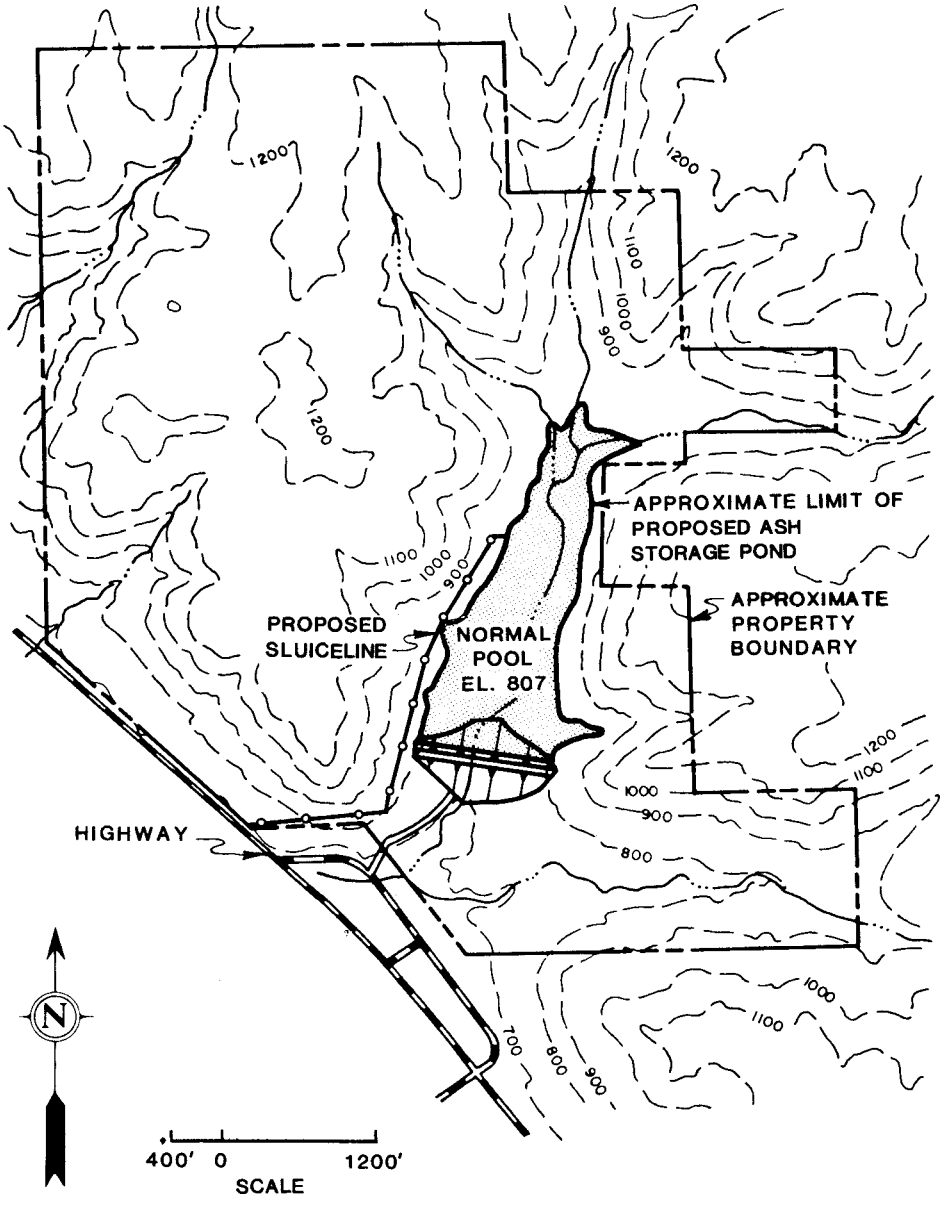

Figure 1-10. Case Study - Site 3 Conceptual Plan for Wet Ash Disposal Area

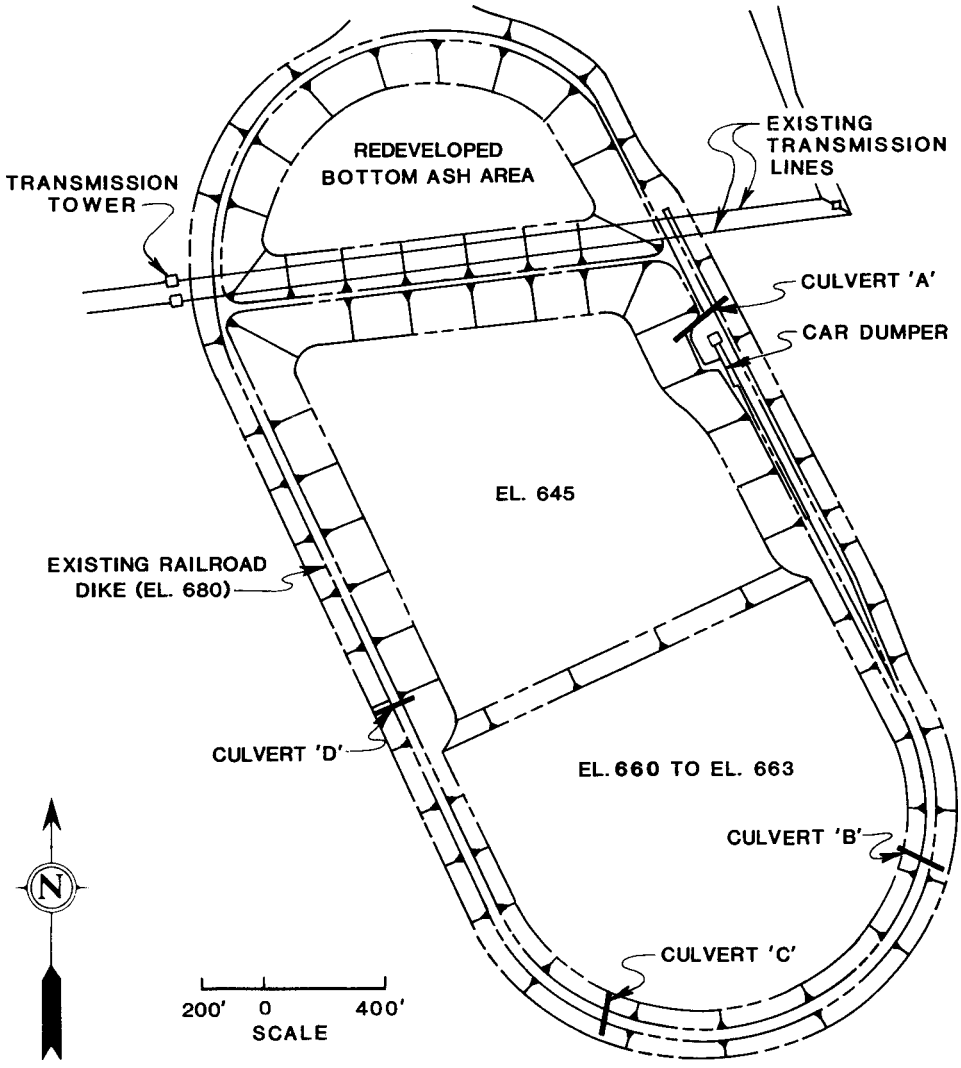

Figure 1-11. Case Study - Site 4 Existing Condition

had been dewatered and excavated to provide material for railroad dike construction. The remaining southern 41 acres (16.6 hectares) were undisturbed wetlands 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.

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 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

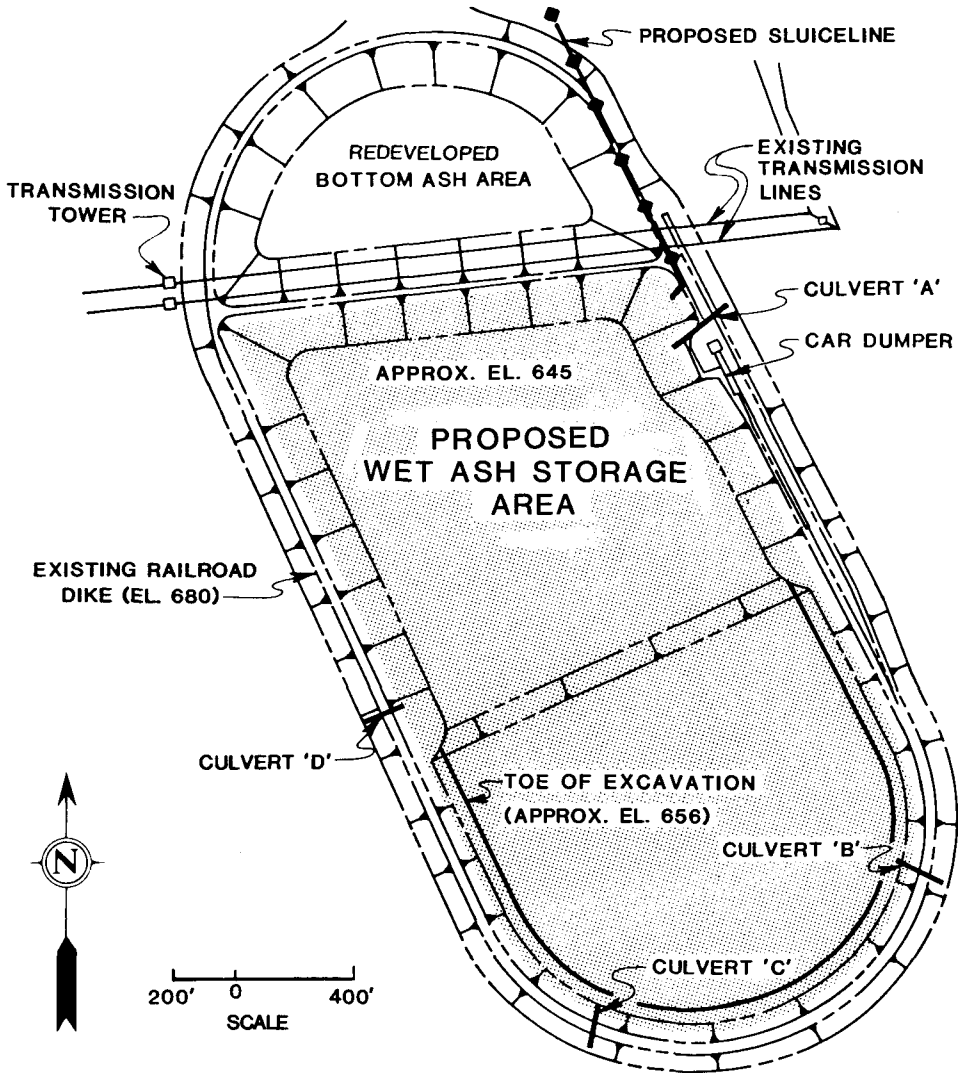

Figure 1-12. Case Study - Site 4 - Conceptual Plan for Wet Ash Disposal Area

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 1-4 summarizes the life-cycle costs based on a Class I - Simplified Design for the case study sites. These calculations were performed in accordance with the procedures outlined in Section 9 - Cost Estimating. A review of the total capital requirement cost information presented in Table 1-4 indicates that the wet disposal alternatives are capital intensive approaches to disposal while the dry disposal alternatives are not. This situation is due in part to the assumption that site work (clearing, grubbing, drainage, etc.) for the dry disposal alternatives will be done annually throughout the 35 year period of disposal activity.

The life-cycle 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 the cost estimate for Class I - Simplified Designs have a range of ± 30 percent. As indicated by Table 1-4, the cost differences between Site 1 - Dry, Site 2 - Dry, and Site 3 - Dry are well 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.

Environmental Evaluation Matrix

The environmental evaluation of each disposal alternative was done using 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. Environmental parameters and primary weighting factors chosen for this evaluation are shown in Table 1-5.

Table 1-4

LIFE-CYCLE COSTS BASED ON CLASS I - SIMPLIFIED DESIGN FOR CASE STUDY SITES

Cost Item	Site 1 Dry	Site 2 Dry	Site 3 Dry	Site 3 Wet	Site 4 Wet
Total Capital Requirement	$396,000	$404,000	$408,000	$6,340,000	$769,600
Levelized Annual Revenue Requirement	593,000	694,000	720,000	2,152,000	780,900
Cost per Ton of Ash	$6.50	$7.50	$7.80	$23.44	$8.50

Table 1-5

ENVIRONMENTAL PARAMETERS AND PRIMARY WEIGHTING FACTORS FOR CASE STUDY SITES

Environmental Parameter	Weighting Factor
Aesthetics	6
Air Quality	5
Aquatic Ecology/Water Quality	8
Cultural Resources	2
Land Use	4
Noise	5
Public Health and Safety	9
Socioeconomics	4
Terrestrial Ecology	5

A scale of one to ten was selected for primary weighting factors, with increasing value indicating increasing significance or importance.

It was thought that environmental parameters presented in Table 1-5 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 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 fly 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 life-cycle 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 decison 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 -Simplified 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.

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.

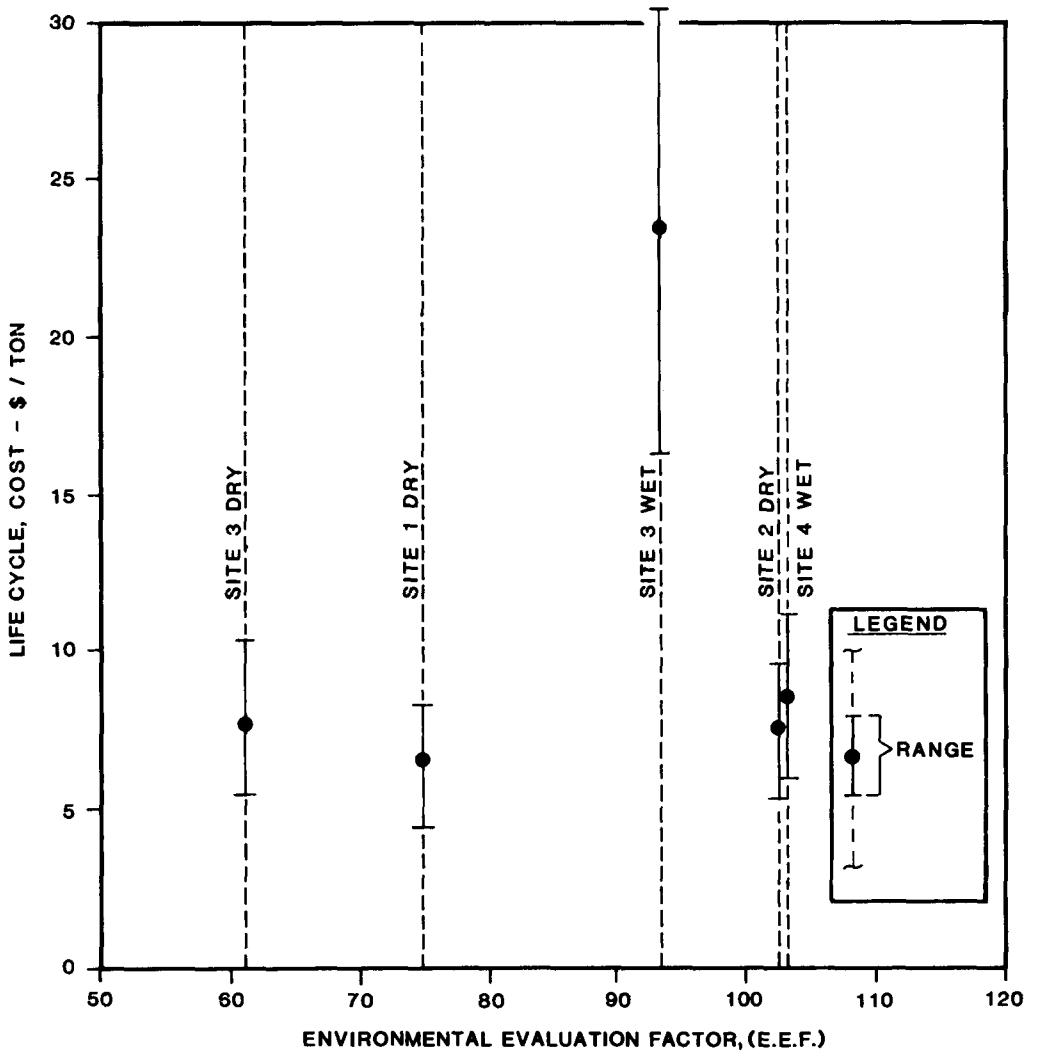

Figure 1-13. Case Study - Comparison of Alternate Disposal Site Costs and EEF's

REFERENCES

1. FGD Sludge Disposal Manual. Palo Alto, Calif.: Electric Power Research Institute, January 1979. FP-977.

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.

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 geographical 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, power plant 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 fly 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. Much of the physical properties data presented in this section is based on ash which is derived primarily from Eastern bituminous coals. The use of Western subbituminous coals and lignite has only recently become widespread, and published literature dealing with the physical properties of the ash from these coals is very limited. As more information becomes available on subbituminous and lignite ashes based on the experience of those power plants now burning these coals, it would be extremely useful and of great interest to the industry if the utilities would publish this data.

PROPERTIES OF COAL

Since the composition of fly 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 in the coal is appropriate. However, the composition of the 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, the degree of pulverization of the coal, the temperature during combustion, and many other factors.

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 in 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 constituents 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. It may also vary from coal type to coal type, and even somewhat within a single seam. Table 2-2 illustrates the range of trace element concentrations found in U. S. coals. Therefore, no generalization of coal elemental composition can be made.

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 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:

Table 2-1

AVERAGE TRACE-ELEMENT CONTENTS
FOR COALS FROM VARIOUS REGIONS
OF THE U. S. (ppm)

Element	SWI[a]	EI[b]	NGP[c]	APP[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]SWI = Forty-eight coals from Western and Southwestern Interior Region.

[b]EI = Eastern Interior Region, 53 coals.

[c]NGP = Northern Great Plains Region, 51 samples.

[d]APP = Seventy-three coals from Appalachian Region.

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.

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.

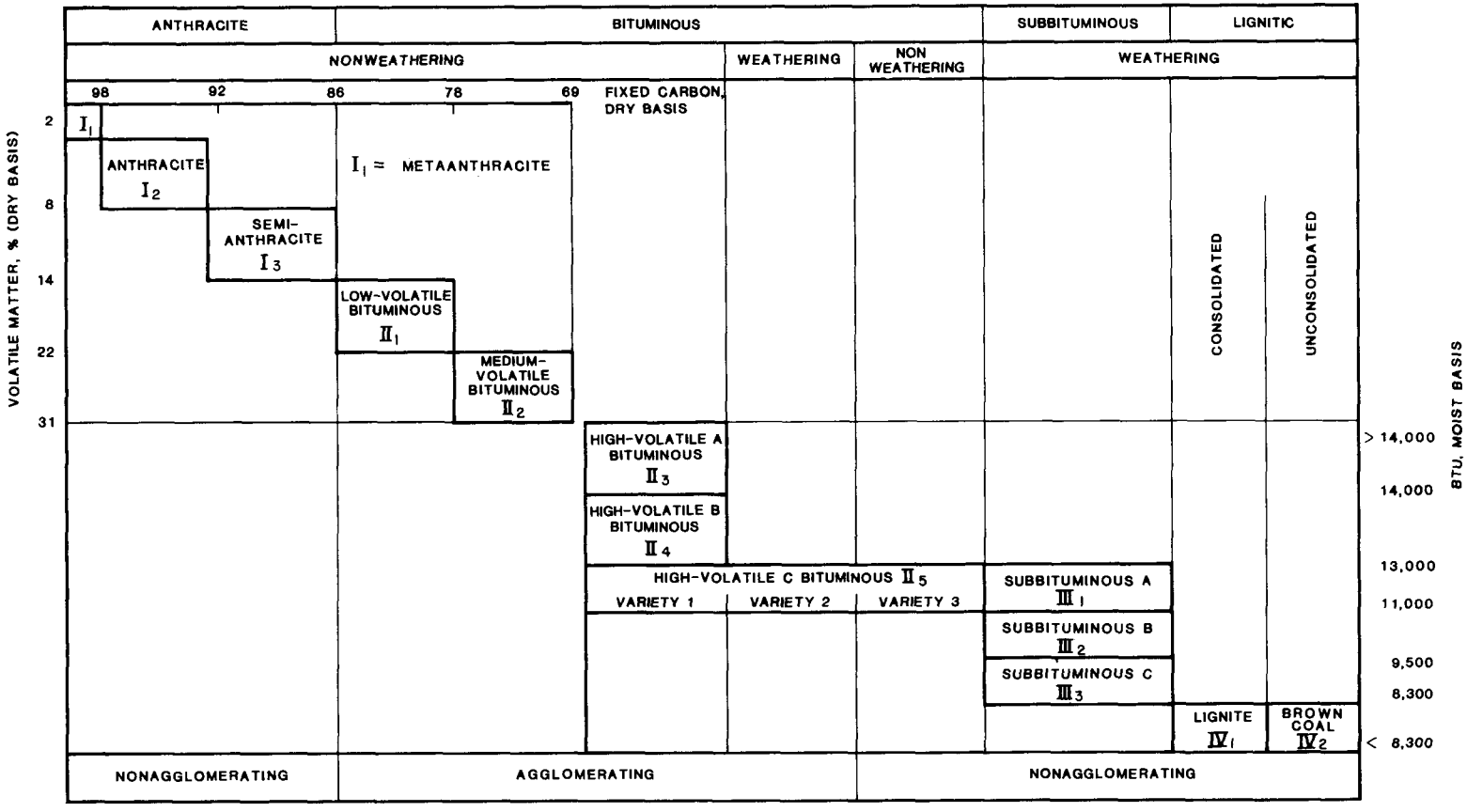

Figure 2-1. ASTM Classification of Coals by Rank

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.

- Anthracite
- Bituminous
- Subbituminous
- Lignite

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:

$$SVI = \frac{\text{Determined Btu/lb - \% Fixed Carbon x 145}}{\text{\% Volatile Matter}}$$

Note that all values in the above equation are based on a dry, ash-free basis.

The proximate analysis for percent ash, volatile matter and fixed carbon and Btu content of various coals has been summarized and is included in Table 2-4. It should be noted that the values in Table 2-4 are based on as-mined or as-received conditions and that most analysis is on a dry basis. Therefore, the data in Table 2-4 were converted to a dry basis as shown in Table 2-5.

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 non-combustible 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,

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	Bituminous	>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.

Table 2-4

PROXIMATE ANALYSIS OF SOME NORTH AMERICAN COALS,
AS MINED OR AS RECEIVED

Rank and Source	Moisture (Percent)	Ash (Percent)	Volatile Matter (Percent)	Fixed Carbon (Percent)	Heat Value (Btu/lb)
Lignite:					
Montana	37.5	6.1	26.8	29.6	6,580
N. Dakota	36.8	5.1	28.2	29.3	7,204
S. Dakota	39.2	8.4	24.7	27.7	6,307
Texas	33.7	7.3	29.3	29.7	7,348
Ontario	46.7	7.4	30.2	16.0	5,280
Saskatchewan	33.5	6.7	24.0	35.8	7,576
Subbituminous:					
Wyoming	23.4	3.6	33.6	39.4	9,382
Alberta	15.0	6.3	33.3	45.4	10,890
Bituminous:					
Utah	7.5	5.6	39.7	47.2	12,520
Illinois	7.9	9.1	40.7	42.3	11,527
British Columbia	6.7	11.3	34.8	47.2	11,690
Alberta	7.4	7.1	32.1	53.4	11,630
Pennsylvania	3.4	5.3	35.9	55.4	11,734
Alabama	3.9	7.5	35.1	53.5	13,343
Nova Scotia	4.0	8.4	32.2	55.4	13,340
Anthracite:					
Pennsylvania	3.2	11.5	9.3	76.0	13,043

Source: L. A. Munro. Chemistry in Engineering. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1964.

Table 2-5

PROXIMATE ANALYSIS OF SOME NORTH AMERICAN COALS, ON A DRY BASIS

Rank and Source	Ash (Percent)	Volatile Matter (Percent)	Fixed Carbon (Percent)	Heat Value (Btu/lb)
Lignite:				
Montana	9.8	42.9	47.3	10,528
N. Dakota	8.1	44.6	46.4	11,399
S. Dakota	13.8	40.6	45.6	10,373
Texas	11.0	44.2	44.8	11,083
Ontario	13.9	56.7	30.0	9,906
Saskatchewan	10.1	36.1	53.8	11,392
Subbituminous:				
Wyoming	4.7	43.9	51.4	12,248
Alberta	7.4	39.2	53.4	12,812
Bituminous:				
Utah	6.1	42.9	51.0	13,535
Illinois	9.9	44.2	45.9	12,515
British Columbia	12.1	37.3	50.6	12,529
Alberta	7.7	34.7	57.7	12,559
Pennsylvania	5.5	37.2	57.3	14,217
Alabama	7.8	36.5	55.7	13,884
Nova Scotia	8.8	33.5	57.7	13,896
Anthracite:				
Pennsylvania	11.9	9.6	78.5	13,474

Source: Adapted from L. A. Munro. Chemistry in Engineering. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1964.

- 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 so 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 suspension. Oil or gas may sometimes also be burned in conjunction with coal but usually at lower percentages. The flames may be as long as 100 feet (30 meters) in order 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 80-85 percent of the ash melts and is tapped from the furnace as boiler slag, leaving only 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 must generate from 10,000 to 250,000 lb (4,540 to 113,500 kg) of steam per hour. However, 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 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:

- mechanical collectors
- fabric filters
- wet scrubbers
- 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

Table 2-6

SEVERAL OPERATING CHARACTERISTICS OF PARTICULATE COLLECTORS

General Class	Specific Type	Typical Capacity	Pressure Loss (in. water)[a]	Power Reqd[b] ($W/ft^3/min$)	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 of 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)	85	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)		94	90	96	98	100	100
	Venturi	6000-30,000 ft^3/min per ft^2 of throat area	10-50 (25-125)	4-12 (140-425)	99+	99	99.5	100	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 in 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.

decision is a matter of balancing the required collection efficiency versus the overall cost of the system. Table 2-6 indicates various operating parameters for the most common particulate control devices.

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.

After the fly ash has been collected from the flue gas stream, it must be transported to either a temporary storage silo or the ash sluicing area. If the fly ash is collected by one of the dry methods, there are three types of dry handling systems which can be used for the transport of the dry fly ash from the points of collection to the silo or to the sluice lines:

- vacuum systems,
- pressure systems,
- combination vacuum-pressure systems.

Vacuum systems have a limit on the effective distance to which they can transport the fly ash. The maximum distance which material can be conveyed by a vacuum system is dependent upon the configuration of the system and the altitude above sea level. Pressure systems are generally used where the length of conveyance is too great for a vacuum system or where the altitude limits the vacuum which can be created. Combination systems are usually economical where the length of the conveying system exceeds the capability of a vacuum system to attain a satisfactory conveying rate. The fly ash can also be transported wet directly from the collection system to the disposal area.

If the fly ash is removed from the flue gas stream by a wet collector, it will be sluiced to a pond for dewatering or disposal. The use of water will affect some of its chemical properties. In general, the use of water will tend to dissolve some of the fly ash particles and the chemical deposits on the surface of other fly ash particles.

Bottom Ash/Boiler Slag Collection

In dry bottom boilers, the bottom of the fire box has an open gate 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 then sluiced to either a settling pond or a dewatering bin. The sedimentation pond can be either a temporary holding facility or a final disposal site. If the ash is to be sold 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 of which are glassy spheres, scoria, iron rich fractions, and some 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 the particles 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 (1), which ultimately produces leachate. 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), and ferric oxide (Fe_2O_3), and smaller quantities of various other oxides and alkalies. The Oak Ridge National Laboratory is currently studying the feasibility of using such processes as acid leaching and salt-soda leaching for the recovery of

alumina and the removal of toxic trace elements from the fly ash at the same time (EPRI RP 1404-2). If an economically practical process can be developed, the utility will have a valuable mineral resource (alumina) which can be sold and a waste material free of toxic elements (arsenic, cadmium, etc.) which can presumably be disposed of in a conventional manner with no danger of environmental contamination.

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 tend to produce higher carbon fly ash than the new, more efficient units. The range of major chemical components in fly ashes is illustrated in Table 2-7.

Table 2-8 presents data concerning the average trace element contents of ash from U. S. coals of various ranks. 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.

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 2-9 shows the chemical composition of five West Virginia bottom 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 distribution 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:

Table 2-7

VARIATIONS IN COAL ASH COMPOSITION WITH RANK

	Rank			
	Anthracite	Bituminous	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.

Table 2-8

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

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.

Table 2-9

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	4.2	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.

- 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 2-10 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 contaminate 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 proposed that implementation of RCRA regulations be delayed

Table 2-10

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	Cl
	Br

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.

while they conduct a site monitoring and evaluation program which is designed to assess the possible 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 proportion of leachable lime to iron present.

Precise 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. In order 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 is on the order of years. Therefore, short-term tests were devised to attempt to rapidly predict the long-term leachate production.

Two new methods of leachate analysis have been recently devised. These methods are the ASTM and the EPA methods. The following is a brief description of these methods:

- ASTM Method - The ASTM is a form of the shake test method in which a mixture of 1.54 lb (700 g)* of as received sample and 6.21 lb (2800 g) of Type IV Regent Water (prepared by either distillation, ion exchange, reverse osmosis, electrodialysis or some combination of the above) is agitated for 48 hours at 68 ± 4°F (20 ± 2°C). This method also includes an alternate sodium acetate buffer solution (pH 4.5 ± 1) for the extraction.

- EPA Extraction Procedure (EP) - The EP test, although not yet finalized, consists of adding fly 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 as currently proposed is explained in detail in the December 18, 1978, Federal Register.

Tables 2-11 and 2-12 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 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 subbituminous 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 and the extract was analyzed according to standard ASTM procedures. The range of values from these analyses is presented in Table 2-13. The ASTM is still evaluating the results of these and other tests to determine the effectiveness of the extraction procedures. The results of the analyses presented in Table 2-13 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 is, in some cases, rather large.

*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.

Table 2-11

ASH SOLIDS ANALYSES (in ppm)

Substance	Fly Ash Range	Avg.	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	Avg.	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	-	-	-
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/OGPA-10.

Table 2-12

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 2-11.

Table 2-13

RESULTS OF LEACHATE TESTS ON COAL ASH

Analysis	Bituminous Coal Fly Ash			Bituminous Coal Bottom Ash			Bituminous Coal Boiler Slag		
	ASTM "A" (16)*	ASTM "B" (16)	EPA E.P. (16)	ASTM "A" (5)	ASTM "B" (5)	EPA E.P. (5)	ASTM "A" (3)	ASTM "B" (3)	EPA E.P. (3)
pH	4.38-12.5	4.5-5.2	4.87-5.57	3.41-8.6	4.5-4.81	4.75-5.3	3.40-6.8	4.44-4.6	3.6-4.8
Ca (mg/l)	150-583	275-1708	36.6-331	8.0-210.0	30.0-320.0	1.2-110.0	3-49	5-51	1-115
Ag (mg/l)	0.0004-0.045	0.0003-0.06	0.0001-0.04	<0.01-<0.05	<0.01-<0.05	<0.01-<0.05	0.01-<0.05	<0.01-<0.05	0.02-<0.05
As (mg/l)	0.0021-2.11	0.8-7.3	0.00059-2.046	0.006-0.2	<0.002-0.4	0.007-<0.4	0.002-0.2	0.002-0.6	<0.01-<0.4
Ba (mg/l)	<0.02-79	0.11-1.0	<0.02-0.5	0.04-0.2	<0.25-0.52	<0.1-0.13	0.07-<0.25	0.09-0.75	0.01
Cd (mg/l)	<0.0002-0.04	0.002-0.05	<0.00005-0.06	<0.003-<0.05	0.004-<0.05	<0.003-<0.05	<0.01-<0.05	<0.01-<0.05	0.03-<0.05
Cr (mg/l)	0.008-0.23	0.04-0.74	0.008-0.39	<0.01-<0.05	<0.01-0.05	<0.01-<0.05	<0.01-<0.05	<0.01-<0.05	<0.01-0.02
Hg (mg/l)	<0.000005-0.020	0.000011-0.5	<0.000001-25.0	0.0003-<0.005	<0.0001-<0.005	0.0003-<0.005	<0.0001-<0.005	0.0001-<0.005	0.0004-<0.005
Pb (mg/l)	<0.001-0.09	<0.001-0.2	<0.00001-0.7	<0.01-<0.2	0.018-<0.15	<0.1-<0.5	<0.01-0.2	0.015-<0.15	<0.01-0.3
Se (mg/l)	0.14-1.25	0.1-1.41	0.0001-1.56	0.070-<0.1	0.002-<0.5	<0.01-<0.2	<0.01-<0.5	<0.01-<0.5	<0.01-<0.2

*Number in parentheses is the number of laboratories reporting an analysis of the ash.

Source: The preliminary information upon which this table is based was furnished by B. C. Malloy, Chairman of ASTM Subcommittee D19.12.

Table 2-13
(Continued)

RESULTS OF LEACHATE TESTS ON COAL ASH

Analysis	Lignite Coal Fly Ash			Subbituminous Coal Fly Ash		
	ASTM "A" (7)	ASTM "B" (7)	EPA E.P. (7)	ASTM "A" (4)	ASTM "B" (4)	EPA E.P. (4)
pH	11.34-12.3	5.6-12.3	4.95-11.45	12.1-13.3	12.01-13.3	5.23-12.55
Ca (mg/l)	190-538	200-1500	310-1300	22-1100	682-1900	682-2000
Ag (mg/l)	<0.009-0.04	0.007-0.04	<0.009-0.04	<0.01-0.09	<0.01-0.08	<0.01-0.08
As (mg/l)	<0.01-0.2	<0.01-0.65	0.004-1.8	<0.002-0.03	0.003-0.4	<0.002-0.5
Ba (mg/l)	0.1-1.069	0.1-1.31	0.1-1.98	0.1-100	0.4-125	0.3-0.94
Cd (mg/l)	0.006-<0.5	0.0013-<0.5	<0.01-0.58	<0.01-<0.05	<0.01-<0.05	<0.01-<0.05
Cr (mg/l)	<0.01-0.78	<0.01-0.56	0.031-0.15	<0.01-0.10	<0.01-0.25	<0.01-0.39
Hg (mg/l)	<0.001-<0.005	<0.0001-<0.005	<0.0001-<0.005	0.0001-0.08	<0.0001-0.11	<0.0001-0.08
Pb (mg/l)	<0.00972-<0.1	0.0047-<0.1	<0.001-0.4	<0.01-0.1	<0.01-0.2	<0.01-0.3
Se (mg/l)	0.0693-1.0	0.06-1.5	0.0176-1.0	<0.01-<0.5	0.032-0.3	<0.002-0.5

Source: The preliminary information upon which this table is based was furnished by B. C. Malloy, Chairman of ASTM Subcommittee D19.12.

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 at 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, bituminous fly ash is usually uniformly-graded material with particles primarily in the silt range (particle diameters between 0.005 mm and 0.074 mm). The grain-size distribution of the fly ash can be improved by blending it with bottom ash or boiler slag.

The particle size of fly ash ranges from 0.001 mm to 0.100 mm in diameter for

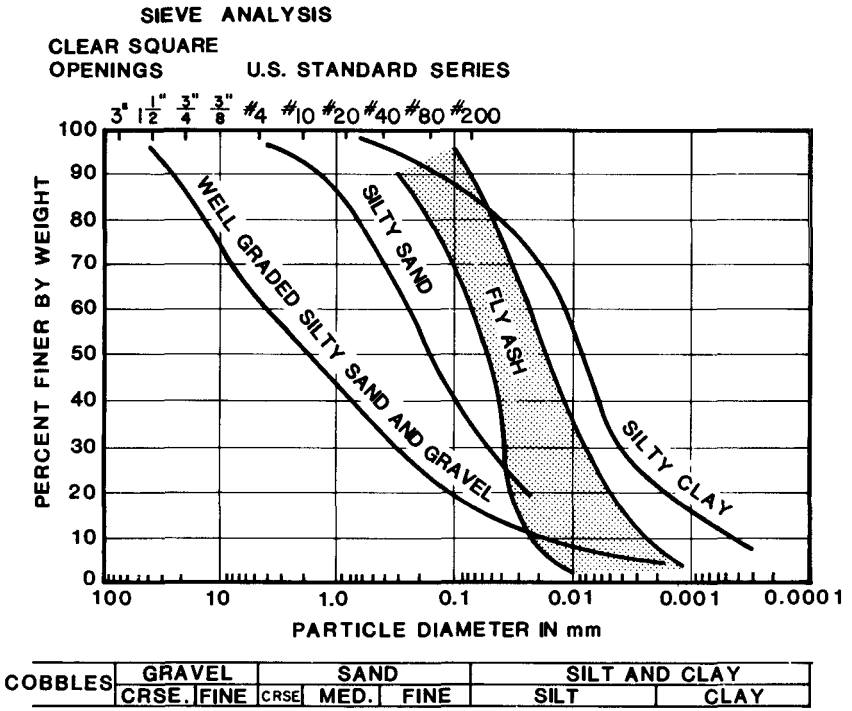

Figure 2-2. Grain size distributions for bituminous fly ash. (Source: J. H. Faber and A. M. DiGioia, Jr. "Use of Ash for Embankment Construction." Presented at the Transportation Research Board Annual Meeting, January 1976.)

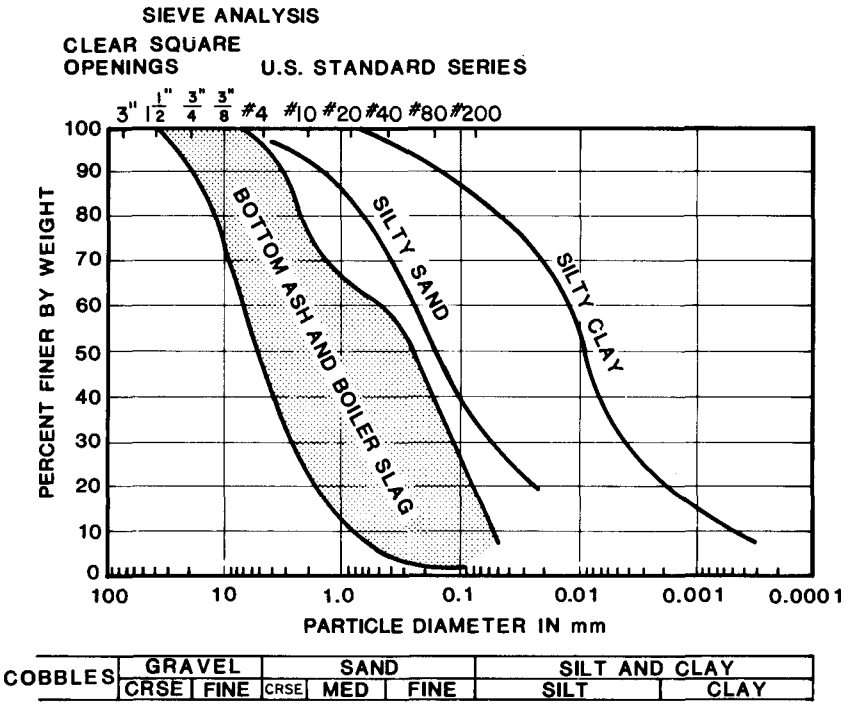

Figure 2-3. Grain size distributions for bituminous bottom ash and boiler slag. (Source: R. K. Seals, L. K. Moulton, and B. E. Ruth. "Bottom Ash: An Engineering Material." Journal of the Soil Mechanics and Foundations Division, ASCE, April 1972, pp. 311-325.)

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 2-3 indicates the range or grain-size distributions for bottom ash and boiler slag. 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. There are two moisture contents 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

compacted when placed in the landfill. Typical values of natural moisture content are 2 to 5 percent for silo-stored ash and 50 to 110 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 2.6. The specific gravity of several West Virginia bottom ashes and boiler slags was found to range from 2.28 to 2.78 for bottom ash and 2.47 to 2.72 for boiler slag. In general, boiler slags will have greater specific gravities than bottom ashes.

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 2-4 presents ten fly ash moisture-density curves for western Pennsylvania bituminous fly 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 from western Pennsylvania bituminous coal can range from 75-105 pcf (1200 to 1680 kg/m^3) with corresponding optimum moisture contents of 30 to 13 percent, respectively.

When the Standard Proctor compaction test (ASTM D 698-66) was performed on several West Virginia bituminous bottom ashes and boiler slags, the following results were compiled (4):

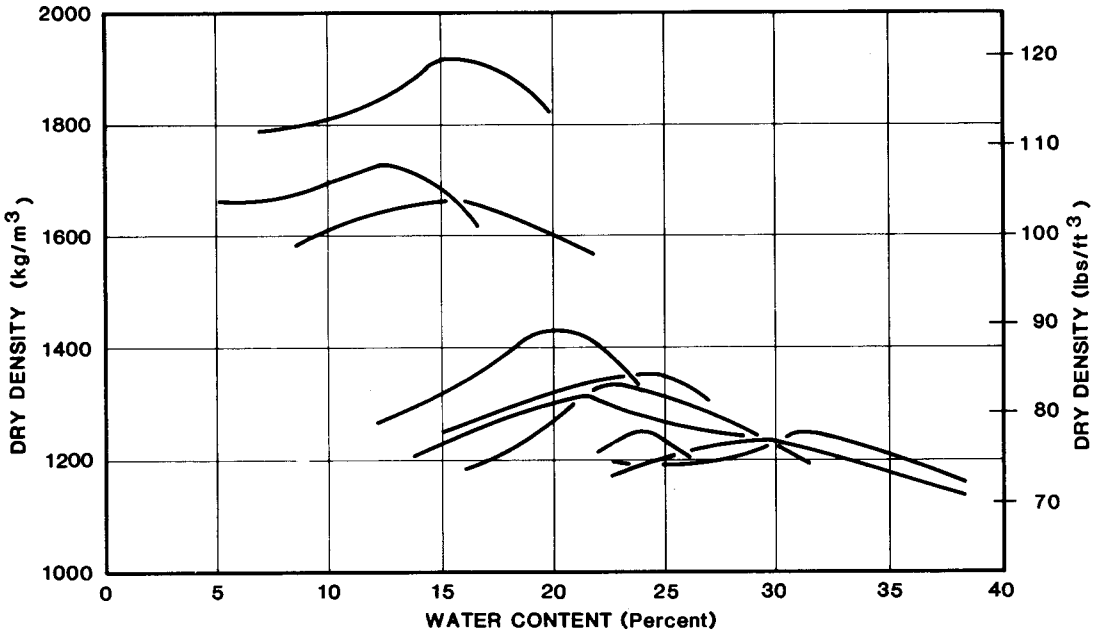

Figure 2-4. Typical Fly Ash Moisture - Density Curves

Source: GAI Laboratory Data

- The maximum dry density of bottom ash ranged from 72.6 to 116.6 pcf (1139 to 1829 kg/cm^3) with corresponding optimum moisture contents ranging from 26.2 to 14.6 percent, respectively.

- The maximum dry density of boiler slag ranged from 91.1 to 102 pcf (1429 to 1600 kg/cm^3) with corresponding optimum moisture contents ranging from 22.0 to 13.8 percent, respectively.

Shear Strength

The 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 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. Typical values for the cohesion and angle of internal friction for various soil types are shown in Table 2-14.

Fly ashes which do not have self hardening properties possess no cohesion; however, they 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 will 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. The unconfined compressive strength of some self-hardening ashes from the western U.S. and Canada has been reported to vary from 7100 to 42,500 pounds per square foot (35kPa to 210kPa). These values vary with both the ash tested and the degree of compaction.

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°. There have not been many studies published on the strength of subbituminous and lignite ashes so that typical ranges of strength parameters, such as cohesion and angle of internal friction, for these ashes are not available.

Table 2-14

TYPICAL SHEAR STRENGTH CHARACTERISTICS FOR VARIOUS TYPES OF COMPACTED SOILS

Soil Type	Cohesion (Saturated) psf	Cohesion (Saturated) kg/m^2	Angle of Internal Friction
Well graded clean gravel	0	0	>38°
Poorly graded clean gravel	0	0	>37°
Silty gravel	-	-	>34°
Clayey gravel	-	-	>31°
Bottom ash, boiler slag	0	0	>38°
Well graded clean sand	0	0	38°
Poorly graded clean sand	0	0	37°
Silty sand	420	2050	34°
Sand, silt, clay mixture	300	1460	33°
Clayey sand	230	1100	31°
Fly ash (non-self-hardening)	0	0	25° - 40°
Inorganic silts	190	930	32°
Low plasticity inorganic clays	270	1320	28°
High plasticity inorganic clays	230	1100	19°

Source: Adapted from U. S. Naval Facilities Engineering Command. Design Manual DM-7. Washington, D. C.: Government Printing Office, 1971.

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° (4).

Compressibility

The compressibility of a fly ash landfill determines the rate and magnitude of settlement of any structures which may eventually be founded on the fill. In contrast to its shear strength behavior where it behaves as a cohesionless material, fly ash behaves very much like a cohesive soil in terms of consolidation and settlement. That is, upon application of vertical pressure, the stress is initially shared by the soil structure and pore water. 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 compressibility of fly ash. Table 2-15 gives some typical values for the compressibility of various soil types.

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 (5).

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). Typical values of the coefficient of permeability for various soil types are shown in Table 2-16.

The engineer's coefficient of permeability applies to the flow of water and was developed as 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 of the soil mass, and the number of discontinuities present in the soil mass. The permeability of bituminous fly ash compacted

Table 2-15

TYPICAL VALUES OF COMPRESSIBILITY FOR VARIOUS TYPES OF COMPACTED SOILS

Soil Type	Compressibility [Percent of Original Height @ 50 psi (345 k Pa)]
Well graded clean gravel	0.6
Poorly graded clean gravel	0.9
Silty gravel	1.1
Clayey gravel	1.6
Bottom ash, boiler slag	1.4
Well graded clean sand	1.2
Poorly graded clean sand	1.4
Silty sands	1.6
Sand, silt, clay mixture	1.4
Clayey sand	2.2
Fly ash	1.8
Inorganic silt	1.7
Low plasticity inorganic clay	2.5
High plasticity inorganic clay	3.9

Source: Adapted from U. S. Naval Facilities Engineering Command. Design Manual DM-7. Washington, D. C.: Government Printing Office, 1971.

Table 2-16

TYPICAL COEFFICIENTS OF PERMEABILITY FOR VARIOUS TYPES OF COMPACTED SOILS

Soil Type	Coefficient of Permeability (ft/yr)	(cm/sec)
Well graded clean gravel	52,000	5×10^{-2}
Poorly graded clean gravel	104,000	10^{-1}
Silty gravel	>1.04	$>10^{-6}$
Clayey gravel	>0.104	$>10^{-7}$
Bottom ash, boiler slag	52,000	5×10^{-2}
Well graded clean sand	>1040	$>10^{-3}$
Poorly graded clean sand	>1040	$>10^{-3}$
Silty sand	52	5×10^{-5}
Sand, silt, clay misture	2.08	2×10^{-6}
Clayey sand	0.52	5×10^{-7}
Fly ash	0.104 - 104	$10^{-7} - 10^{-4}$
Inorganic silt	10.4	10^{-5}
Inorganic clay	0.104	10^{-7}

Source: Adapted from U. S. Naval Facilities Engineering Command. Design Manual DM-7. Washington, D. C.: Government Printing Office, 1971.

to its maximum dry density has varied from 0.104 to 104 ft/yr (10^{-7} - 10^{-4} cm/sec) in laboratory tests (6). The coefficient of permeability for bituminous bottom ash and boiler slag has been shown to vary from 31,200 to 93,600 ft/yr (3 x 10^{-2} - 9 x 10^{-2} cm/sec) (4).

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 compacted fine 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.

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.

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Section 3

CURRENT DISPOSAL PHILOSOPHIES

INTRODUCTION

In selecting a new 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, design ash handling method, and management practices.

While most 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 recently proposed and enacted environmental regulations. Two federal laws and their resulting regulations have been deemed most significant with respect to their effect on ash disposal practices: the Federal Water Pollution Control Act as amended by the Clean Water Act of 1977 and the Resource Conservation Recovery Act of 1976. Additional regulations implemented by individual states will result from these two laws and will also greatly influence future ash disposal practices.

This section presents an overview of current ash disposal practices in the utility industry in various regions of the country and discusses in detail these two environmental regulations as well as other factors which may influence future ash disposal systems.

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 ash disposal practices.

OVERVIEW OF CURRENT PRACTICE

The National Ash Association in cooperation with the Edison Electric Institute annually surveys utilities to determine the amount of ash produced, the degree of utilization, and disposal practices. Based on a 1978 survey of 131 utilities accounting for 90 percent of the coal burned, the estimated total ash production was 68.1 million tons (61.8 million metric tons) of fly ash, bottom ash, and

boiler slag. Approximately 24 percent of the total 16.4 million tons, (14.9 million metric tons), was utilized. The remaining 76 percent was disposed of. Fifty-one percent was sluiced in slurry form to ash disposal ponds and the remainder was handled dry and placed in landfills. American Electric Power, the largest investor owned utility in the United States, is switching to dry disposal as are other utilities (1). Reasons for these changes include increased ash marketability and reduced disposal volume required for that portion of the ash disposed. Also influencing this change are increasingly stringent effluent regulations for ash transport water and increased environmental concerns with operating present wet ash systems.

In presenting data on ash disposal practices, the National Ash Association has divided the country into nine regions as shown on Figure 3-1. Data shown on the figure is for 1977, the most recent data currently available. Regions 2 through 8 account for over 98 percent of the total ash production. A summary of disposal practices and key factors governing the selection process decisions in each of these regions is given in the following paragraphs. Information is generalized and although exceptions may exist in all cases, the information is useful to present an overview of the current disposal practices nationwide.

Region 2 includes Pennsylvania, New York, and New Jersey and accounts for 11 percent of the total ash produced nationwide. Of these three states, Pennsylvania is by far the largest producer consuming 80 percent of the coal burned in this region. In central and western Pennsylvania as well as portions of upstate New York, dry disposal methods predominate. The hilly topography of this area is one factor in selecting dry disposal methods since many sites are developed as valley fills. Large flat areas suitable for pond construction are not readily available.

Region 3 includes Michigan, Wisconsin, Illinois, Indiana, and Ohio, and produces 31 percent of the total national ash production. While Ohio is the largest coal-burning state, consuming over 50 million tons (45 million metric tons) in 1977, all the other states in this region also produce large quantities of ash. The dominant method of ash disposal in this region is sluicing to ash ponds; however, the trend toward dry disposal to increase marketability and to reduce disposal site volumes by American Electric Power is significant. Environmental requirements are also a factor in the trend from wet to dry disposal.

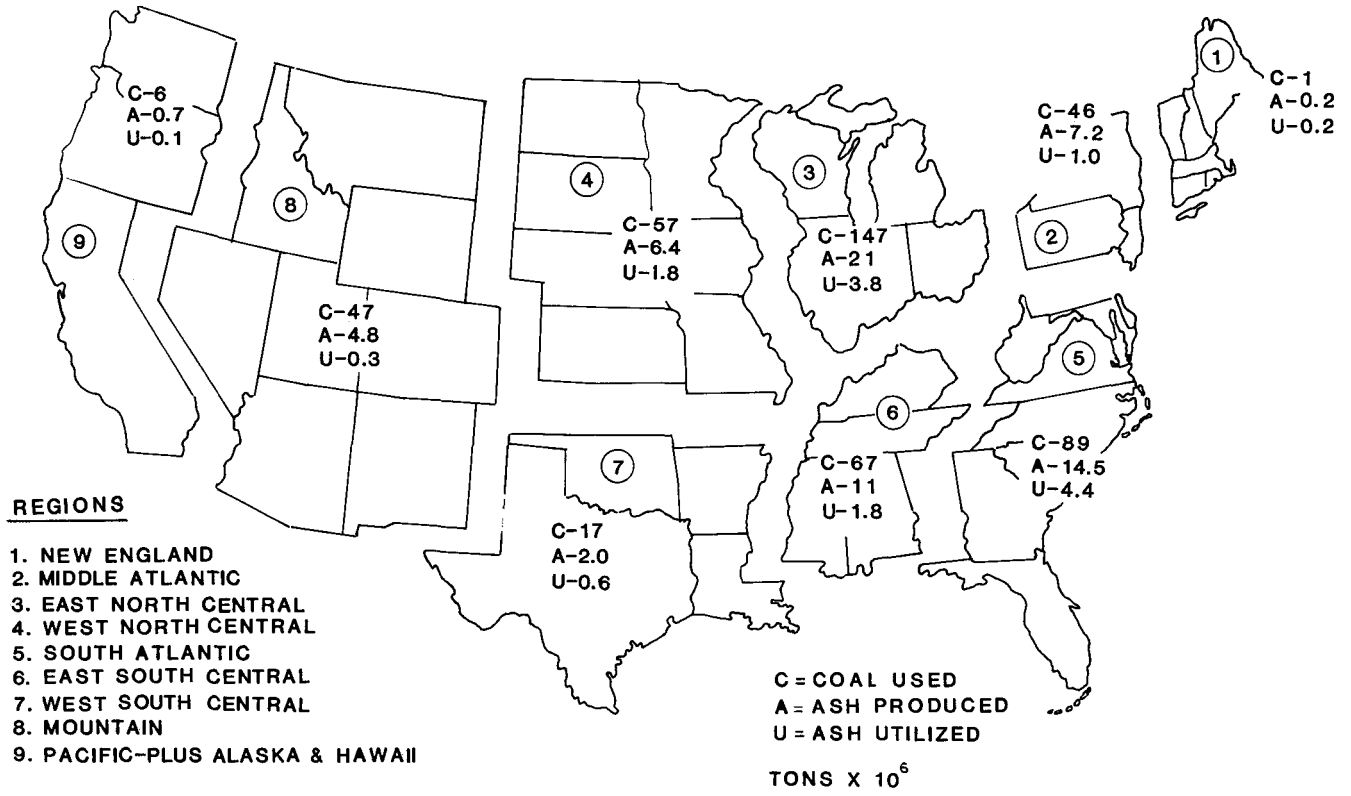

Figure 3-1. Regional Breakdown of the United States

Source: J. H. Faber. "Ash Availability and Uses." In Proceedings of the Ash Management Conference, Texas A & M University, September 1978.

Region 4 includes Minnesota, Iowa, Missouri, North and South Dakota, Nebraska, and Kansas, and accounts for 9 percent of the total national ash production. Over 50 percent of the coal burned in this region is in Minnesota and Missouri. Ash disposal in this region is predominantly at wet sites but some significant dry disposal operations exist.

Region 5 includes West Virginia, Virginia, Delaware, Maryland, North and South Carolina, Georgia, and Florida. This region is the second largest coal burning region accounting for 21 percent of the total national ash production. Ash handling is predominantely wet with two notable exceptions. In the northern part of the region, particularly in West Virginia and Maryland, a number of ash disposal operations are dry landfills. As in neighboring Region 2, the hilly topography in this portion of the region is one factor in selecting dry disposal sites. The other exception is that many utilities in the southeast handle a portion of their ash dry. The ash is placed in storage silos for sale. Based on 1977 figures Region 5 had the highest degree of ash utilization, both as a percentage of production and on a total tonnage basis.

Region 6 includes Kentucky, Tennessee, Mississippi, and Alabama and is responsible for 16 percent of the total national ash production. The dominant method of ash handling in this region is wet sluicing to ash ponds. The Tennessee Valley Authority, the primary utility in the region, uses wet disposal in all of its coal fired generating stations.

Region 7 includes Oklahoma, Arkansas, Louisiana, and Texas. Most of the coal consumed (95 percent) is by power plants in Texas. The region burns relatively little coal accounting for three percent of the total ash production. Dry disposal methods are the most prevalent because of the reactive nature of lignite and western coal ashes. Many of these ashes react with water and undergo hardening reactions with the evolution of considerable heat. Depending upon the degree of reactivity of the ash and the individual preference of the utility, conditioning of the dry ash with water may be at the power plant or at the disposal site.

Region 8 includes Montana, Idaho, Wyoming, Nevada, Utah, Colorado, New Mexico, and Arizona. While covering a large area, Region 8 accounts for only 7 percent of total ash production. A number of utilities practice wet disposal in spite of the relatively arid conditions in this part of the country, although dry disposal methods are also common. With increased production of western coal and

additional economic and population growth projected for this region, future plants may trend towards dry disposal because of environmental regulations, water scarcity, and potential utilization of reactive ash as a concrete additive and for soil cement.

REGULATORY TRENDS

Disposal of fly ash either in wet or dry sites has only recently become an area of environmental concern. Discharge of the ash pond supernatent and landfill runoff to surface waters has previously been allowed with only minimal requirements concerning water quality. Similarly, the possibility of groundwater contamination by leachate from ash disposal sites has also only recently become an area of concern. Other aspects of ash disposal which have received recent attention concern its use in filling wetlands and abandoned mines, and the handling and transportation of the material. Table 3-1 summarizes federal laws which may affect ash handling and disposal (2). It is interesting to note that all of these laws have been passed recently, most of them in the 1970's.

Many of the laws listed 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 of in or adjacent to coal mines. In addition to the federal laws listed in the table, state and local laws as well as regulatory decisions may be applicable to ash disposal practices.

The two federal laws which have the greatest impact on ash disposal are:

- The Clean Water Act of 1977 (CWA).
- The Resource Conservation and Recovery Act of 1976,(RCRA).

These two laws are particularly significant since they are generally applicable to ash disposal and therefore have an impact on all types of ash disposal systems.

The Clean Water Act through the National Pollution Discharge Elimination System (NPDES) permit program, sets effluent limitations for point source discharges to surface waters. These standards apply to discharges from ash ponds as well as runoff from ash landfills. The stringent discharge criteria promulgated under these acts are instrumental in accelerating the trend from wet to dry disposal systems.

Table 3-1

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

The Resource Conservation and Recovery Act was passed in response to concern about groundwater pollution caused by leachate resulting from solid waste disposal sites. Regulations and guidelines for disposal of all solid wastes are presently being promulgated under this act. Since fly ash and bottom ash are solid wastes, disposal practices for these materials will be subject to the rules and regulations promulgated under this act. While the exact outcome that RCRA will have on ash disposal practices is unclear, it is certain that more stringent environmental standards will have to be adhered to in the future. Details of the RCRA regulations as proposed for promulgation through the summer of 1979 are discussed subsequently. Actual promulgation of regulations governing ash disposal are anticipated to be in 1980 or later.

The 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 (EPA) established discharge limits for various industries and for various pollutants. This act was amended again in 1977 as the Clean Water Act.

The effluent guidelines and standards for steam-electric power plant ash ponds require that by July 1, 1983, the "Best Available Technology Economically Achievable" (BATEA) standard be implemented. This standard is limited to total suspended solids of 30 milligrams per liter for the 30 day average of the ash pond discharge. This standard is quite stringent. For plants on which construction started after the date of the regulations (Federal Register, March 1974, Pages 36185 to 36307), the EPA proposed the even more stringent "New Source Performance Standard" (NSPS) of zero discharge for fly ash pond effluents. As a result of a court challenge to the proposed NSPS, revised standards for fly ash pond discharges are being developed by EPA. It is expected the revised standards will be promulgated in late 1979 or early 1980.

Interestingly, standards for runoff from fly ash landfills are less stringent than those for ponds. Both the BATEA standards and the NSPS standards for material storage pile runoff have been set at 50 milligrams per liter total suspended solids. While less stringent than the standards for ash ponds, the storage pile runoff standards are also quite 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.

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 were 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 Resource Conservation and Recovery Act was preceded by two other laws which dealt with the handling of solid wastes. These laws were the Solid Waste Disposal Act of 1965 and the Resource Recovery Act of 1970. The Solid Waste Disposal Act was an amendment to existing air pollution legislation. The primary objective of this act was to provide funds to identify and quantify the municipal solid waste disposal problem. 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 solid waste management. The 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.

As a result of the information obtained under the Resource Recovery Act, the Resource Conservation and Recovery Act was passed in 1976. Table 3-2 presents the organization and contents of the several subtitles which comprise the RCRA.

Of particular interest is Subtitle C which 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.

Section 3001 of Subtitle C defines a waste as hazardous if it is specifically listed in these regulations or if it is ignitable, corrosive, reactive, or toxic. There are approximately 160 wastes or waste sources which are listed in the regulations as presumed hazardous. While utility solid wastes are not presumed hazardous, in some cases they may fail the criteria proposed in Section 3001 and be classified as hazardous wastes.

The proposed Section 3002 regulations of Subtitle C define the responsibilities of hazardous waste generators. Generators of hazardous wastes must keep records identifying the quantities, constituents, and disposition of the waste; use a manifest system to assure that the waste is delivered to a permitted facility; and submit reports to the EPA or an authorized state agency on the quantities and disposition of the wastes.

Proposed Section 3003 regulations which deal with the transportation of the hazardous wastes are being jointly promulgated by the EPA and the U. S. Department of Transportation.

Proposed Section 3004 regulations are the standards for treatment, storage, and disposal facilities. These standards are to be used as the basis for issuing permits, and will include design and engineering specifications to prevent contamination of groundwater, surface water, or air by the wastes. They also include management requirements, i.e., safety measures, personnel training, and recordkeeping and reporting. If certain large volume wastes, including fly ash and bottom ash, are classified as hazardous under Section 3001, they would be designated as Special Wastes under proposed Section 3004 Regulations. A limited set of interim standards has been proposed for facilities handling these utility wastes and the EPA plans to obtain more information to determine what specific control standards are appropriate. Figure 3-2 is a flow diagram presenting a decision tree used to determine which parts of Section 3004 apply to a particular waste. It also provides an overview of the RCRA framework.

Table 3-2

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

Sections 3003
Standards for transporters of hazardous wastes

Section 3004
Standards for siting and operation of hazardous waste treatment, storage and disposal facilities

Section 3005 through 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

Table 3-2
(Continued)

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

Section 3005 regulations cover permitting procedures.

Section 3006 lists the guidelines for determing if a state should receive authorization from the EPA to enforce the federal hazardous waste regulations within its boundaries.

Section 3007 of RCRA gives the EPA the right to inspect all waste handling facilities.

Section 3008 specifies various civil and criminal penalties which can be imposed for non-compliance. Fines of up to $25,000 and imprisonment for up to one year are authorized for each day of violation.

Section 3009 specifies the relationship of federal to state authority.

Section 3010 provides the rules for notifying the EPA if an industry is generating or handling a hazardous waste.

Also of particular interest to the electric utility industry is Subtitle D, calling for the EPA to publish guidelines for the development of comprehensive state or regional solid waste management programs. Disposal of solid wastes which are classified as non-hazardous wastes must conform to Subtitle D criteria. Disposal of utility wastes classified as non-hazardous must conform to the provisions of Subtitle D. Under Subtitle D, reference is made to guidelines for

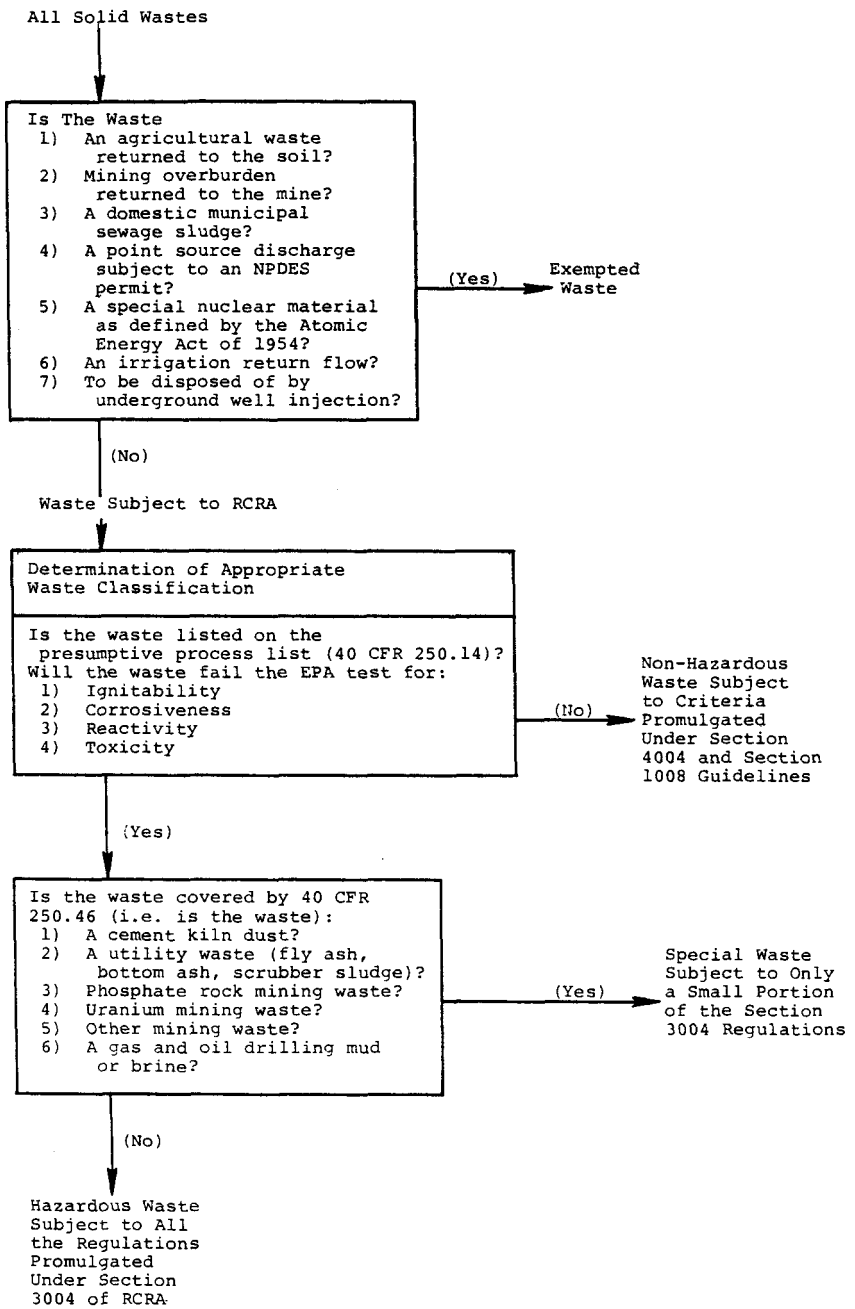

Figure 3-2. Flow Chart for Determining Applicable RCRA Regulations

non-hazardous waste landfills. These guidelines are proposed for promulgation under Subtitle A of RCRA and are likely to have a significant impact on future ash disposal practices.

Three sections of Subtitles C and D are of primary importance to future ash disposal practices:

- Subtitle C, Section 3001 - Identification and listing of hazardous wastes.
- Subtitle C, Section 3004 - Standards for disposal of hazardous wastes.
- Subtitle D, Section 4004 - Minimum standards for non-hazardous solid waste disposal sites.

The rules and regulations contained in these three portions of the Resource Conservation and Recovery Act are fully delineated below. Details of the proposed guidelines for non-hazardous waste landfills to be promulgated under Section 1008, Subtitle A of RCRA are discussed in Section 4 of this manual.

Section 3001 - Hazardous Waste Criteria

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 criteria of Section 4004, the EPA has developed a hazardous waste classification criteria. These criteria are described in the Federal Register, December 18, 1978, Part IV. A waste is classified as hazardous if it exhibits any of the following characteristics:

- Ignitability
- Corrosivity
- Reactivity
- Toxicity

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 D93-72 or D3278-73; is not liquid and can cause a fire through friction, absorption of moisture, spontaneous combustion, or the retention of heat from processing; 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.

A waste is corrosive if a representative sample of the waste is aqueous and has a pH less than or equal to 3 or greater than or equal to 12. 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 (54°C) as determined by using the National Association of Corrosion Engineers Standard TM-01-69. Slurried fly ash can have a pH as low as 3 or as high as 12 for some fly ashes. However, values of either extreme are not commonplace.

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, is capable of detonation or explosive reaction, or can be classified as an explosive under other federal regulations. A waste is thermally unstable and hazardous if explosion, ignition, or decomposition of the waste will occur at 257°F (125°C) after five minutes. The Explosion Temperature Test as described in the Federal Register, December 18, 1978, p. 58962, is used to determine thermal instability. Fly ash and bottom ash are not reactive wastes.

The one hazardous waste characteristic which fly ash and bottom ash are most likely to possess is heavy metal toxicity. Under the proposed regulations, a waste is classified as toxic if the extract of that waste, obtained by using the Extraction Procedure, has a heavy metal concentration in excess of the values given in Table 3-3. Details of the Extraction Procedure were published in the Federal Register on December 18, 1978, by the EPA. The extract is analyzed for heavy metal concentrations by using the atomic absorption techniques described in "Manual of Methods for Chemical Analysis of Water and Wastes," Environmental Protection Agency, Office of Technology Transfer, Washington, D. C., 1979 (EPA-600/4-79-02). The values for the allowable heavy metal concentrations listed in Table 3-3 are based on ten times the National Interim Primary Drinking Water Standards which are currently being revised by the EPA. The criteria on Table 3-3 will be revised to reflect changes in the drinking water standards, if the standards are revised.

Table 3-3

MAXIMUM ALLOWABLE EXTRACT LEVELS FOR HEAVY METALS

Metal	Extract Level, mg/l
Arsenic	0.50
Barium	10.00
Cadmium	0.10
Chromium	0.50
Lead	0.50
Mercury	0.02
Selenium	0.10
Silver	0.50

In the December 18, 1978, issue of the Federal Register the EPA also published an Advance Notice of Proposed Rulemaking concerning the possible expansion of the Section 3001 criteria for identifying wastes as hazardous. Comments were requested by July 1, 1979. Two areas are under consideration as being suitable as additional criteria for judging a waste to be hazardous: one area is radioactivity, and the other is an expansion of the toxicity criteria based on the material causing mutations, tumors or cancer in laboratory animals or cultures. Both of these areas are of possible concern with utility wastes. Some fly ash has been shown to fail the radioactive criteria as now proposed. In regard to the biological testing associated with the proposed toxicity criteria, the immediate concern is centered on the expense of the testing procedure. It is estimated to exceed $10,000 per sample.

Section 3004 - Hazardous Waste Disposal Regulations

As presently proposed, if the extract of a particular fly ash or bottom ash has a heavy metal concentration in excess of the acceptable limits given in Table 3-3, then it will be classified as a hazardous waste and will be subject to regulation under Section 3004 of RCRA after promulgation of the regulations. However, utility wastes, (i.e., fly ash, bottom ash, and FGD sludges), if

classified as hazardous, would be considered to be special wastes due to the large volume of waste which is generated and the relatively low potential hazard which they pose. Therefore, these utility wastes would be subject to only a small portion of the hazardous waste regulations. The EPA is researching the current disposal practices for hazardous utility wastes and plans to promulgate standards for the disposal of these wastes in the early 1980's, i.e., 1982 or 1983. The following paragraphs summarize those proposed hazardous waste regulations which would apply to utility waste disposal until more detailed regulations have been established. The present regulations would require increased recordkeeping, groundwater monitoring, and site security, and would impose restrictions on the siting of new ash disposal facilities.

The owner/operator of an off-site utility waste disposal facility must obtain a detailed physical and chemical analysis of the waste from the power plant prior to the beginning of the disposal operation. This is to enable the site owner/ operator to determine the proper disposal methods for the waste.

If the utility waste is determined to be hazardous, siting restrictions will apply to the location of new disposal areas. Existing and abandoned sites are exempted from the siting criteria, at present. However, if an abandoned site is creating a hazardous pollution problem, the EPA has authority under Section 7003 to take legal action against the landowner to seek a solution to the problem. The impact on existing active sites is unclear; however, RCRA requires that active sites be brought into compliance.

Therefore, it is anticipated the trend will be to phase out existing sites not in compliance with the siting criteria. Whether this phasing out will be by attrition or some more rapid means is uncertain. The following restrictions on the siting of new disposal facilities for hazardous wastes will apply:

- A disposal site cannot be located in an active fault zone, i.e., a land area which, based on geologic evidence, has a reasonable probability of being affected by the movement along the fault to the extent that a disposal facility built in this area would be damaged.

- A disposal site cannot be located in a regulatory floodway. A regulatory floodway is defined as the channel of a river or other watercourse and the adjacent land areas which must be reserved in order to discharge the 100-year flood without cumulatively increasing the elevation of the water surface more than a designated height. The 100-year floodways for some areas of the U. S. have been

mapped by the U. S. Geological Survey, the U. S. Army Corps of Engineers, and the Department of Housing and Urban Development. Offices of these organizations or the county planning agency are likely sources of information to determine if a proposed disposal area is in a regulatory floodway. If the proposed site has not been mapped by these agencies, a hydrologic analysis using the same methods must be conducted. The methodology is available from the Department of Housing and Urban Development, Federal Insurance Agency, Washington, D. C.

- A disposal site cannot be located in a coastal high hazard area (an area designated on Flood Insurance Rate Maps developed by the Federal Insurance Administration as Zone VI-30) unless it can be proven that the site will be designed, constructed, operated, and maintained in such a manner that it will not be inundated by high velocity waters, such as hurricane wave wash and tsunamis.

- A disposal site cannot be located in a 500-year floodplain unless it can be shown that the site will be designed, constructed, operated, and maintained in such a manner that it will not be inundated by a 500-year flood. The 500-year floodplain can be determined from Department of Housing and Urban Development, Federal Insurance Agency Mapping in some cases or by a hydrologic analysis. An EPRI sponsored study of 551 power plants revealed that only 109 were outside of the 100-year floodplain and only 33 were outside of the 500-year floodplain. The results of this study are published in EPRI Publication FP 1205.

- A disposal site cannot be located in a wetland unless a National Pollutant Discharge Elimination System (NPDES) permit is obtained and, if dredging or filling of the wetland is involved, a permit issued under the authority of Section 404 of the Clean Water Act is obtained from the U. S. Army Corps of Engineers.

- A disposal site cannot be located in an area where it will jeopardize the continued existence of endangered and threatened species as listed in Title 50 of the Code of Federal Regulations (CFR), nor result in the destruction or adverse modification of their critical habitat. Information concerning endangered and threatened species and their critical habitats is obtainable from the U. S. Fish and Wildlife Service, Office of endangered species. An exception to this regulation will be granted if it can be shown, after consultation with the Office of Endangered Species, that locating the site in the critical habitat will not jeopardize the existence of the Endangered Species which are there.

- A disposal site cannot be located in the recharge zone of a sole source aquifer, i.e., an area through which potable water enters an aquifer which serves as the sole or principal supply of drinking water for a large percentage of the population in a given area. An exception to this regulation will be granted if it can be demonstrated that the site will be designed, constructed, operated, maintained, and monitored to prevent contamination of the water supply.

- Active portions (areas where disposal is actually taking place) of a disposal site must be at least 200 feet* (60 meters) from the property line unless it can be shown that any unexpected release or discharge of waste can be controlled before the hazardous material crosses the property boundary.

For a hazardous utility waste, the security at both existing and new disposal sites must meet the following requirements:

- The site must have 6-foot* (2-meter) fence, or other type of natural or artificial barrier, surrounding the active portion of the site to prevent the unknowing and/or unauthorized entry of persons or domestic livestock. For a wet disposal system, this means the pond must be fenced, and for a dry disposal system, portions of the landfill which have not been closed must be fenced. Upon closure of a section of the landfill, the fence may be removed or moved to another section of the disposal area.

- All access points to the active portion of the site must be controlled by an attendant, or a mechanical or an electro-mechanical device, when disposal operations are in progress, and must be secured against entry when the site is not operating.

- Warning signs must be posted at the access points to the active portion of the site unless it can be shown due to the nature of the waste being handled that a warning sign is not necessary. What problems are involved in obtaining a variance from the signing requirement are uncertain.

As proposed, the regulations state that if a utility's solid waste is designated as hazardous and it is disposed of off the power plant site, even if the utility owns the disposal site, a manifest system to track the waste from the time it leaves the power plant until it reaches the disposal site must be instituted. One copy of the manifest must be retained by the disposal site operator for a period of three years; one copy must be given to the transporter; and the original copy of the manifest must be sent to the power plant generating the waste within 30 days. If there is any discrepancy between the shipment as described by the manifest and the shipment as received at the disposal site, the site operator must notify the EPA of the discrepancy.

An operating log must be maintained by the operator of the disposal site and is to be open for inspection by any duly designated agent of the EPA. The following information is to be recorded in the log and retained until closure of the site:

*The proposed regulations are published in metric units.

- A description of each waste shipment by name, i.e., fly ash or bottom ash.
- The DOT hazard class of the waste or its EPA characteristic(s) (i.e., corrosive, toxic, etc.).
- The quantity of waste delivered, the method of disposal used, and the dates of disposal.

Whether the disposal of the utility waste occurs on-site at the power plant or at an off-site disposal facility, the EPA requires that an annual report containing the following information be submitted within four weeks of the end of the reporting period to the EPA Regional Administrator:

- Disposal site's ID code (for off-site disposal)
- Generator's ID code for both on-site and off-site disposal
- Closing date for the reporting period
- Name and common code of the waste
- Hazard class of the waste
- Quantity of waste handled
- Method of disposal

If an off-site disposal facility receives a hazardous utility waste shipment which is not accompanied by a manifest, the operator must submit a quarterly report to the EPA Regional Administrator. This report must contain the same information given in the annual report plus a brief explanation of why the shipment was unmanifested.

If an accidental release of the hazardous waste occurs at the disposal site and this discharge of waste has the potential for damaging human health or the environment, the emergency coordinator for the disposal site must telephone either the U. S. Coast Guard National Response Center or the government official designated as the on-scene emergency coordinator for that geographic area to report the incident.

As proposed in the regulations, the operator of the hazardous waste disposal facility must perform daily a visual inspection of the site and record the observations in the operating log. The daily inspection must include the following:

- All waste storage areas must be checked to see if the storage devices show signs of rust, corrosion, or cracking and to see if any spills may have occurred.
- Dikes are checked for structural weakening and drainage systems are checked for a possible stoppage.
- Equipment must be checked to ensure that it is operating properly.
- Fences or other barriers must be checked for damage.
- Vegetation on or around the site must be checked for damage.
- The active portion of the facility must be checked for fugitive air emissions.

Within 180 days after completion of site closure, the disposal facility operator must file a survey plat, certified by a registered professional land surveyor, with the local land authority and the EPA Regional Administrator. The survey plat must indicate the type and location of the hazardous waste disposed of at the disposal site. The site must be properly maintained for a period of 20 years after the date of closure unless the Regional Administrator decides, based on information provided by the site owner/operator, that post-closure care is not necessary for the full 20 years. Post-closure care will consist of groundwater monitoring and the submission of periodic monitoring reports, as discussed below.

The proposed hazardous waste regulation which applies to fly ash and bottom ash concerns groundwater monitoring. In most cases, a groundwater monitoring system will be required if the waste is classified as hazardous. The groundwater monitoring system is to consist of a minimum of four wells which must meet the following criteria:

- One well is to be placed hydraulically upgradient from the disposal area so that representative samples of the groundwater flowing into the area can be collected.
- Three wells, each sunk to a different depth, are to be installed hydraulically downgradient of the site in order to detect any leachate migration. All three wells can be sunk to one depth if it can be shown that this is the depth where contamination is most likely to occur.
- At least one of these three wells must be located immediately adjacent to the disposal area. The other two wells are to be placed within the property line of the site in locations which provide the greatest opportunity for the interception of leachate.

- All monitoring wells must be cased, and the space between the casing and the borehole must be backfilled with an impermeable material to prevent surface water from entering the well and to prevent the exchange of water between aquifers.

A groundwater monitoring system will not be required if it can be proven that the geologic and hydrologic conditions under the site indicate that the leachate has no potential for reaching the groundwater. The difficulty in obtaining a variance so that no groundwater monitoring system is required is uncertain.

The background level of the groundwater quality must be established by conducting a monthly comprehensive water quality analysis, described below, of the samples collected in the monitoring wells for at least one year. For new disposal sites, the comprehensive analysis of groundwater samples must begin at least three months prior to the beginning of disposal operations. After the background level for the groundwater quality has been established, the comprehensive analysis of samples is to be done on an annual basis. A minimum analysis of groundwater quality, also described below, must be performed at the following frequencies:

- Semi-annually, if the groundwater flow rate ranges between 82 and 164 ft/year (25 and 50 m/year).*
- Quarterly, if the flow rate is greater than 164 ft/year (50 m/year).*

A minimum water quality analysis will consist of tests for the following:

- Specific conductivity, mho/cm at 25°C
- pH
- Concentration of chloride, mg/liter
- Total dissolved solids concentration, mg/liter
- Dissolved organic carbon concentration, mg/liter
- Concentrations of the specific heavy metals which resulted in the ash being classified as hazardous

A comprehensive water quality analysis will test for all of the above plus:

- Concentrations of contaminants and the levels of the properties listed in the EPA Interim Primary and Proposed Secondary Drinking Water Standards shown in Table 3-4

*The proposed regulations are published in metric units.

Table 3-4

EPA INTERIM PRIMARY AND PROPOSED SECONDARY DRINKING WATER STANDARDS

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	
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

- Concentration of beryllium, mg/liter
- Concentration of nickel, mg/liter
- Concentration of cyanide, mg/liter
- Concentration of phenolic compounds, mg/liter
- Presence of organic constituents, as determined by a scanning by gas chromatography

After the background level is established, the comprehensive analysis may be reduced by eliminating the analysis of characteristics that could not result from disposal of the ash. Quarterly reports of the monitoring data must be submitted to the EPA or to the appropriate state agency, enforcing the hazardous waste regulations. All monitoring and analysis records must be retained by the site operator for at least three years.

If the quality of the groundwater collected for sampling differs by a statistically significant amount, as determined by the Student's t, singletailed test at the 95 percent confidence level, from the background quality, the site operator must:

- Notify the Regional Administrator of the EPA within seven days.
- Determine, if possible, the cause of the variation in quality.
- Determine the extent of the groundwater contamination or potential for groundwater contamination and discontinue operation of the site until the Regional Administrator determines what action must be taken.

At present, these are the only hazardous waste regulations which would be applicable to fly ash and bottom ash that are classified as hazardous after promulgation of the final regulations. For the time being, these utility wastes are exempt from the storage standards of the proposed Hazardous Waste Regulations. However, the EPA anticipates that regulations regarding the storage and disposal of special wastes, such as hazardous fly ash and bottom ash, will be written within the next two to three years (1982 to 1983). The EPA is funding a research program which calls for the monitoring of actual ash disposal practices and to provide the necessary background data for the promulgation of detailed utility waste disposal regulations for both hazardous and non-hazardous ashes. In the immediate future, portions of the proposed hazardous waste regulations will be reproposed. Due to over 1,200 comments received by EPA after the regulations

were originally proposed, as well as new information received, significant changes in the proposed regulations are anticipated. These changes will probably require reproposal or partial reproposal of major portions of the Section 3001 and 3004 criteria, including the special waste regulations. Portions of these changes are to be issued in early 1980.

Section 4004 - Non-Hazardous Waste Disposal Criteria

If a utility waste is classified as non-hazardous under the criteria established for Section 3001 of RCRA, then it will be subject to the criteria under Section 4004 of RCRA. These citeria are for determinig if a particular waste disposal facility employs environmentally acceptable disposal practices. They were issued in the September 13, 1979 issue of the Federal Register, pp. 53438 to 53468. These criteria apply to almost all non-hazardous wastes and to all forms of land disposal, including landfills and surface impoundments. They became effective October 15, 1979. The two major concerns of these criteria are:

- protection of sensitive areas, such as critical habitats and floodplains
- protection of the quality of groundwater, surface water, and the air

If a waste disposal facility does not meet these criteria, it must be closed or upgraded within a reasonable time frame (not to exceed five years). The states are expected to incorporate these criteria into their solid waste regulations and then to enforce the regulations to bring about the closing or upgrading of unacceptable sites. Since enforcement is to be by the states, penalities are not specified as they are under Section 3004 of Subtitle C. States are also to incorporate operational guidelines promulgated under Section 1008 of RCRA with regulations. The details of these guidelines and the possible impact on future disposal sites are covered in Section 4 of this manual.

The following siting restrictions apply to the selection of sites for the disposal of non-hazardous wastes classified under Section 4004 of RCRA:

- The facility cannot be located in a 100-year floodplain unless it can be shown that the facility will not restrict the flow of the flood or reduce the temporary water-storage capacity of the floodplain such that increased flooding upstream or downstream of the facility can result, and is designed, constructed, operated, and maintained to protect against inundation by the flood.

- The disposal facility cannot be located in a critical habitat area unless the disposal site operation will not jeopardize the endangered species present and the Office of Endangered Species approves of the disposal plan.

An acceptable ash disposal site cannot adversely affect the quality of the surface water or groundwater in the area. All point source discharges of pollutants (such as channeled surface leachate, leachate seepage, surface runoff, and leachate treatment effluent) to off-site surface waters must comply with the NPDES permit issued to the site. Non-point sources of contaminants must be controlled so that non-point source discharges to off-site surface waters are minimized.

Underground drinking water sources beyond the limit of the final boundary of the ash deposit are to be protected from contamination. The definitions of underground drinking water sources and contamination are important to understanding the impact of the regulation.

An underground drinking water source is any geologic formation or formations capable of supplying usable quantites of groundwater and;

- being used for human consumption, or
- containing less than 10,000 mg/l total dissolved solids

Contamination is defined as introducing a substance to the groundwater that would cause the concentration of the introduced substance to exceed the limits specified in the National Interim Primary Drinking Water Standards. In cases where the groundwater already exceeds the standards, any further increase would be considered contamination.

Included in the Federal Register with the above regulations is a proposal to extend the definition of contamination to include the substances listed in the Secondary Drinking Water Standards, with the exception of hydrogen sulfide and corrosivity. These standards are listed on Table 3-4. If adopted, these standards could have a significant impact on ash disposal practices. In many cases, ash leachate would exceed the limits due to sulfate, pH, or other criteria. In these cases, leachate prevention measures such as liners could be required for ash disposal sites.

Provisions for allowing contamination to extend beyond the boundary of the ash deposit are included in the regulations. Variance of this type would be obtained from the state on a case-by-case basis in compliance with provisions listed in the regulations.

Disposal facilities must control air emissions in compliance with federal, state, and local air pollution control regulations. Also, access to the disposal area must be controlled so as to minimize the potential danger to the general public presented by the operation of heavy equipment.

SUMMARY

The two federal laws which have the most significant impact on ash disposal practices are the Clean Water Act of 1977 (CWA) and the Resource Conservation and Recovery Act of 1976 (RCRA). Current ash disposal practices are trending away from wet disposal to landfilling. The CWA requirements will continue this trend. The requirements of RCRA will also influence future trends in ash disposal, although specific regulations governing ash are not yet promulgated. The following section of this manual, Section 4, provides some insight into what form these future regulations may take.

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1. D. L. Kinder and R. E. Morrison. "An Engineering Approach for Using Power Plant Ash in a Structural Fill," In Proceedings of the Fifth International Ash Utilization Symposium, Atlanta, February 1979.

2. J. W. Jones, "Disposal of Power Plant Wastes." In Proceedings of Energy/ Environment III, the Third National Conference on the Interagency R&D Program, Washington, D. C., June, 1978. EPA-60019-78-022.

Section 4

IMPACT OF RCRA ON NEW DISPOSAL SITES

INTRODUCTION

As noted in Section 3 of this manual, the Resource Conservation and Recovery Act (RCRA) is likely to significantly affect ash disposal practices in the utility industry. Both existing and future sites will be impacted, although to what extent is presently undetermined. As presently proposed, for those ashes that are classified as hazardous wastes under Section 3001 of RCRA, the regulations to be promulgated under the special waste provisions of Subtitle C, Section 3004 of RCRA will apply. These proposed regulations specify siting restrictions as well as site security and record keeping practices. They would also require groundwater monitoring except in those cases where it can be proven that groundwater pollution will not occur. Those ashes which are classified as non-hazardous wastes will be subject to the requirements of Subtitle D, Section 4004 of RCRA. These regulations specify siting restrictions and encourage groundwater monitoring. Additional guidelines for non-hazardous waste disposal are proposed under Section 1008 of Subtitle A.

Sections 3004 and 1008 provide general requirements which are proposed by EPA for design and operation of the disposal sites. It is anticipated that specific management practices for ash will be specified in the future. In fact, a study is currently underway by the EPA to provide background data for such regulations. It is presently anticipated that the regulations will be promulgated in 1982 or 1983. Because of their potential impact on the utility industry, the development of these regulations will be watched by many, particularly those planning new disposal sites in the interim. In order to provide a framework for understanding how the special waste regulations are expected to be developed, it is useful to review the following three items:

- The EPA study of the environmental impact of present ash disposal practices,
- The stringent regulations already proposed for disposal of hazardous wastes under RCRA,

- The guidelines for non-hazardous waste regulations issued under RCRA.

Also of interest in contemplating design and construction requirements for future sites is a review of the current engineering practice used in the design and construction of disposal sites. Considerable detail on site design is contained in the EPRI FGD Sludge Disposal Manual, FP-977, and the EPRI Fly Ash Structural Fill Handbook, RP 1156.

EPA STUDIES

The EPA Industrial Environmental Research Laboratory in Research Triangle Park, North Carolina, has funded several research projects related to power plant solid wastes. Many projects have been in direct support of the EPA regulations. Others have been directed towards investigating alternate disposal methods or by-product utilization.

As part of the expanded program, the EPA is undertaking a two-part study of ash disposal practices in the utility industry. This study is planned as direct support of future modifications of the special waste regulations for disposal of utility wastes classified as hazardous under RCRA. The first part of the study involves a survey of ash disposal site characteristics and management practices. The survey was conducted in the spring of 1979 by Versar Incorporated. The purpose of the survey was to identify representative sites to be used for more detailed future studies. In the second part of the study, another contractor is to conduct field testing and groundwater monitoring at the selected sites. The purpose of the field studies is to assess the environmental impact of current disposal practices with emphasis on groundwater quality. The results of these studies will influence future revisions of the RCRA regulations concerning disposal of utility solid wastes. These revisions are expected to be issued in 1982 or 1983. To overview the EPA studies and comment on the rule-making process, a group of utilities has formed an ad hoc group called the Utility Solid Waste Advisory Group (USWAG) under the auspices of the Edison Electric Institute. Initially, USWAG is interacting with the EPA Industrial Environmental Research Lab by reviewing and commenting on the scope, program, and results of the EPA studies. The ultimate role of USWAG in the regulatory process is uncertain at this time and will be determined by the nature of future developments. Other organizations conducting studies in regard to proposed RCRA regulations and ash disposal include ASTM, the Department of Energy, and EPRI.

RCRA HAZARDOUS WASTE REGULATIONS

According to the proposed regulations, if classified as a hazardous waste, ash will be designated as a special waste and will, thus, be exempt from some of the hazardous waste regulations. In trying to anticipate the nature of possible future regulations, it is of interest to know the nature of the regulations from which an ash, classified as hazardous, is presently exempt.

Although other major differences also exist, the principle difference in design requirements between hazardous and hazardous special waste categories is in regard to landfill liners. For hazardous wastes the EPA has taken the position that landfills are required to be designed, constructed, and operated so that discharges are minimized or do not occur. Liners are, therefore, required. Depending on geologic and climatic conditions liners may be one of two designs.

Where site conditions are such that the evaporation rate exceeds precipitation by at least 20 inches (51 centimeters)* per year and subsurface conditions are such that at least 10 feet (3 meters)* of natural in-place soil with a coefficient of permeability of less than 0.1 feet per year (10^{-7} centimeters per second)* exists, then no leachate collection system or liner system is necessary. At locations which do not meet both of the geologic and climatic criteria, liners and leachate collection systems are required. Two alternate designs are included in the regulations and are shown in Figure 4-1.

Other requirements from which ash is temporarily exempted include some stringent standards with regard to financial responsibility, record keeping, and site enclosure.

For hazardous wastes, the RCRA regulations as currently proposed do not include many specific design and operating details. Rather, the EPA is preparing a number of detailed operating and design manuals. These manuals will provide detailed information on waste management technology in greater detail than given in the regulations and will cover acceptable practices for different types of landfills. The manuals will be organized to correspond closely with the regulations but will be guidance manuals with no regulatory authority.

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*The proposed regulations are published in metric units.

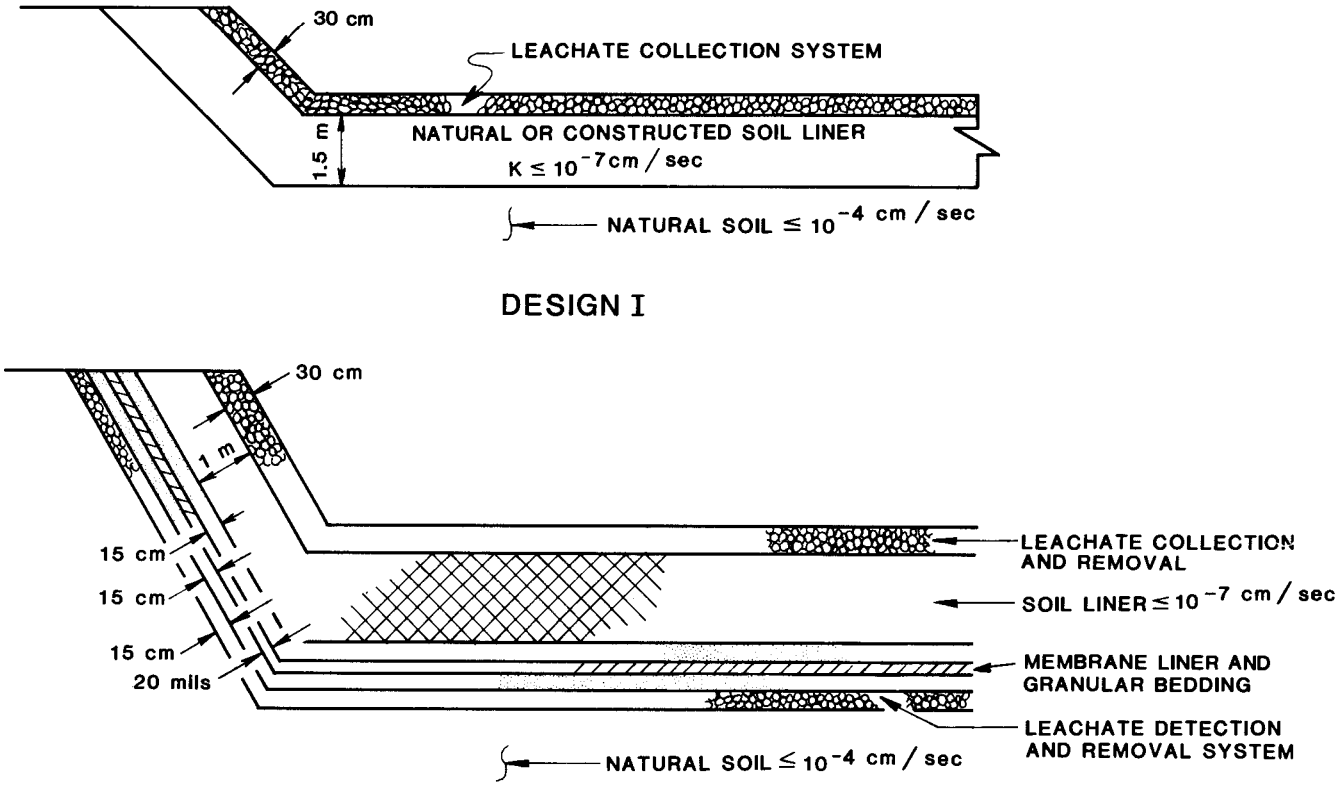

Figure 4-1. Liner Requirements for Hazardous Waste Disposal Sites

RCRA NON-HAZARDOUS WASTE GUIDELINES

While specific design and operating details have not been issued by the EPA for hazardous waste sites, guidelines for the design and operation of non-hazardous waste sites have been proposed. These guidelines were published in the Federal Register on March 26, 1979, under authority of Section 1008 of RCRA. The purpose of these proposed guidelines is to suggest preferred methods for the design and operation of solid waste landfills for non-hazardous wastes. Final promulgation of the guidelines is scheduled for January 1980. Regulatory standards for non-hazardous solid waste landfills will be promulgated by the states based on these guidelines.

These proposed guidelines are of interest because they give some idea of the EPA thinking regarding acceptable landfill design and operating practices. However, it cannot be assumed that the regulations governing the disposal of special wastes, when they are promulgated in the future, will be at least as stringent as these guidelines. Rather some special wastes may never be subjected to specific disposal site design criteria; they may instead be controlled only by siting criteria and monitoring programs. In any event, it is anticipated that in some cases those states which do not already have established programs for the control of non-hazardous solid waste disposal will accept these guidelines as a basis for their state solid waste regulations. In some cases, this will occur with very little modification in content. Thus, ash which is classified as a non-hazardous waste under RCRA will eventually be subject to the provisions of these guidelines. This is the best that can happen and will result in more stringent controls than result from existing state regulations in many cases.

The proposed 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 the requirements of the various sections 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. A study of 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, stormwater, 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.
- 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; any 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 all 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.
- Liner materials should have a coefficient of permeability of 0.1 ft/year (1×10^{-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 be covered and rest on 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 additional requirements for runoff control are also included:

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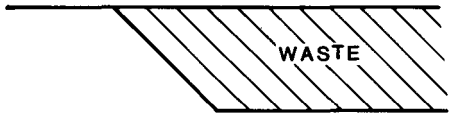
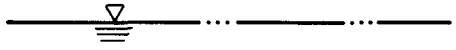
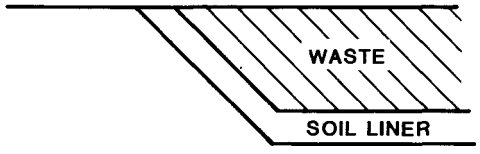
*The proposed guidelines are published in metric units.

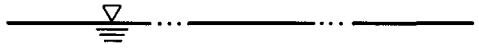




CASE I

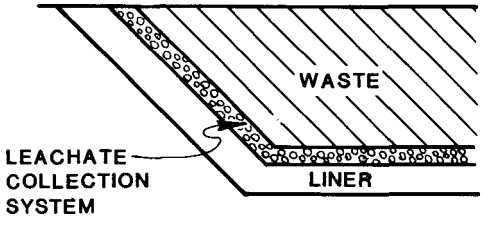
NATURAL HYDROGEOLOGIC CONDITIONS SUFFICIENT TO PREVENT CONTAMINATION, NO CONTROL REQUIRED

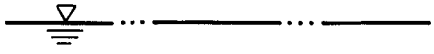




CASE II

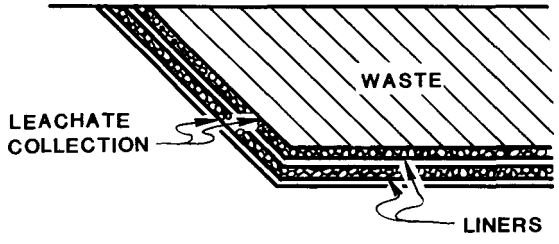
LINER REDUCES AND CONTROLS LEACHATE QUANTITY AND IMPROVES QUALITY BY SOIL ATTENUATION. ADDITIONAL LEACHATE IMPROVEMENT BY DILUTION OR ATTENUATION IN SITE SOILS

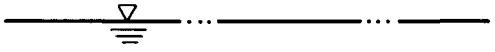




CASE III

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

- Locating the landfill in an area where drainage from adjacent lands onto the site is minimal.
- Constructing suitable runoff diversion ditches surrounding the site.
- Sloping the landfill surface to grades not in excess of 30 percent.
- Using well compacted, fine-grained soil for final cover.
- Routing 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 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.

SUMMARY

The exact impact that RCRA will have on ash disposal is presently uncertain.

Although the regulations which will control ash disposal in the future have not been promulgated to date, the following can be concluded:

- It is likely that some ashes will be classified as hazardous based on RCRA toxicity criteria. This classification will be due to their heavy metal trace element contents (1). 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 (2) and radioactivity (3). Regulations governing and defining these criteria under RCRA are presently in draft form. However, if promulgated as presently drafted, these criteria could greatly increase the quantity of the ash classified as a hazardous waste.

- Disposal of solid waste classified as hazardous will be directly regulated by the U. S. Environmental Protection Agency, or by the states under direct authority of the USEPA.

- Currently, if fly ash and bottom ash are classified as a hazardous waste then they will be treated as a special waste. Under the special waste criteria as proposed, only a limited set of disposal regulations apply. The EPA is currently conducting studies to determine which disposal regulations are appropriate for fly ash, bottom ash, and FGD sludge classified as a hazardous waste. These regulations are expected to be promulgated in 1982 or 1983.

- Disposal of 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 the EPA proposed guidelines, published in the Federal Register, March 26, 1979. These guidelines are more comprehensive and stringent than most current state regulations.

- Therefore, whether ash is classified as a hazardous waste and controlled by the USEPA, 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.

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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.

Section 5

CONCEPTUAL DESIGN OF ASH DISPOSAL SYSTEMS

INTRODUCTION

In developing cost estimates for ash disposal, it is first necessary to create a conceptual design of the ash disposal system as a whole, including ash handling, transport, and placement. In this section, major wet and dry disposal system components are discussed and a method of estimating ash quantities is presented. The overall intent of this section is to provide background information necessary for site selection as outlined in Section 1 and for cost estimating as discussed in Section 9. Basically, ash quantities are used to size system components which, in turn, are analyzed 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 SYSTEMS

Ash disposal schemes are generally categorized as either wet or dry. Sections 1 and 3 examine these schemes and their variations along with factors which influence their selection (ash characteristics, site characteristics, disposal regulations, etc.). Section 4 describes criteria and guidelines to be considered in the design of wet and dry systems. Section 6 illustrates actual disposal systems. Figure 5-1 shows possible variations in disposal systems.

Ash disposal entails the transport of ash from the power plant to disposal areas for placement. Wet systems commonly use sluicing through pipelines to move ash from the plant to the pond area. Dry systems commonly use trucks to transport ash, although rail, barge, or conveyor systems may be feasible. A detailed presentation of these and other methods of power plant solid waste transport can be found in the EPRI FGD Sludge Disposal Manual, FP-977.

As described in Section 1 of this manual, selection of an ash disposal system involves comparing conceptual systems and associated sites on the basis of cost and environmental impacts. In order to prepare cost estimates as described in

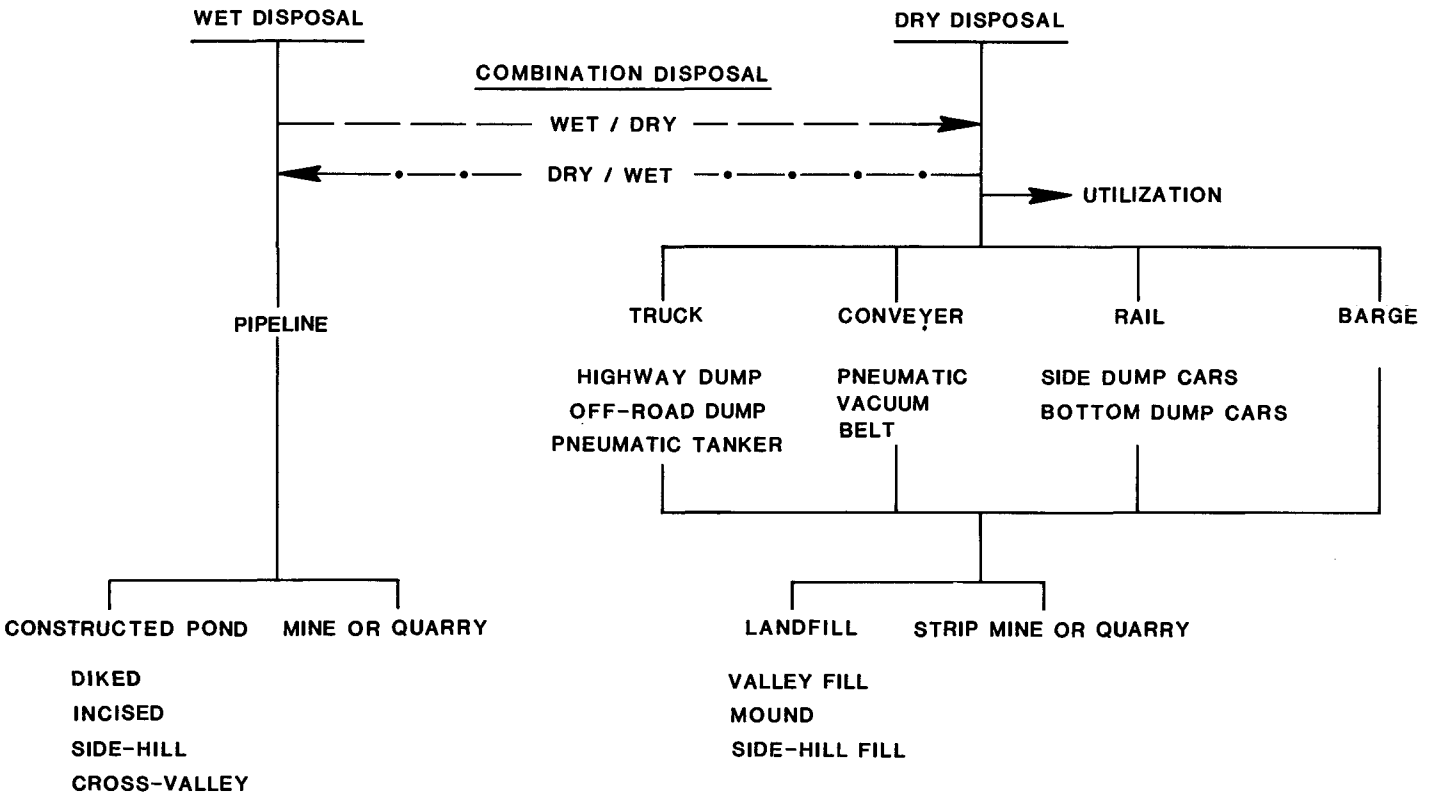


Figure 5-1. Variations in Ash Disposal Schemes

Section 9 of this manual, it is necessary to size the disposal system. Methods of determining the quantity of ash to be handled are presented in this section. It is also necessary to develop a conceptual disposal scheme.

In summary, the steps in developing a conceptual ash disposal scheme are as follows:

- Select basic method; wet or dry,
- Determine ash quantity,
- Select method of ash transport,
- Select potential disposal sites,
- Determine if other components will be required in the system; site liner, monitoring, security, manifest system, post-closure survey.

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 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 determining ash quantities can be summarized as follows:

Step 1: Calculate average annual coal consumption

$$\text{Tons coal/year} = [\text{unit rating, (kW)} \times \frac{\text{days}}{\text{year}} \times \text{hours/day} \times \text{capacity factor} \times \text{heat rate, } (\frac{\text{Btu}}{\text{kWh}})] \div (\frac{\text{lb}}{\text{ton}} \times \frac{\text{Btu}}{\text{lb}})$$

Step 2: Calculate annual ash quantity

Tons ash/year = tons coal burned/year x % ash in coal

Step 3: Calculate 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 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 generally 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 wet disposal volumes 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 wet disposal volume is the sum of the fly and bottom ash volumes.

Example Problem: Find the disposal volume required for a power plant with characteristics listed below. No ash will be utilized.

Given: Plant
2 units @ 500 MW ea
70% average capacity or 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

1. Estimate Average Annual Coal Consumption

Coal Consumption

$$\text{Tons coal/yr} = (1{,}000{,}000\ \text{kW} \times \frac{365\ \text{days}}{\text{yr}} \times \frac{24\ \text{hr}}{\text{day}} \times 0.70$$

$$\times\ 9{,}000\ \frac{\text{Btu}}{\text{kWh}}) \div (2000\ \frac{\text{lb}}{\text{ton}} \times 10{,}500\ \frac{\text{Btu}}{\text{lb}})$$

$$= 2{,}628{,}000\ \text{tons/year}$$

2. Estimate Ash Quantities

Fly Ash

Tons/year = (2,628,000 tons coal burned/year x 12% ash in coal

x 80% fly ash in ash x 99% collection efficiency)

= 250,000 tons/year or 7,500,000 tons in 30 years

Bottom Ash

Tons/year = (2,628,000 tons coal burned/year x 12% ash in coal

x 20% bottom ash in ash) = 63,000 tons/year

or 1,900,000 tons in 30 years

3. Estimate Required Disposal Volumes

Dry Disposal

Fly Ash - (in place dry density = 70 lb/ft^3)

$$\text{Disposal Volume} = (7{,}500{,}000\ \text{tons} \times 2{,}000\ \frac{\text{lb}}{\text{ton}}) \div (70\ \frac{\text{lb}}{\text{ft}^3}$$

$$\times\ 27\ \frac{\text{ft}^3}{\text{yd}^3}) = 8{,}000{,}000\ \text{yd}^3$$

Bottom Ash - (in place dry density = 90 lb/ft^3)

Disposal Volume = (1,900,000 tons x 2,000 $\frac{lb}{ton}$) ÷ (90 $\frac{lb}{ft^3}$

x 27 $\frac{ft^3}{yd^3}$) = 1,500,000 yd^3

Total Disposal Volume = 9,500,000 yd^3

Wet Disposal

Fly Ash - (in place dry density = 60 lb/ft^3)

Disposal Volume = (7,500,000 tons x 2,000 $\frac{lb}{ton}$) ÷ (60 $\frac{lb}{ft^3}$

x 27 $\frac{ft^3}{yd^3}$) = 9,300,000 yd^3

Bottom Ash - (in place dry density = 70 lb/ft^3)

Disposal Volume = (1,900,000 tons x 2,000 $\frac{lb}{ton}$) ÷ (70 $\frac{lb}{ft^3}$

x 27 $\frac{ft^3}{yd^3}$) = 2,000,000 yd^3

Total Volume = 11,300,000 yd^3

Section 6

CASE STUDIES

INTRODUCTION

During the course of collecting data for this manual, twenty coal-fired generating stations, which are believed to represent most of the variations in ash disposal methodologies in the U.S.A., were visited. The alternative methodologies are shown in Figure 6-1. Information gathered during these visits has been cataloged and assembled in this section. This section is not intended to provide design guidance but is merely a compendium of concepts that utilities have used in the past. While each generating station and ash disposal system is different, common comparative features were noted and are included to provide background information. These include:

- Plant size and location,
- Boiler type,
- Average coal consumption,
- Average ash content in coal,
- Ash disposal method.

Table 6-1 shows the information emphasized in the descriptions. Additional plant and operational details, where available, are included to better describe the generating station as a whole. Much of this data is summarized on Table 6-2.

Two wet sites and two dry sites, three of which are in the major coal burning regions of the country, and the other, which is in an area which may become a major coal burning area, were selected for an in-depth discussion of their ash disposal systems. These plants were selected because they represent the general practice for larger, more modern plants in their portions of the country as discussed in Chapter 3.

The remaining brief descriptions of generating stations point out variations in ash disposal systems. These variations in basic wet or dry disposal practices

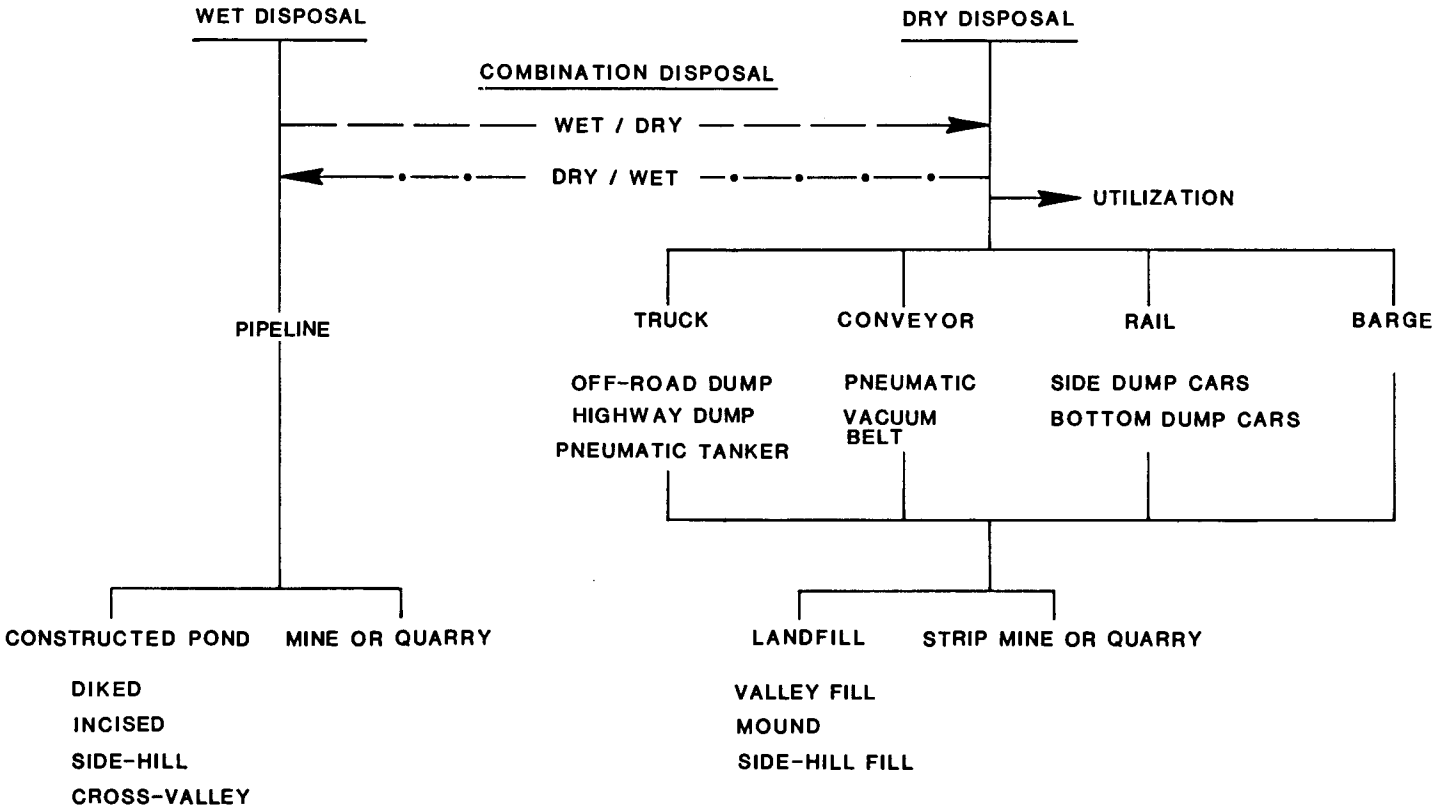


Figure 6-1. Ash Disposal Methodologies

Table 6-1

CASE STUDIES ON SPECIFIC ASPECTS OF FLY ASH DISPOSAL

Process	Power Plant
A. Wet Disposal	
1. Operation Alternatives	
a. Once thru ash slurry systems	Bull Run, Allen
b. Once thru ash slurry systems w/effluent treatment	
• Carbon Dioxide	Labadie, Rush Island
• Acid	Brunner Island
• Lime	Sunbury
c. Partial sluice water recycle system	Kingston, Jack McDonough
d. Total recirculation	
• Bottom ash slurry water only	Montrose, San Juan, Navajo
• 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
3. Strip Mine	San Juan, Montrose
4. Disturbed Area Restoration	Front Street
5. Fixation	Waukegan
C. Environmental Considerations	
1. Monitoring	
a. Ash pond discharge	Allen
b. Groundwater monitoring	King, San Juan
2. Revegetation	
a. Wet	Allen

Table 6-1
(Continued)

b.	Dry	
	• Eastern	Keystone, Powerton
	• Western	Navajo, San Juan
3.	Constructed Site Liner	Powerton, Front Street

are the result of specific problems encountered by utilities and are included to illustrate the broad range of current variations in the two primary disposal methods and to serve as a possible reference for utilities with similar problems.

The selection of the method of ash disposal and location of the disposal areas at a given plant has been a mixture of a given utilities experience with a disposal method and its economic trade offs, common practice in a region, topographic and property constraints and any unusual contractual requirements. For instance, many northeastern utilities truck their dry ash to compact it in a disposal area due to a lack of available disposal areas and high property acquisition costs.

Data on monitoring systems is presented only where it varies from that required under 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 geographic location of these plants is shown in Figure 6-2 which also delineates the primary areas of coal combustion within the United States. The Allen and Gibson Stations are located in the South Atlantic and North Central portions of the country, respectively, where wet ash disposal is predominant. Keystone Station, located in the Middle Atlantic region, and

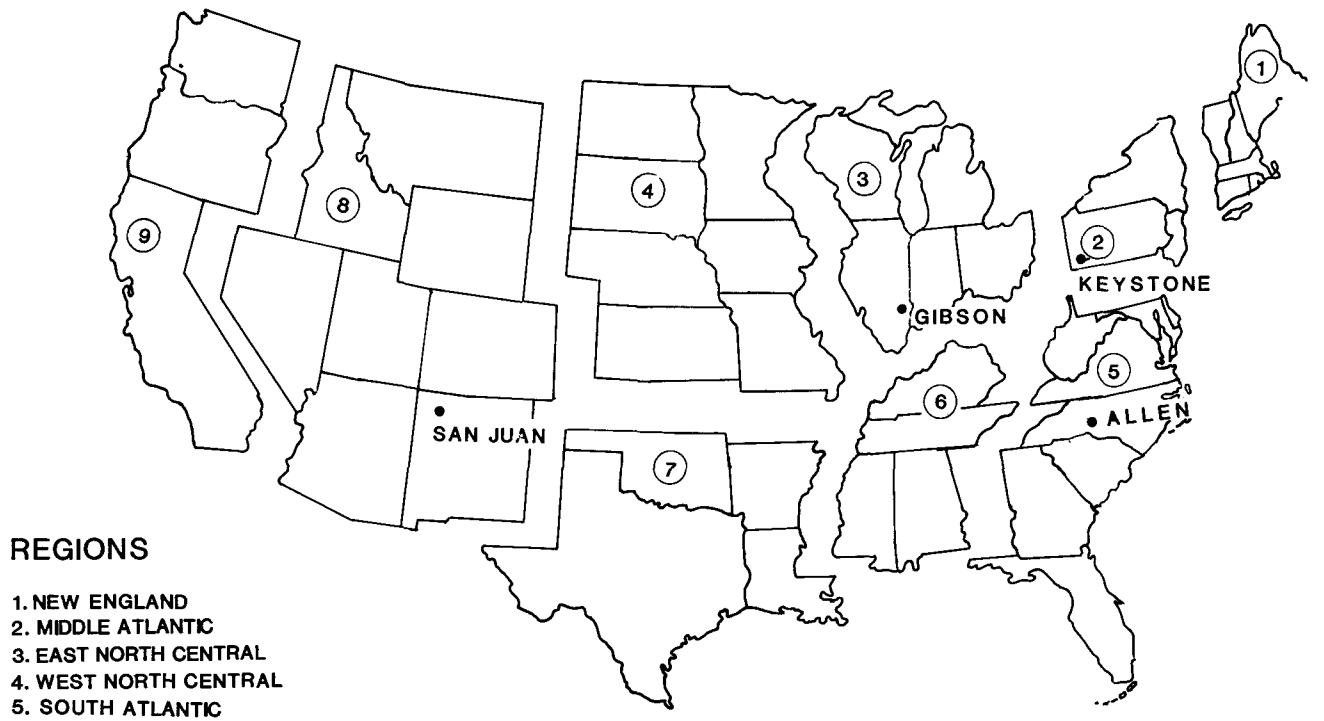


Figure 6-2. Location of Sites

TABLE 6 - 2

SUMMARY OF POWER PLANT DATA

PLANT NAME	OWNER / OPERATOR	LOCATION: TOWN /& OR COUNTY	LOCATION: STATE	TOPOGRAPHY	POP. DENSITY	GENERATING CAPACITY: NO. UNITS	GENERATING CAPACITY: UNIT SIZE (MW)	GENERATING CAPACITY: TOT. CAP. (MW)	BOILER DATA: TYPE	BOILER DATA: SUPPLIER	AIR CLEANING EQUIP.: TYPE	AIR CLEANING EQUIP.: SUPPLIER	AIR CLEANING EQUIP.: RATED EFF.	COAL INFORMATION: QUANTITY BURNED (TPD)	COAL INFORMATION: ORIGIN	COAL INFORMATION: ASH CONTENT %	COAL INFORMATION: SULFUR CONTENT %	COAL INFORMATION: HEAT VALUE (BTU/LB x 10^3)	REFUSE QUANTITIES: FLY ASH (TPD)	REFUSE QUANTITIES: BOTTOM ASH (TPD)	REFUSE QUANTITIES: PYRITIC REFUSE (TPD)	DISPOSAL SYSTEM: TYPE	DISPOSAL SYSTEM: TRANS. SYSTEM	DISPOSAL SYSTEM: DISPOSAL AREA: DIST FROM PLANT (MI.)	DISPOSAL AREA: SIZE (AC.)	DISPOSAL AREA: CAPACITY (TONS x 10)	CLIMATE[1]: AV. ANNUAL PRECIP. (INCHES)	CLIMATE[1]: AV. ANNUAL TEMP. (°F)	COMMENTS
ALLEN	DUKE PWR.	BELMONT, GASTON CO.	N.C.	ROLLING	MODERATE	2 3	165 275	1155	W.B.	C-E	EP	R-C J-W	99.5	5155	W.KY.	14	1.5	11.9	526	175	N/A·	W	P	0.25	130	5.6	46	61	
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	23000	IND. ILL. KY.	8-15	1-4	10-11	[2100]	[530]	N/A	W	P	0.25	225 60 210 20	N/A N/A N/A N/A	43	57	
KEYSTONE STATION	PENNA. ELECTRIC CO.	ELDERTON, ARMSTRONG CO.	PA.	ROLLING	LOW	2	840	1680	D.B.	C-E	EP	R-C	99	15000	PA.	22	2	11.6-11.7	2800	560	45-50	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	FARMINGTON SAN JUAN CO.	N.M.	FLAT	LOW	2	350	700	W.B.	F-W	EP	J-W	99	9000	N.M.	20	0.8	9.2-9.5	1500	300	N/A	D	T	2	N/A	15.4	10	50	PLANT RECOVERS ELEMENTAL SULFUR & SULFURIC ACID.
BULL RUN	TVA	CLINTON, ANDERSON CO.	TN.	ROLLING	LOW	1	950	950	W.B.	C-E	EP	A-S	99	7500-8000	KY.-TN.	16.8	1.0	11.1	1360	340	N/A	W	P	1	200	16.2	52	58	
LABADIE	UNION ELECTRIC CO.	LABADIE, FRANKLIN CO.	MO.	FLAT	LOW	4	600	2400	D.B.	C-E	EP	R-C	99.5	15137	S. ILL.	10.7	2.5	10.8	1216	405	N/A	W	P	0.25	150	10.0	36	56	B.A. UTILIZED BY STATE HIGHWAY DEPT.
RUSH ISLAND	UNION ELECTRIC CO	RUSH TOWER, JEFFERSON CO.	MO.	FLAT	LOW	2	600	1200	D.B.	C-E	EP	L-C	99.6	8800	VAR.	13.4	1.0	10.5	890	300	N/A	W	P	0.25	96.4	9.2	37	56	
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	12500 MAX	PA.	14.4	2.2	12.2	1100	370	60	W	P	0.25	35 95	1.5 3.5	41	53	
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	4100 ANTHRACITE COKE & BIT.	PA.	17.9	2.0A&C 2.2 B	9.9 12.1	550	180	N/A	W	P	1.25	45 50	1.2 2.4	41	51	B.A. IS RECOVERED & SOLD.
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	12000-16000	KY.-TN.	16.0	2.21	11.5	2000-2700	360	N/A	W	P	1	248	[6.5]	52	58	B.A. IS RECLAIMED & USED LOCALLY. PORTION OF F.A. IS SOLD FOR USE IN CONCRETE. CENOSPHERES ARE COLLECTED & SOLD
PLANT JACK McDONOUGH	GEORGIA POWER CO.	SMYRNA, COBB CO.	GA.	ROLLING	MODERATE	2	245	490	W.B.	N/A	EP	B-E	99*	3800	KY.-TN.	10	(1.6)	12.0	[304]	[76]	N/A	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	CLINTON, HENRY CO.	MO.	FLAT	LOW	3	170	510	D.B.	C-E	EP	R-C	99.5	5000(AV) 7000(MAX)	LOCAL	24-26	6	9.5	855	173	140	D	R	5	N/A	N/A	39	56	28% OF F.A. IS SOLD.
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*	9000	WY.	8-9	0.4-0.7	9.3	[612]	[153]	N/A	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.	MADISON, JEFFERSON CO.	IND.	FLAT	LOW	N/A	N/A	1284	N/A	N/A	EP	N/A	N/A	11000	IND.&KY.	12-15	(4.0)	N/A	814	665	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.	TERRELL	N.C.	ROLLING	LOW	4	N/A	2025	D.B.	C-E	MC & EP	AEROTECH B-E R-C	99*	10000	KY. & TENN.	13.5	(1.2)	11.8	552	186	N/A	W	P	1	268	6.7	47	60	MOST OF F.A. IS MARKETED
NAVAJO GENERATING STATION	SALT RIVER PROJECT	PAGE, COCONINO CO.	ARIZ.	FLAT	LOW	3	805	2415	W.B.	C-E	EP	J-W	99.5*	24000	BLACK MESA	10	0.51	11.0	1920-2400	480-960	N/A,	D	T	2	102	[22.8]	< 7	57	SUB-BITUMINOUS MOST OF THE F.A. IS CURRENTLY MARKETED.
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*	1000	PA.	15	< 1.5	N/A	120	30	1	D	T	7	41.8	0.316	38	49	
WAUKEGAN STATION	COMMONWEALTH 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	5000	WEST-ERN	10-12	0.38-0.58	9.3-9.8	500	100	N/A	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.	OAK PARK HEIGHTS, WASH. CO.	MINN.	N/A	N/A	1	581	581	C	B-W	EP	R-C	99	5000	MONT. & ILL.	9.5 AVG.	(1.2)	8.9	160	160	N/A	D	T	N/A	N/A	2.5	26	42	ALSO UTILIZES PETROLEUM COKE
POWERTON GENERATING STATION	COMMONWEALTH EDISON CO.	PEKIN, TAZEWELL CO.	ILL.	GENTLY SLOPING	LOW	2	900	1800	C	B-W	EP	R-C	99.5	12000	WEST-ERN	10	0.24-0.53	9.3-9.8	500	685	N/A	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.

[1] CLIMATES OF THE STATES, N.O.A.A. VOL. 1&2, 1974.

KEY

R	RAIL	S	STOKER
T	TRUCK	J-W	JOY WESTERN
P	PIPE	C-E	COMBUSTION ENGINEERING
D	DRY	AA-F	AMERICAN AIR FILTER
W	WET	A-S	AMERICAN STANDARD
MC	MECHANICAL COLLECTOR	R-C	RESEARCH COTTRELL
EP	ELECTROSTATIC PRECIPITATOR	B-E	BUELL-ENVIROTECH
D.B.	DRY BOTTOM	B-W	BABCOCK&WILCOX
W.B.	WET BOTTOM	L-C	LODGE-COTTRELL
C	CYCLONE	( )	DATA FROM VERSAR REPORT
		[ ]	DATA CALCULATED BY GAI

San Juan Station, located in the Mountain region, are both situated in areas where dry ash disposal is predominant.

BRIEF DESCRIPTIONS OF ASH DISPOSAL PRACTICES

In the course of visiting the remaining sixteen ash disposal sites about the United States, substantial variations of ash disposal practice were observed which were felt to be noteworthy. A description of particular processes, methods of operation, etc., which might be helpful to other power station owners and/or operators and which vary from those observed in the four sites described in detail are presented in the 16 short descriptions included at the end of this section. These stations are:

Bull Run Plant - Tennessee Valley Authority
Labadie Plant - Union Electric Company
Rush Island Plant - Union Electric Company
Brunner Island Station - Pennsylvania Power and Light Company
Sunbury Power Station - Pennsylvania Power and Light Company (W.O.)
Kingston Plant - Tennessee Valley Authority
Plant Jack McDonough - Georgia Power
Montrose Station - Kansas City Power and Light Company
Naughton Station - Utah Power and Light Company
Clifty Creek Plant - Indiana - Kentucky Electric Corporation
Marshall Station - Duke Power Company
Navajo Station - Salt River Project
Front Street Station - Pennsylvania Electric Company
Waukegan Station - Commonwealth Edison Company
Allen S. King Plant - Northern States Power Company
Powerton Station - Commonwealth Edison Company

ASH DISPOSAL AREA SITE DESCRIPTIONS

Allen Station

Allen Station, as shown in Figure 6-3, is a 1140 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. The power plant consumes 5,155 tons (4,675 metric tons) per day of bituminous coal at normal operating capacity. There are five units, of which two are 165 MW units and three are 275 MW units. Units 1 and 2 were brought on line in 1957

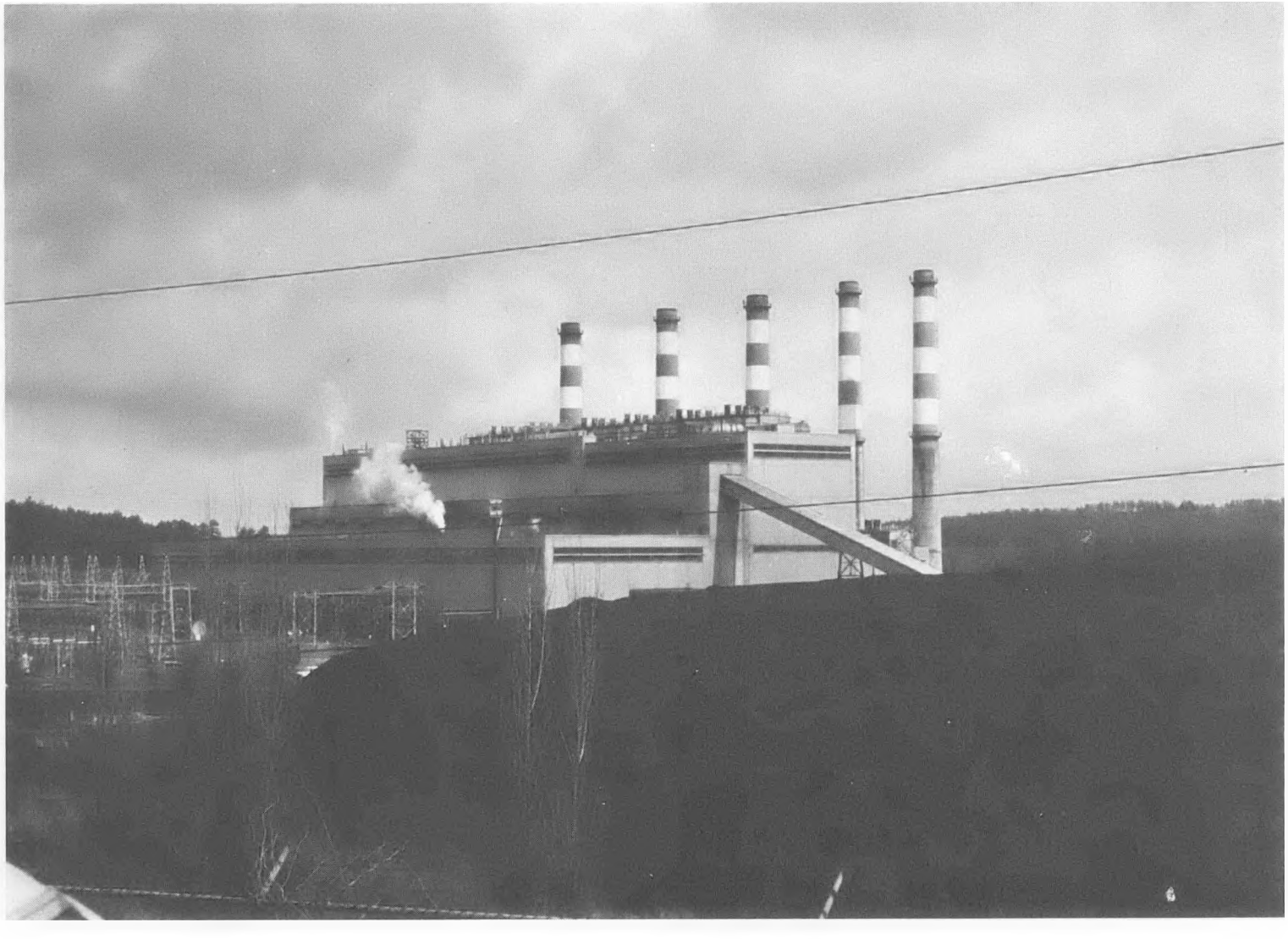


Figure 6-3. Allen Station

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, wet bottom type and operate GE turbines. The boilers are fueled primarily by Western Kentucky Coal with less than 1.5 percent sulfur, an average of 14 percent ash content, and an average heat value of 11,900 Btu/lb (27655 kj/kg). 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 water. It 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 from the electrostatic precipitators, 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 fly 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. In addition to the ash slurry, all other plant water, except cooling water, is also discharged to these ponds. 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, as shown in Figure 6-4, is comprised of active and abandoned sites. The original ponds, which include the two west coves, 20 to 30 acres

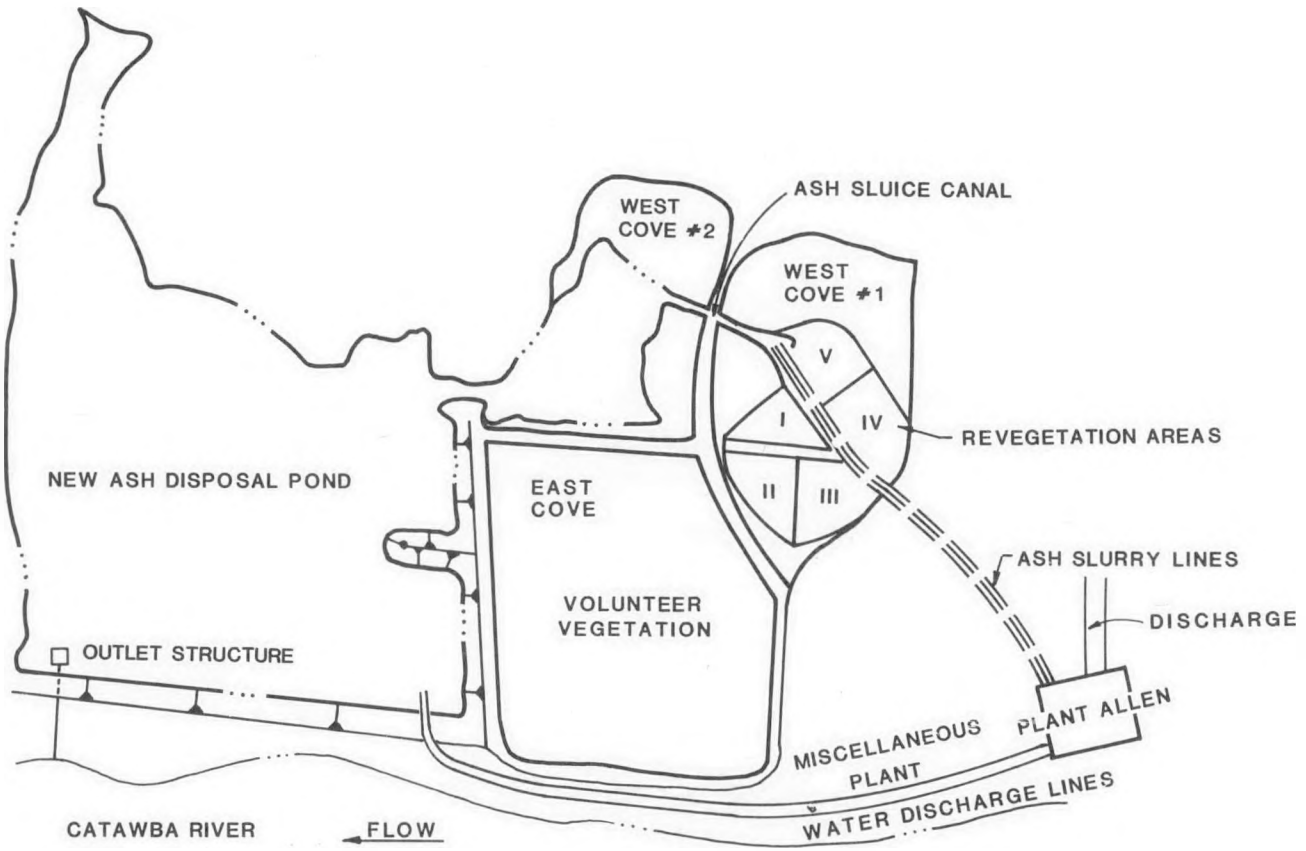


Figure 6-4. Allen Station Ash Disposal System

(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 are presently filled to capacity and are being used for revegetation research. Duke Power Company is studying the effects on revegetation created by varying the depth of soil cover on fly ash in the west cove. Table 6-3 shows the details of the revegetation study. Figure 6-4 indicates revegetation areas. Although varying appreciably in depth of soil cover, 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 terrestial 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 disposal. Silty clay was excavated from the pond area to provide the material for the pond embankment. The dike will be raised to 90 ft (27.4 m) in 1981 to increase disposal volume.

Figure 6-5. Revegetated Pond Areas at Allen Station

Figure 6-6. Volunteer Vegetation on Ash Pond at Allen Station

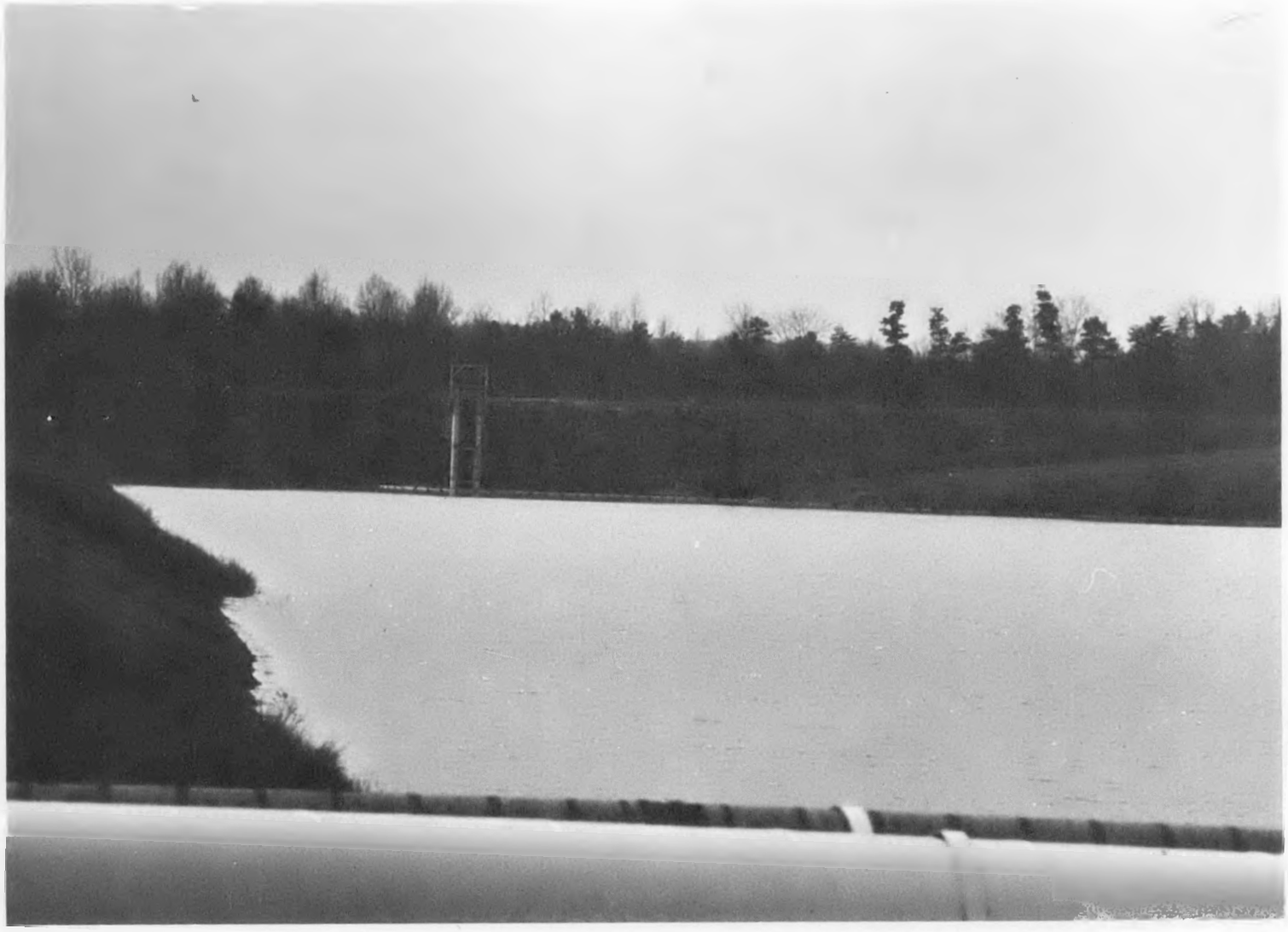


Figure 6-7. Current Ash Disposal Basin at Allen Station

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 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.

In addition, Duke is presently studying at the same site ash basin leachates and monitoring ground waters 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 ponds) 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; three are on line and one will be started up in the winter of 1979. 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 five. Plant cooling water is obtained from a closed recirculation system which uses a 3,000-acre (12.14 ha)

Figure 6-8. Gibson Station

Figure 6-9. Gibson Station Ash Pond

Figure 6-10. Removal of Ash Deposits Near Slurry Discharge, Gibson Station

by 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 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). 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 near-by ash deposits or the pond embankment (see Figure 6-10).

A similar problem has been avoided in the Units 3 and 4 ash pond since the slurry pipe extends approximately 1,000 ft (305 m) into the 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

Figure 6-11. Keystone Station

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 carious 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 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 gasses are then exhausted through two 800 ft (244 m) stacks.

Bottom ash is sluiced to hydro-bins for dewatering and sale. There is also a bottom ash pond for emergency backup. Approximately 25 percent of the bottom ash is sold and the remaining 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

Figure 6-12. Keystone Ash Disposal Area

Figure 6-13. Ash Embankment, Keystone Station

Figure 6-14. Ash Placement, Keystone Station

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.

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 presently has two 350 MW units, which were brought on line in 1973 and 1976. These units are Foster-Wheeler wet-bottom boilers. Two additional 550 MW units are under construction and are scheduled to go on line in 1979 and 1982. These units are Babcock and Wilcox wet-bottom boilers. Sub-butuminous 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

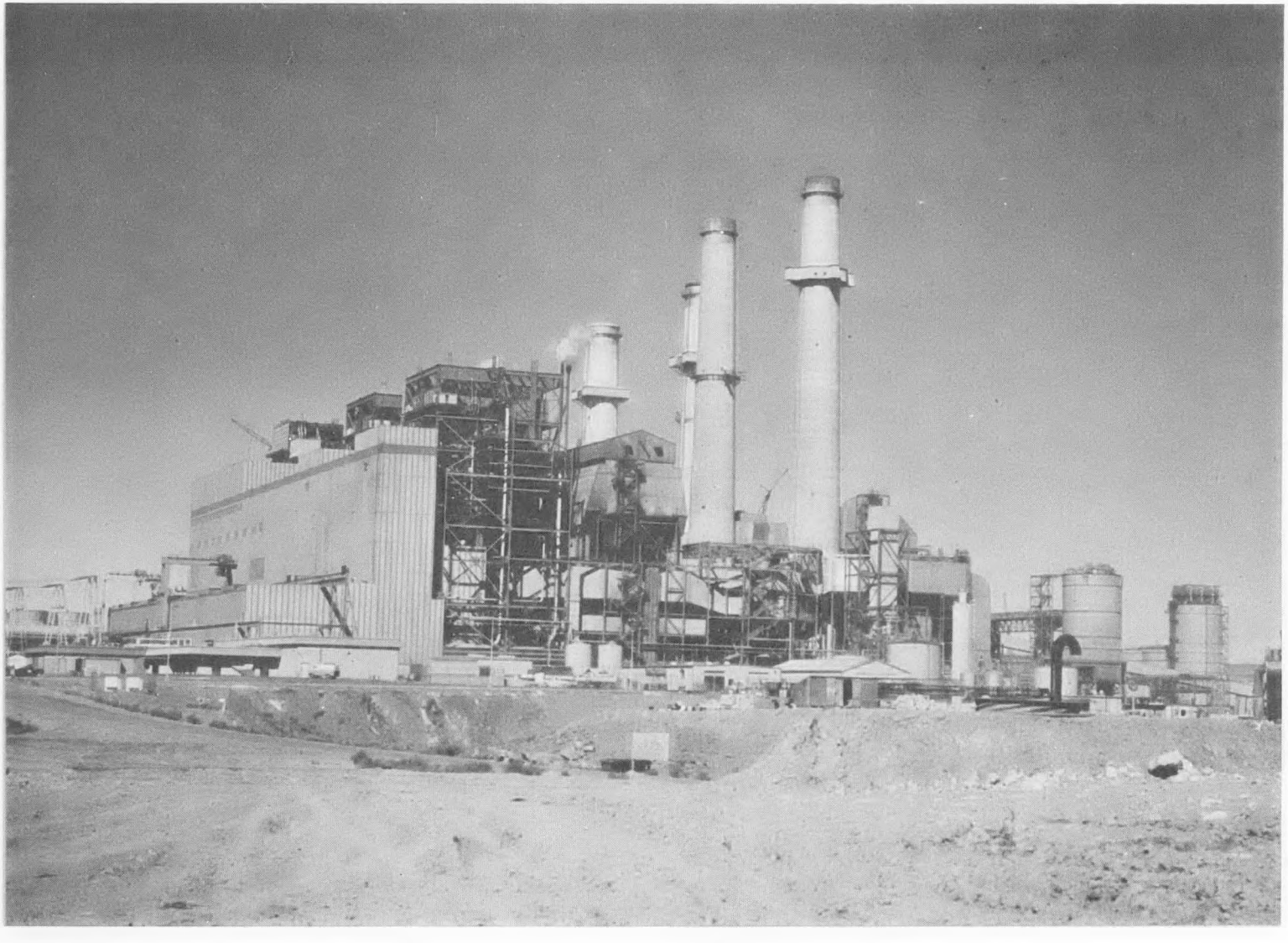


Figure 6-15. San Juan Power Plant

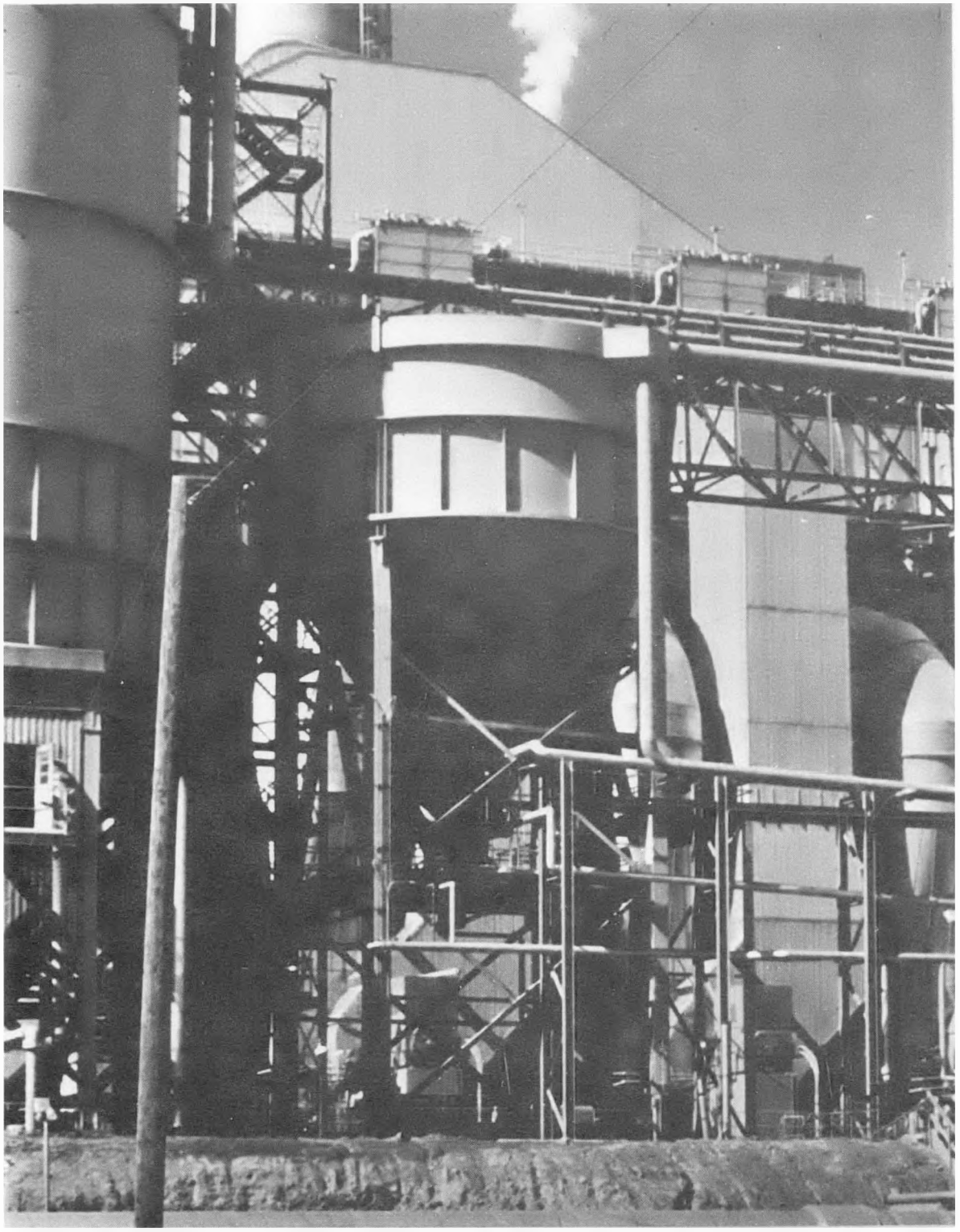


Figure 6-16. Bottom Ash Dewatering Bins, San Juan Power Plant

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 hotside 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.

Bottom ash is quenched and sluiced together with the pyritic refuse to dewatering bins, as 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.

Prior to loading, fly ash is passed through dustless unloaders where it is moistened with water (5-6 percent moisture content). Approximately 1500 tons (1363 metric tons) and 300 tons (272 metric tons) of fly ash and bottom ash, respectively, are produced per day. 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 (.9- to 1.8 m) lifts until alternate areas are filled to within 5 ft 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.

Figure 6-17. Ash Truck, San Juan Power Plant

Figure 6-18. Ash in Strip Mine Pit, San Juan

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 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 (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 ricegrasses, fourwing saltbush, shadscale, alkali sacaton, sand dropsed, 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.

Figure 6-19. Secondary Ash Disposal Area, San Juan Power Plant

Figure 6-20. Reclaimed Area, San Juan

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.

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.

Figure 6-21. Water Harvesting, San Juan

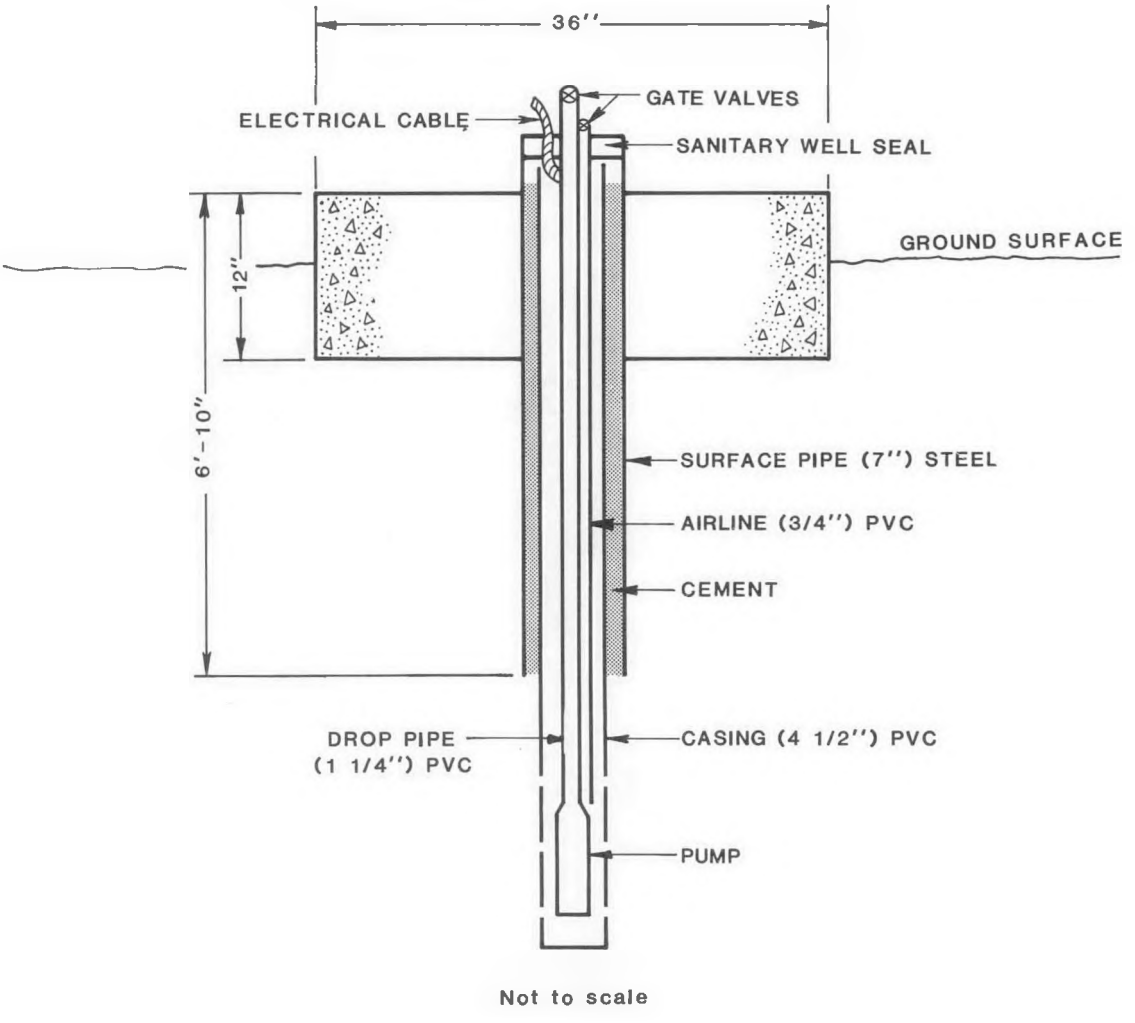


Figure 6-22. Monitoring Well Cross Section

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 burnt 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 6-23). 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 6-23. Ash Levee and Skimmer, Bull Run

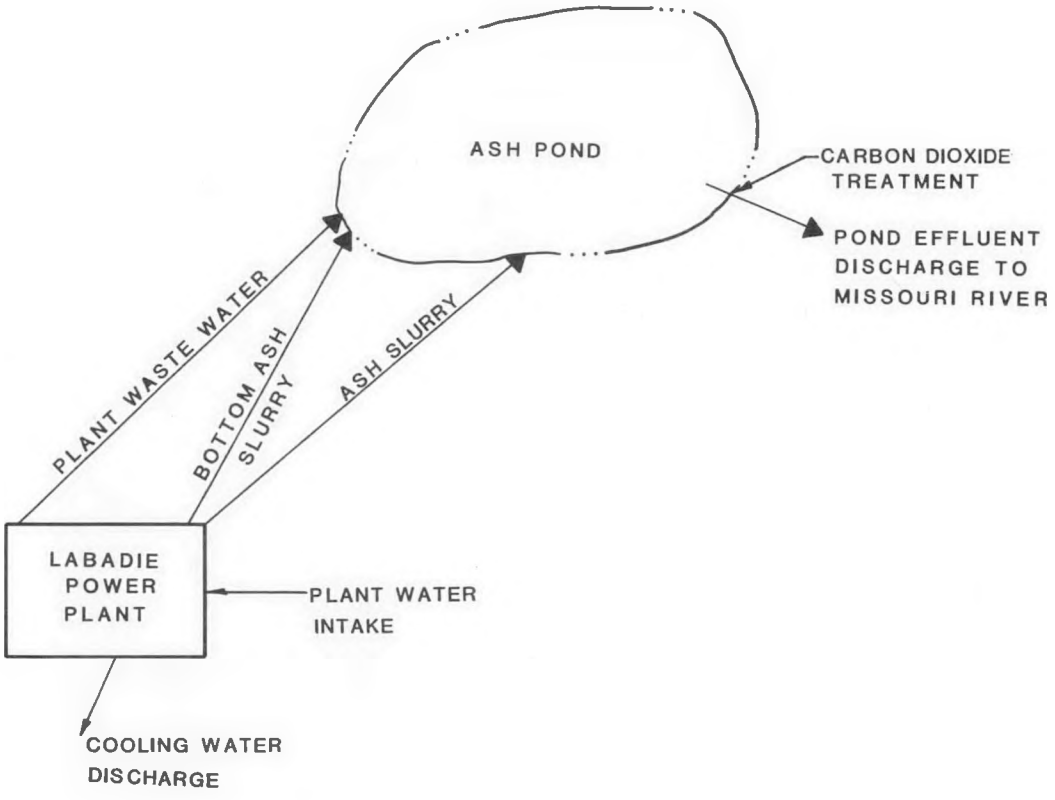


Figure 6-24. Ash Disposal Schematic, Labadie

Figure 6-25. Bottom Ash Excavation, Labadie

Figure 6-24 indicates the general power plant ash pond arrangement. All water wastes, i.e., ash slurries, blowdown water, pyritic refuse slurry, acid wash 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 6-25). 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-Cotrell electrostatic precipitators and a 700 ft (213 m) high dual dive stack. Both bottom ash and fly ash are sluiced to the pond though separate lines. However, 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 6-26. 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

Figure 6-26. Rush Island Ash Disposal Basin

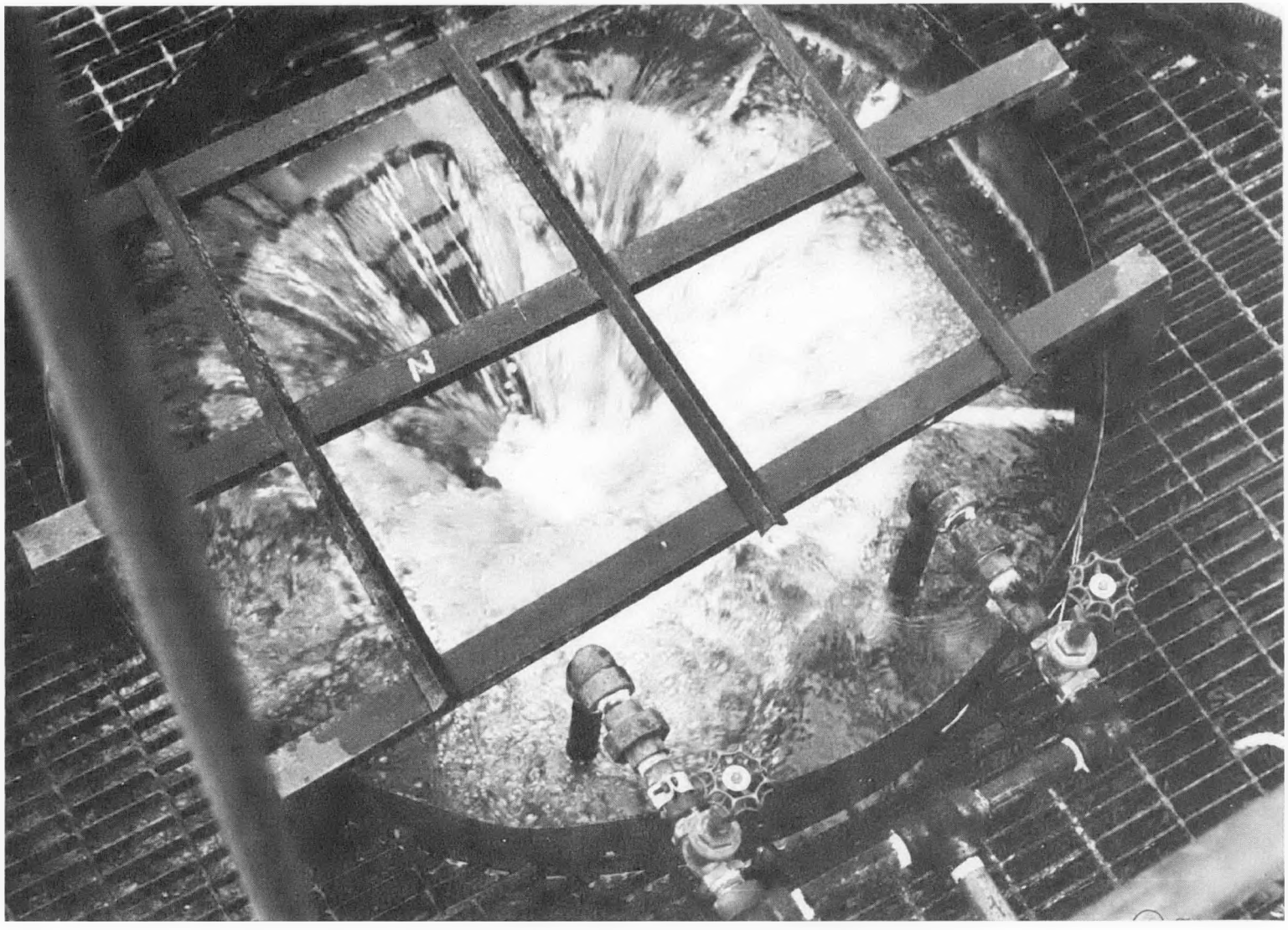


Figure 6-27. Treatment of Ash Pond Effluent With Carbon Dioxide, Rush Island

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 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 6-27). 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 6-29, 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

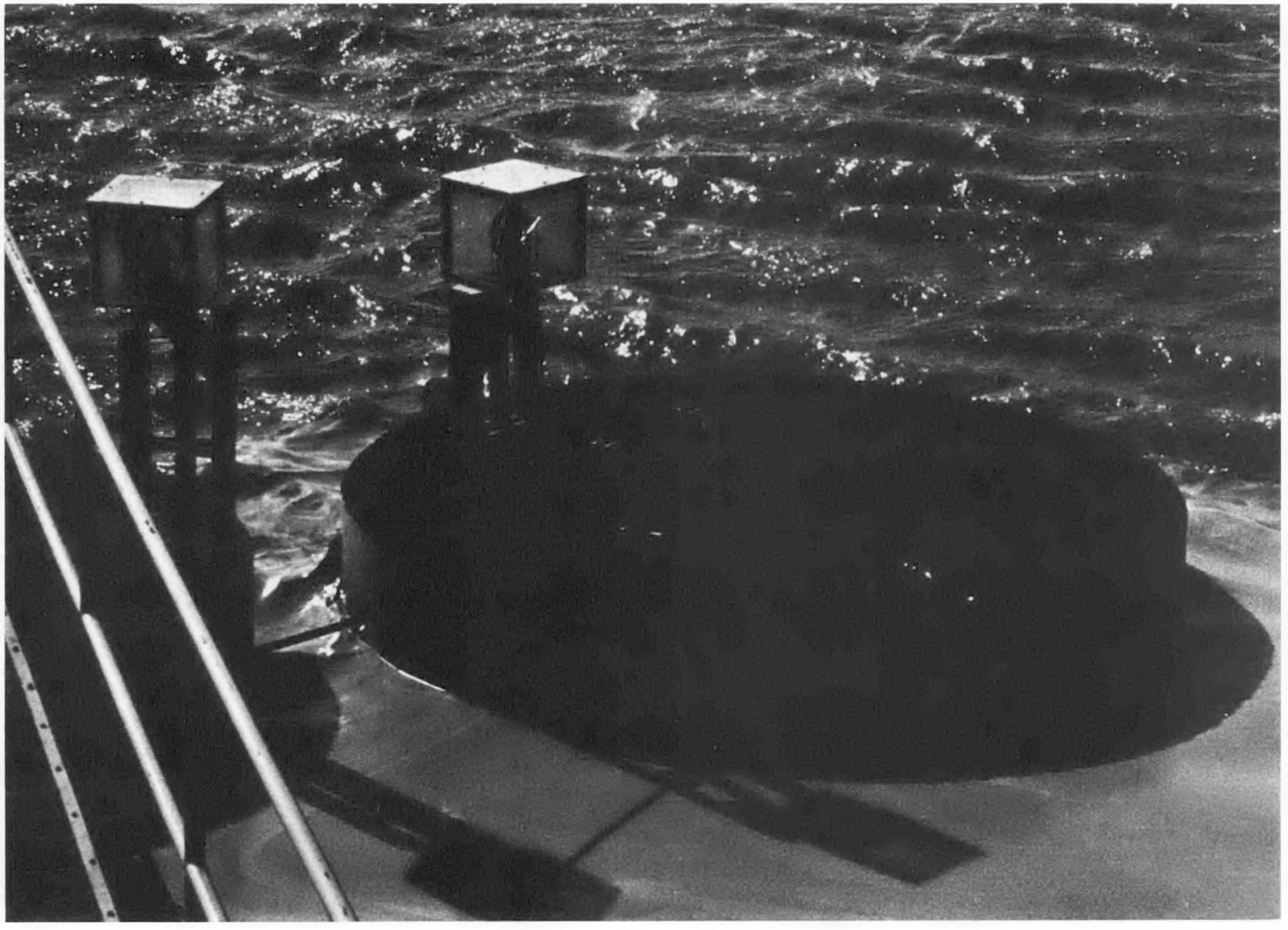


Figure 6-28. Treatment of Ash Pond Effluent with Acid, Brunner Island

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 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 due to its use of 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 air 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 6-29. 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

Figure 6-29. Bottom Ash Pond, Sunbury

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 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. The Kingston Steam Plant has an unusual method of partial ash pond water recirculation and the placement or replacement of ash in the ash ponds by draglines.

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 6-30 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

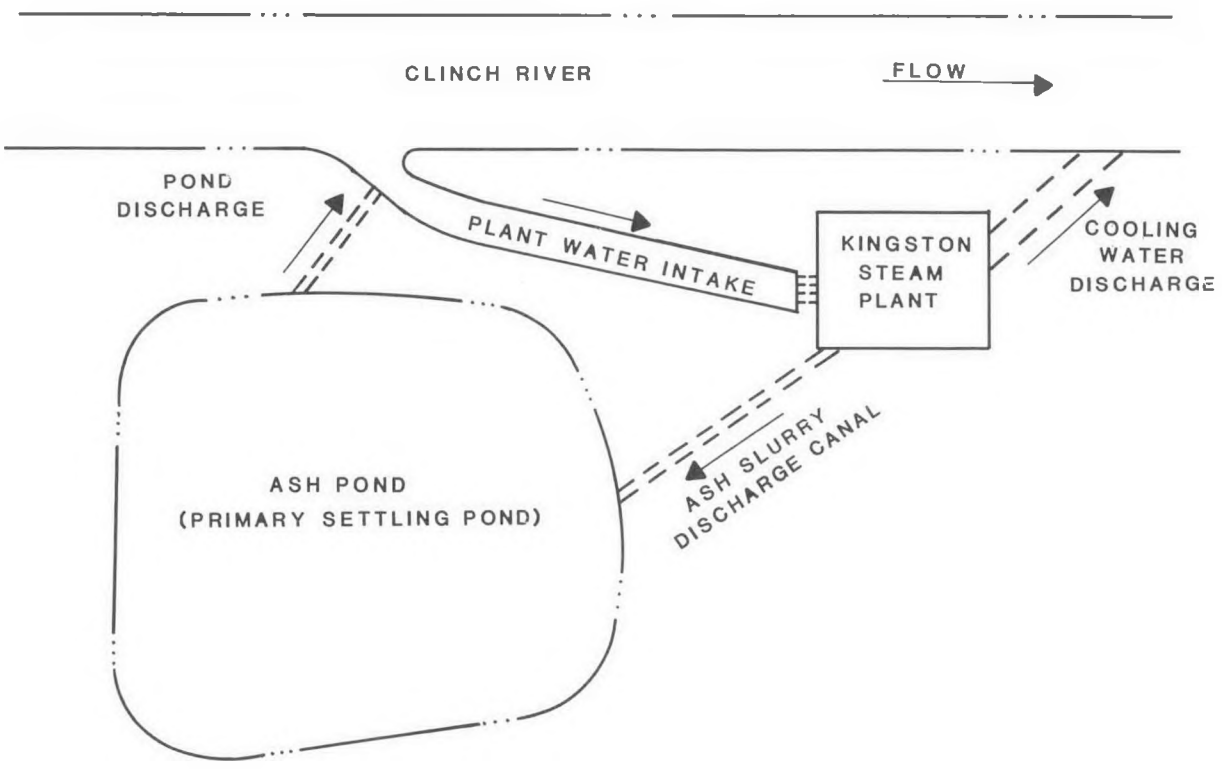


Figure 6-30. Schematic of Kingston Steam Plant Water Distribution

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 6-31). 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.

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 6-32, 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

Figure 6-31. Bottom Ash Excavation, Kingston

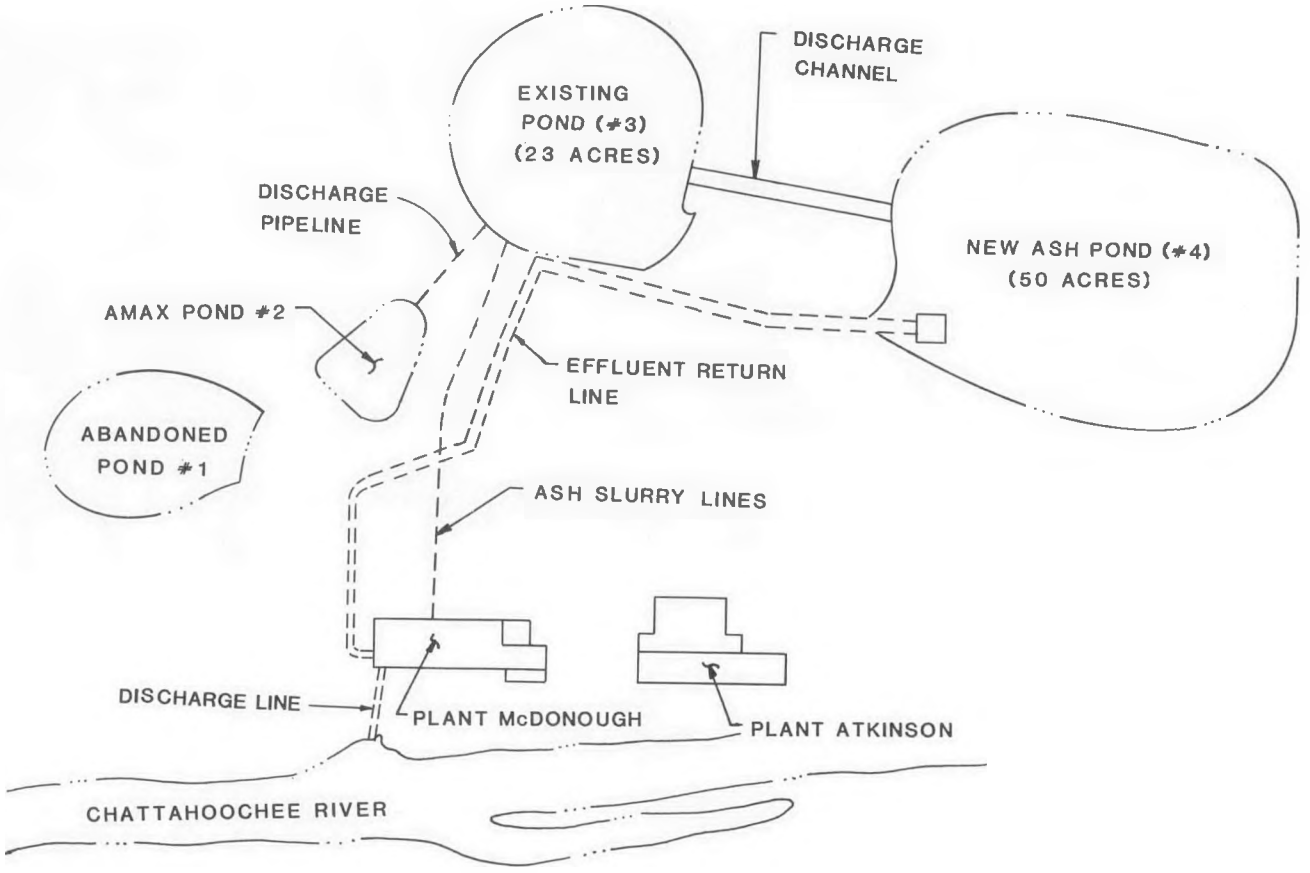


Figure 6-32. Ash Disposal System, Jack McDonough

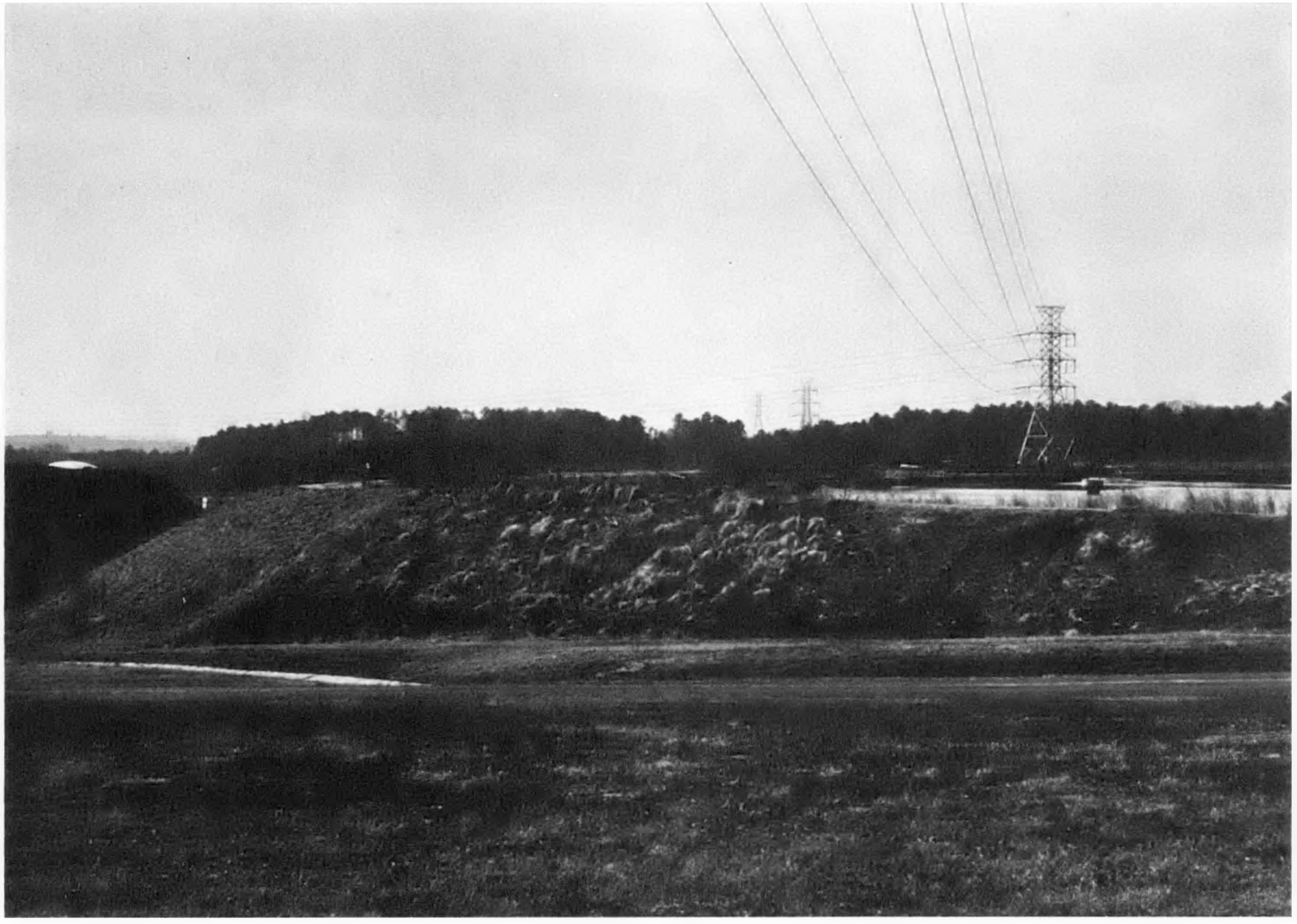


Figure 6-33. Ash Pond Embankment, Jack McDonough

of the ash pond effluent is recycled.

The pond embankment is shown in Figure 6-33. 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 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 the 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 buildups 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 6-34. 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 6-35, 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 due to ash sticking in the

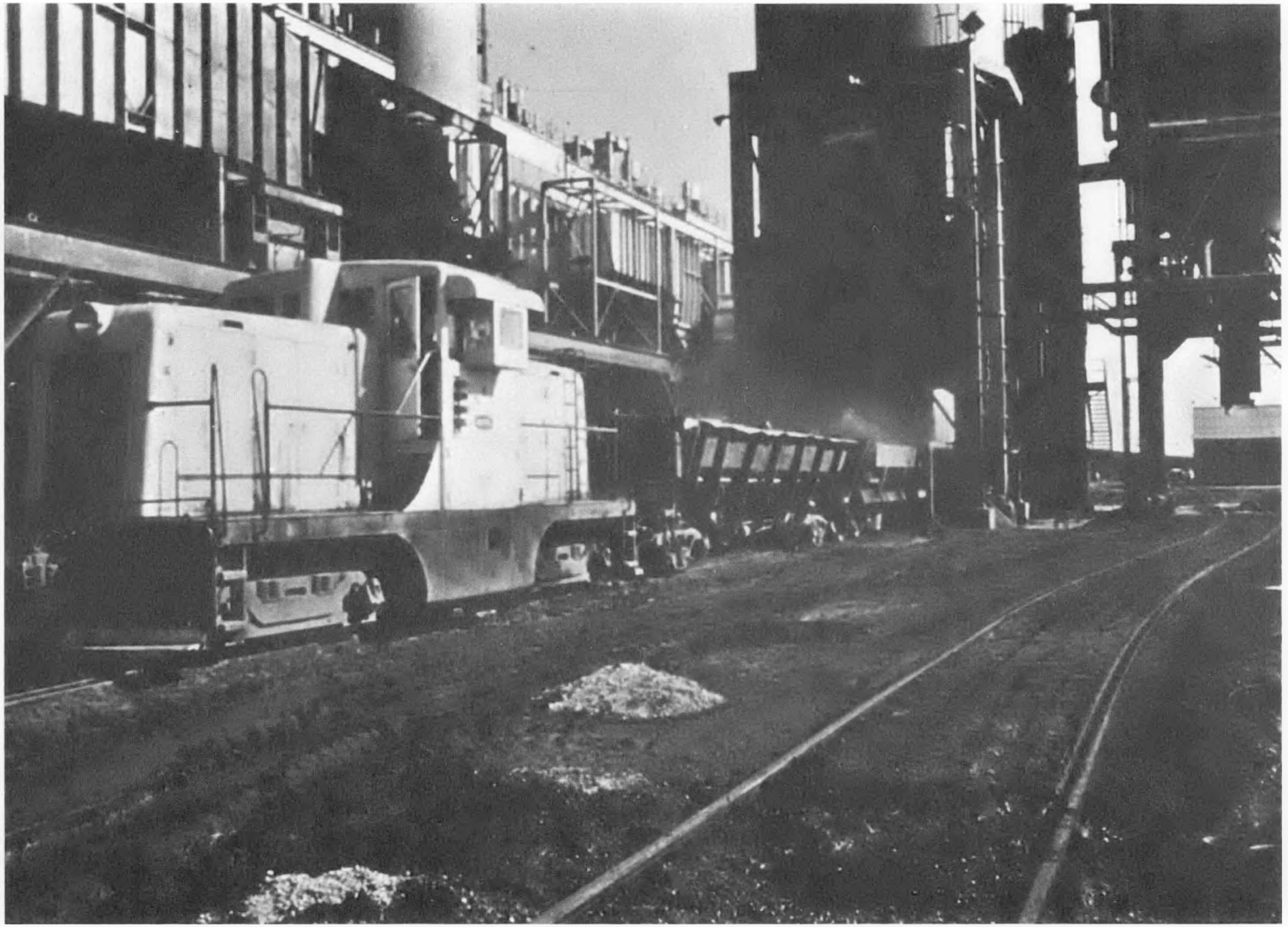


Figure 6-34. Ash Loading, Montrose

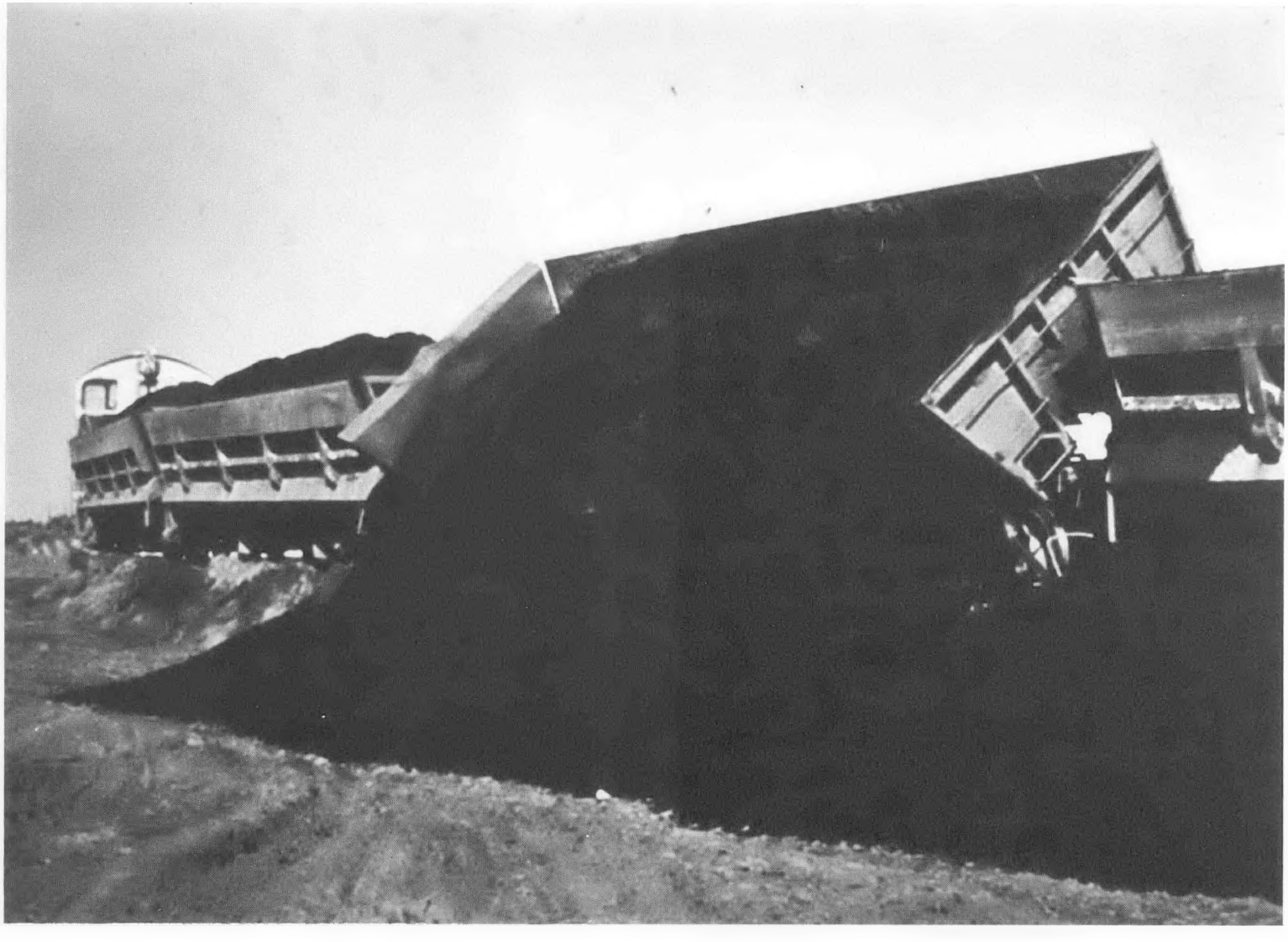
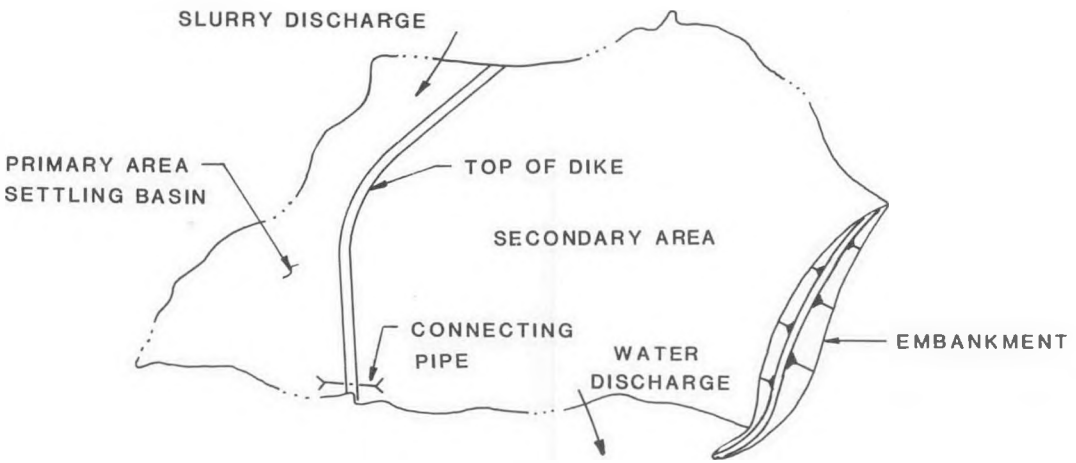
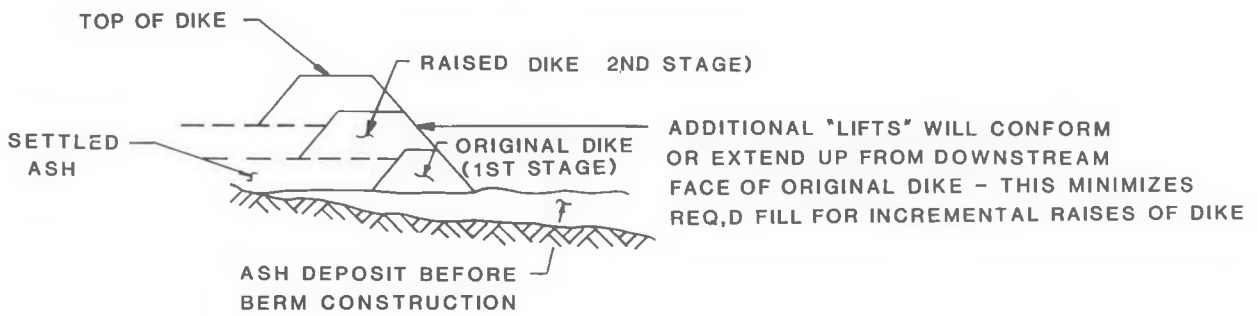


Figure 6-35. Ash Dumping, Montrose



ASH POND 1



TYPICAL BERM SECTION

Figure 6-36. Schematic of Ash Disposal Pond, Naughton

Figure 6-37. Dividing Berm, Naughton

car. If the material 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 has 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 operated ponds in order to provide an acceptable effluent and in order to observe a method of constructing the 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 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 6-36. The 320 MW Unit Three 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 two foot difference in water level between the areas (see Figure 6-37). The difference in water level is controlled by the primary area discharge structure. Ash entering the primary area is settled, and the supernantant 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 are slated for completion 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 is presently being converted to a fly ash disposal pond. 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.

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 6-38. 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

Figure 6-38. Floating Slurry Lines, Clifty Creek

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. Besides 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 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 6-40). 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

Figure 6-39. Ash Dredge, Marshall

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 burnt 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.

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

Figure 6-40. Sand Cover on Exterior of Ash Fill, Navajo

pyritic refuse. The compacted fly ash has a permeability of 17 feet/year (1.6 x 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 6-40).

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. 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 6-41).

Figure 6-41. Ash Placement, Front Street

Figure 6-42. Front Street Ash Disposal Area

The ash disposal area, as shown in Figure 6-42, 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 in 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 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

Figure 6-43. Ash Disposal Area, Waukegan

in the disposal of ash from western coal.

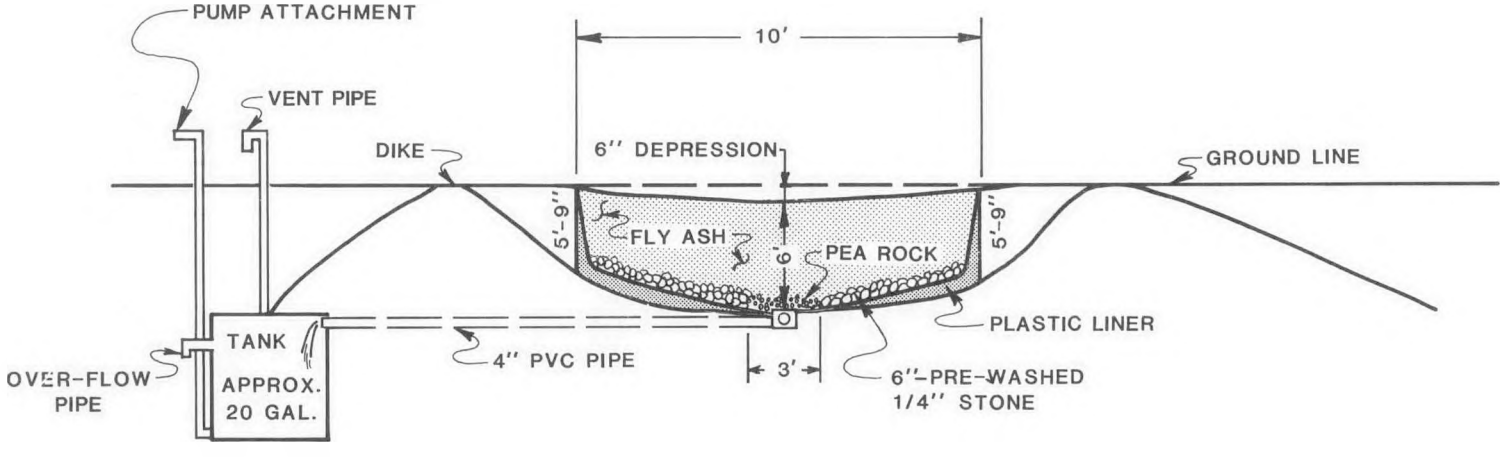
Bottom ash is slurried at the boilers at a rate of 100 tons (91 metric tons) per day and dewatered in dewatering bins. The bottom ash is then sold or trucked to the ash disposal area for use as access road base material.

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 6-43, 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.

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 ash placement area. Fly ash is pneumatically transferred from the precipitator hopper to a storage



Six inches of Pea Rock, 3'-0'' wide over 4'' drain pipe fill rest of area with 1/4'' washed stone.

Figure 6-44. Fly Ash Test Cells, King

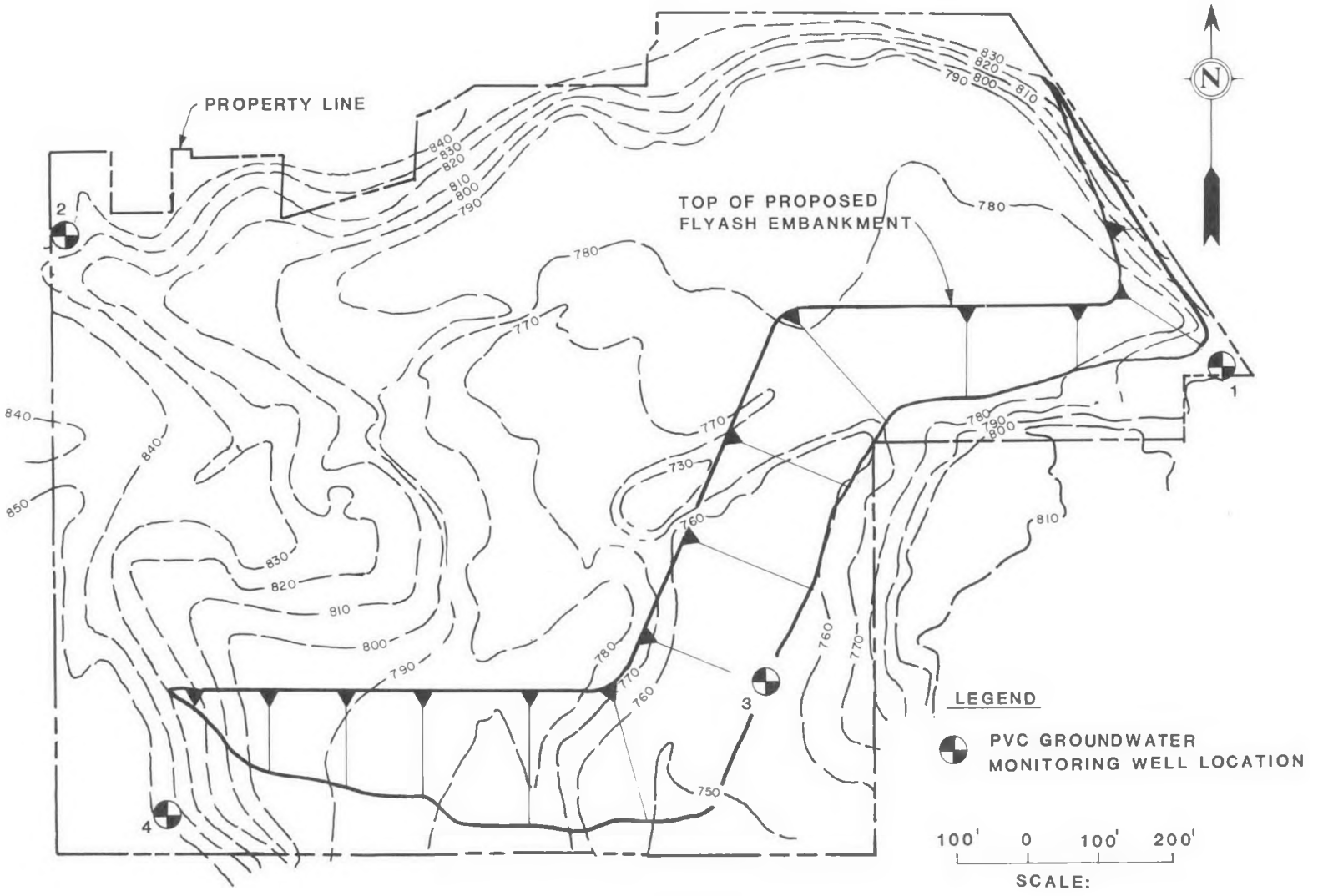


Figure 6-45. Ash Storage Area, King

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 cells have been constructed to analyze in-place leachate generation and its impact on the groundwater system.

Figure 6-44 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. As of March 1979, no leachate has been collected. 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 6-45, 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 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 up to this year has 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 6-46). 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.

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 6-47, some portions of the

Figure 6-46. Site Liner, Powerton

Figure 6-47. Reclaimed Area, Powerton

completed fill have been seeded with winter wheat in order 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.

Section 7

MONITORING

INTRODUCTION

The environmental monitoring of an ash disposal area is increasingly being required by federal, state, and local regulations. These requirements are based on the ash disposal area's potential for adversely affecting the water quality in the vicinity of the disposal area. The purpose of monitoring is to determine if there are any pollutants emanating from the disposal area and to determine what their effect is on the water quality of the area. Since pollutant transport may be by either surface water or groundwater, monitoring will include sampling each, both upstream of the site as well as downstream to allow comparison to background data.

There are two opposing views concerning the advisability of installing monitoring systems. One school of thought holds that monitoring is an unnecessary expense that cannot be justified unless required by regulatory agencies. The other opinion holds that monitoring systems can provide useful background data, particularly considering the trend toward more stringent requirements on the part of regulatory agencies. Monitoring data demonstrating that no pollution problem exists can be used to counter requests for expensive features such as liners. Alternately, should a problem develop, detecting it early will minimize the cost of any remedial measures required.

In general, the method and frequency of sampling is a function of the process being monitored. If the process is cyclic and hazardous in nature, sampling should be accurate and frequent; if the process is routine and innocuous, then sampling can be of minimal accuracy and infrequent in nature. In many cases, the selection of a monitoring system will be made by the regulatory agency. Site specific and ash specific data may or may not be used in this selection process.

The monitoring of an ash disposal site may consist of air, surface water and groundwater monitoring. However, the monitoring of air pollution is usually not

required by regulatory agencies, and is not discussed in this manual. Surface water and groundwater monitoring is not currently required by most regulatory agencies. For those that do require monitoring, the sampling frequency and number of monitoring points will vary. The typical minimum number of water monitoring points are as follows:

- Surface water - ash pond discharge or subsurface drain outlet, sedimentation pond outlet, and upstream surface flow, if present.
- Groundwater - up gradient, down gradient.

If these monitoring points are determined and placed in operation at a reasonable interval prior to the start of construction, valuable background data will be obtained that can be used in the design and operation of the disposal area or in evaluation of the monitoring data (including possible future litigation).

Environmental monitoring has been studied and reviewed in the literature. Many of these references have become the standard in the field due either to their excellent coverage of the material or to their widespread use by regulatory agencies, and are therefore worthy of further mention. Table 7-1 is a brief listing of some publications that are concerned with the field of pollution monitoring. In addition, Table 7-2 is a brief listing of some regulatory and professional organizations dealing with pollution monitoring. Although neither Table 7-1 nor 7-2 is a complete listing, they do include some of the fundamental texts or references and general organizations concerned with monitoring. In addition, there are many environmental information services, journals, and organizations that also deal with the area of environmental monitoring. In some instances these sources can be of great assistance as far as specific data or information.

REGULATORY REQUIREMENTS

Monitoring requirements may be either federal, state, or local in nature. State and local monitoring requirements are variable, are changing rapidly, and will not be reviewed due to the present state of uncertainty. Instead, 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 requirements 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) Permits. In addition, there are other federal regulations that could also affect the monitoring requirements of an ash disposal area. Table 3-1 in

Table 7-1

REFERENCES FOR POLLUTION MONITORING

Sampling

National Handbook of Recommended Methods for Water-Data Acquisition
U. S. Department of the Interior, Geological Survey

Manual on Analysis for Water Pollution Control
World Health Organization, Geneva, Switzerland

Procedures for Groundwater Monitoring at Solid Waste Disposal Facilities
EPA/530/SW-611, August 1977

Environmental Chemistry

Guidelines Establishing Test Procedures for the Analysis of Pollutants, 40 CFR Part 136

Chemistry for Environmental Engineering, Clair N. Sawyer and Perry L. McCarty, 3rd edition, 1978

Methods for Chemical Analysis of Water and Wastes, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, EPA-60014-79-020

Handbook for Analytical Quality Control, in Water and Wastewater Laboratories, Analytical Quality Control Laboratory, Cincinnati, Ohio, 1972

Standard Methods for the Examination of Water and Wastewater, APHA, WPCF and AWWA, 1975

ASTM Standards: Part 31, Water, 1979 and Part 42, Analytical Methods, 1978

Aquatic Chemistry, Werner Stumm and James J. Morgan, 1970

Environmental Engineering

Wastewater Engineering, Metcalf and Eddy, Inc., 1972

Water and Wastewater Engineering, Gordon M. Fair, John C. Geyer and Daniel A. Okun, 1968

Physicochemical Processes for Water Quality Control, Walter W. Weber, 1972

Section 3 of this manual lists these other federal regulations which may be applicable.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) of 1976 (Public Law 94-580, October 21, 1976) provides for the specific controls over solid waste disposal. Proposed guidelines and regulations were published by the Environmental Protection Agency on December 18, 1978, to govern the determination and disposal of hazardous wastes. Section 3 of this manual reviews the requirements of this act.

Table 7-2

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)

As currently proposed, if analysis shows the ash to be classified as a hazardous waste, then the monitoring of the disposal area will be regulated by RCRA, unless it can be proven that there is no potential for leachate to reach the groundwater table. In most cases, it can be assumed that monitoring will be required. For ash which is not classified as a hazardous waste, state regulatory agencies will still require monitoring in many cases. State regulations for non-hazardous ash will be developed in accordance with the proposed Subtitle A, Section 1008 guidelines which encourage monitoring. While the exact nature of these monitoring requirements is uncertain, it can be assumed that the regulatory agencies will follow the EPA lead and require a monitoring program similar to the RCRA requirements in some cases. Proposed monitoring requirements are shown on Table 7-3.

Proposed RCRA hazardous waste monitoring regulations for utility wastes require at least four monitoring wells, at least one upgradient and three downgradient with one of the downgradient wells located adjacent to the site, and all the wells located within the site property lines. In addition, these monitoring wells are to be located at depths where groundwater pollution is likely to occur.

Table 7-3

PROPOSED GROUNDWATER MONITORING REQUIREMENTS

Background Testing (12 months):

- Frequency - Monthly
- Number of Samples - Minimum of Four
- Analysis - Comprehensive

Testing During Operation (continuing):

Frequency - Annual	Additional[2]
Number of Samples - Minimum of Four	Minimum of Four
Analysis - Comprehensive[1]	

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)

Minimum Analysis:

- Specific conductivity
- pH
- Chloride
- Total dissolved solids
- Dissolved organic carbon
- Principal hazardous constituents found in the ash

[1]May be reduced to exclude those pollutants not contained in or derived from ash.

[2]Varies depending on groundwater flow rate.

Sampling of the monitoring wells shall begin three months prior to the commencement of disposal, with sampling on a monthly basis continuing for a period of one year. These analyses will provide the background levels required to determine the degree of effect of the solid waste disposal site on the groundwater. After this first year of monitoring, the sampling period is dependent on the groundwater flow rate. The periodicity of sampling after the first year is as follows:

- Groundwater flow rate less than 82 ft/year (25 meters/year) - annual sampling, comprehensive analysis.
- Groundwater flow rate 82 to 164 ft/year (25 to 50 meters/year) - semi-annual sampling, one comprehensive analysis, one minimum analysis.
- Groundwater flow rate greater than 164 ft/year (50 meters/year) - quarterly sampling, one comprehensive analysis, three minimum analyses.

The samples obtained from the groundwater monitoring system during the first year of operation must be given a comprehensive analysis shown on Table 7-3.

Upon reviewing current (January 1, 1979) chemical analyses costs for an independent chemical laboratory, the cost of this analysis would approach $500 per sample. Assuming a minimum 12-month sampling period, monthly sampling, and four monitoring wells per site, an analysis cost of approximately $25,000 would be incurred. After the background conditions are established during the first year, those characteristics not common to 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 additional samples are only subject to a minimum analysis, shown on Table 7-3.

This minimum analysis would incur a minimum cost of $30 per sample plus the analysis cost of the principal hazardous constituents found in the solid waste. 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 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.

Also included in the proposed RCRA regulations for both hazardous and non-hazardous wastes, is the requirement that site runoff be collected. The collected runoff is then a point source subject to the requirements of the Clean Water Act.

Clean Water Act

If the ash disposal area involves a point surface water discharge, a National Pollutant Discharge Elimination System (NPDES) permit will be required. This permit program was established by the Federal Water Pollution Control Act Amendments of 1972, and continued under the Clean Water Act of 1977. The majority of the state water quality agencies currently administer the NPDES permit program. Permitting under the NPDES system currently requires 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 emanate from the site. Currently, maintaining a pH between 6 and 9 and suspended solids below 30 mg/l for ponds and 50 mg/l suspended solids from dry sites are the criteria which the discharge must satisfy. However, depending on the size and quality of the receiving stream, the discharge requirements can be made more stringent to negate 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 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. To assure compliance with permit terms and conditions, all permittees are required to monitor discharges according to the frequency and analyses required in the permit document. The monitoring is usually reported on a monthly basis and analyses are conducted for those pollutants for which effluent guidelines are set in the permit.

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, when conducted at the federal

level, 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. After these samples are gathered, 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 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(s) point. 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 at the pond inlet and outlet.

In addition, sampling points in the receiving stream are 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.

A great deal of care is not required in selecting monitoring point locations for large streams and rivers due to the assimilation and buffering capacity of the water. However, as the stream becomes smaller, the ability of the water to assimilate the discharge is decreased. An additional sampling complication is that smaller streams undergo daily variations in both their inorganic and organic composition due to physical and biological (benthic) 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 in 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 and other points of discharge within the river, as well as seasonal variations in flow. If one is not careful in the selection of monitoring points and times, one could confuse the effects of a natural process for pollution from some source. Thus, monitoring points and times must be selected much more carefully as the size of the stream decreases.

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 ash disposal areas since the effluent or discharge from these processes is quite consistent. This method consists of manually

collecting the sample in a suitable container, preserving 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 (see Table 7-1). These cleanings should be followed by at least three complete rinsings with distilled water and in the case of trace metals should be followed by a distilled-deionized water rinse. 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 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, 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 single or composite. Single samples are those samples that are obtained and then analyzed. A composite sample is one where small samples are obtained at specified time intervals 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 sampling may also be of two types: grab 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. Monitoring the groundwater below the ash disposal area is important to determine if and when the groundwater is being affected.

The location of the groundwater monitoring points is not as obvious as that of surface water monitoring points since groundwater does not travel in well defined paths that are immediately obvious. In addition, the rate of groundwater movement under natural conditions is quite slow when compared to surface waters. It, therefore, does not require as frequent sampling. Even though the sampling period need not be frequent, it must be done often enough to detect changes in the groundwater quality. 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 experienced geohydrologist. To accurately determine the proper location of a groundwater monitoring well requires a knowledge of the 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 extremely 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 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 primary direction and flow rate of the primary and secondary aquifers. This is accomplished by reviewing the boring logs, the direction and slope of the rock dip, and the rock types and permeabilities.

Location. 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 levels (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 capillary water, only partially fills or saturates the material above the groundwater level, and thus produces a capillary fringe. If sufficient data exist, groundwater level contours can also be estimated. This groundwater level data then indicates the direction of groundwater flow, i.e., from higher to lower elevations, but does not indicate the specific aquifers in which it is transported.

Groundwater flow is primarily in either porous or semi-porous soil layers or rock strata, or at the interfaces between rock strata. 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. The aquifer permeability may 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 will be influenced by the soil grain size distribution, but will be affected by other factors. Soil density, porosity, and homogeneity will influence overall permeability of the soil layers. Horizontal and vertical permeability may vary by an order of magnitude or more due to non-homogeneity.

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 that rock strata and the 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. Indeed, 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. If at all 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, other groundwater systems may include three or more aquifers although these systems would be relatively uncommon. With this information, the monitoring wells may be accurately located.

Figure 7-1 shows an example of groundwater contours superimposed upon an ash disposal area. The small arrows indicate the general groundwater flow directions

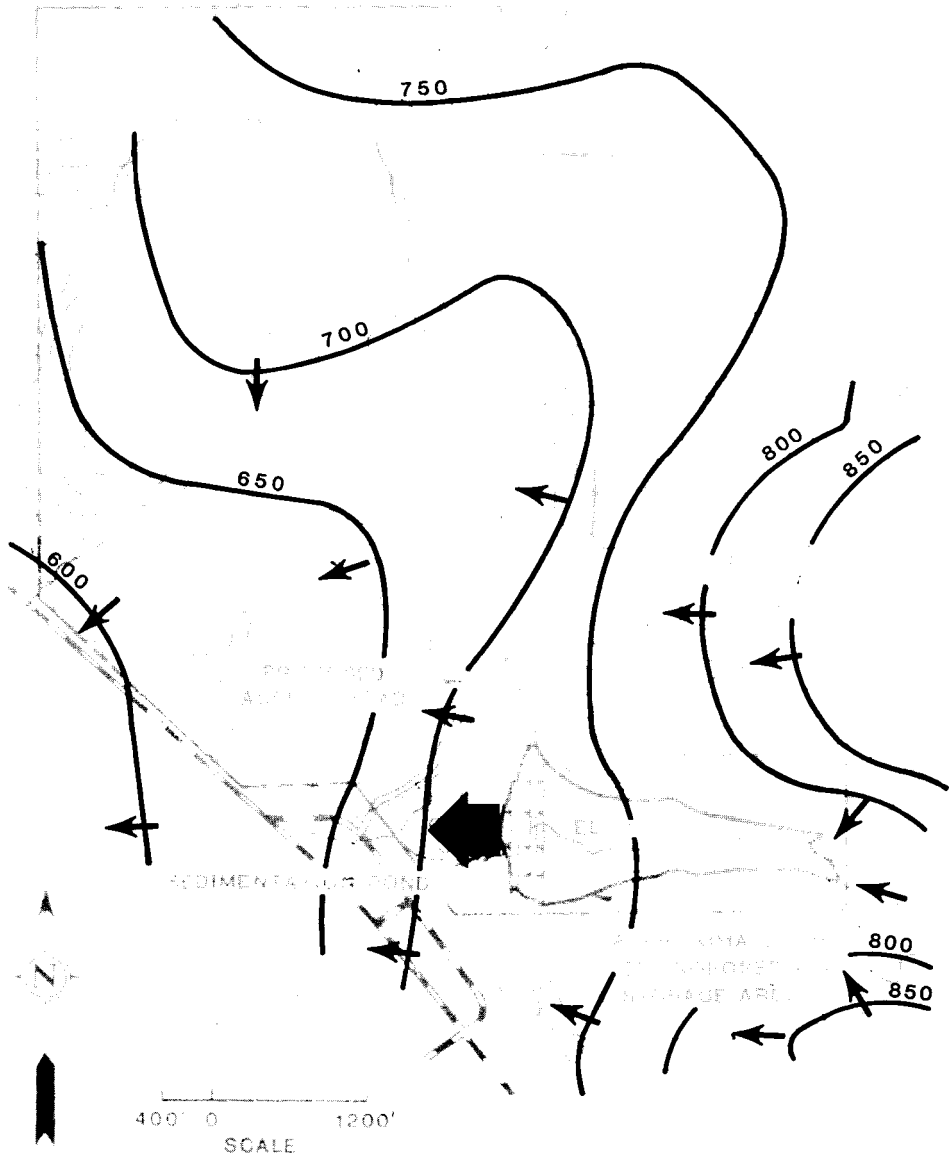


Figure 7-1. Groundwater Contours

whereas the large arrow indicates the estimated direction of travel for the ash disposal site leachate. Figure 7-2 then describes the groundwater monitoring points necessary to monitor 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 collection of both upgradient and downgradient samples is necessary; 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.

In some cases, 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 that includes the other wells projected onto that 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. Since the primary wells produce a combined sample, there will be little indication of the exact source of any contaminants encountered.

Although adequate for a dry disposal site or a lined wet disposal site, this groundwater system analysis is not sufficient for an unlined wet disposal area. This is due to the alteration in the groundwater surface contours by the water percolating from the wet disposal area. This situation is analyzed by assuming the effect of the wet disposal area on the groundwater system. Figure 7-4 indicates this effect which is to create a mound in the groundwater table. The dark lines are the revised groundwater level contours and the dotted lines are the existing groundwater level contours. As can be seen, the wet disposal area drastically affects the groundwater system. The small arrows again indicate directions of groundwater flow which tends to flow away from the mound. There is now no single primary direction of travel for the ash disposal leachate. As indicated by the three large arrows, the leachate would spread out in a general westerly direction.

Figure 7-5 indicates the monitoring wells required to monitor the groundwater system. The upgradient wells, U-1 and U-2, are designed to sample the background water. Although these wells could be combined, the magnitude of the entering groundwater would dictate two wells. In addition, due to the siting of the ash disposal pond, these wells may receive leachate from the pond due to the superimposed

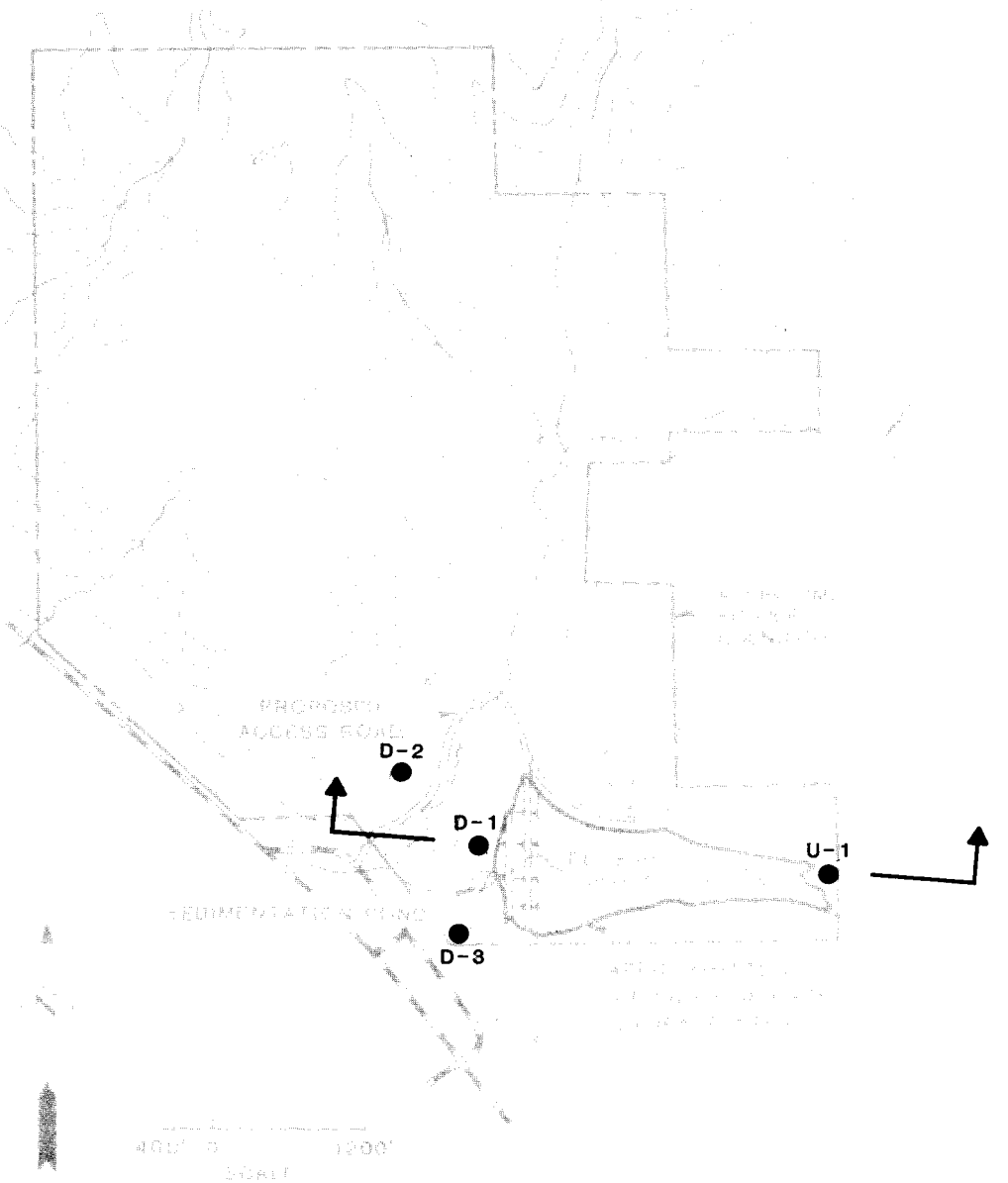


Figure 7-2. Groundwater Monitoring Points for Dry Disposal

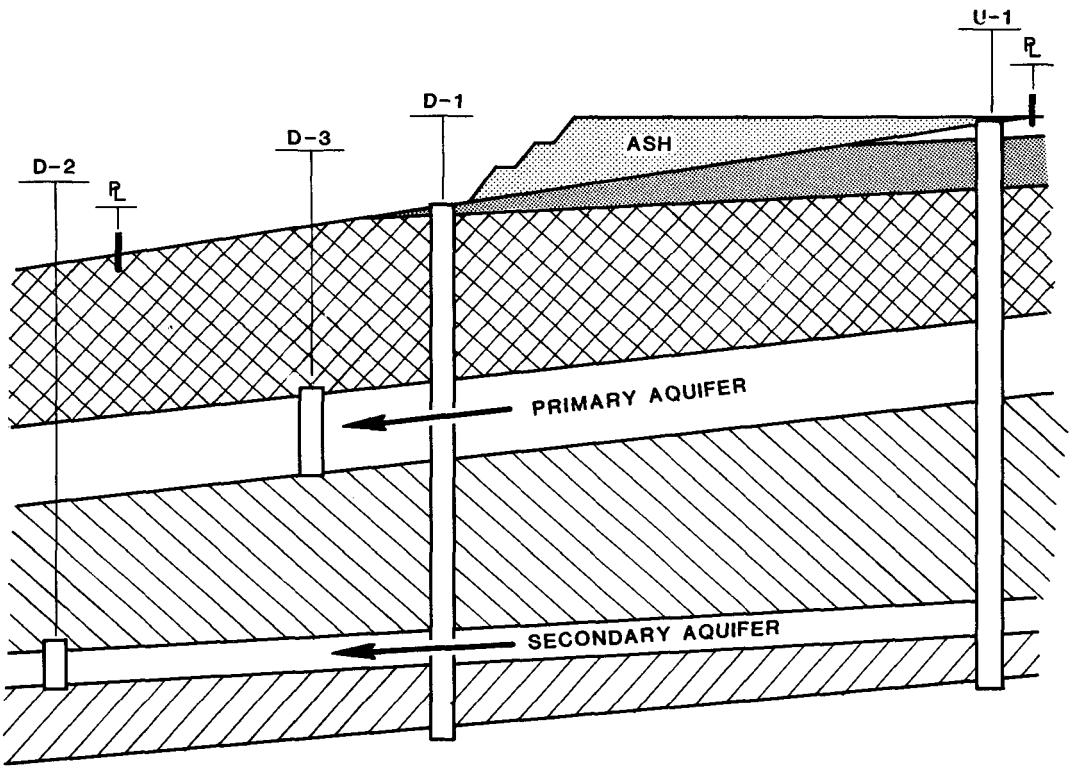


Figure 7-3. Geologic Cross-Section of Disposal Area

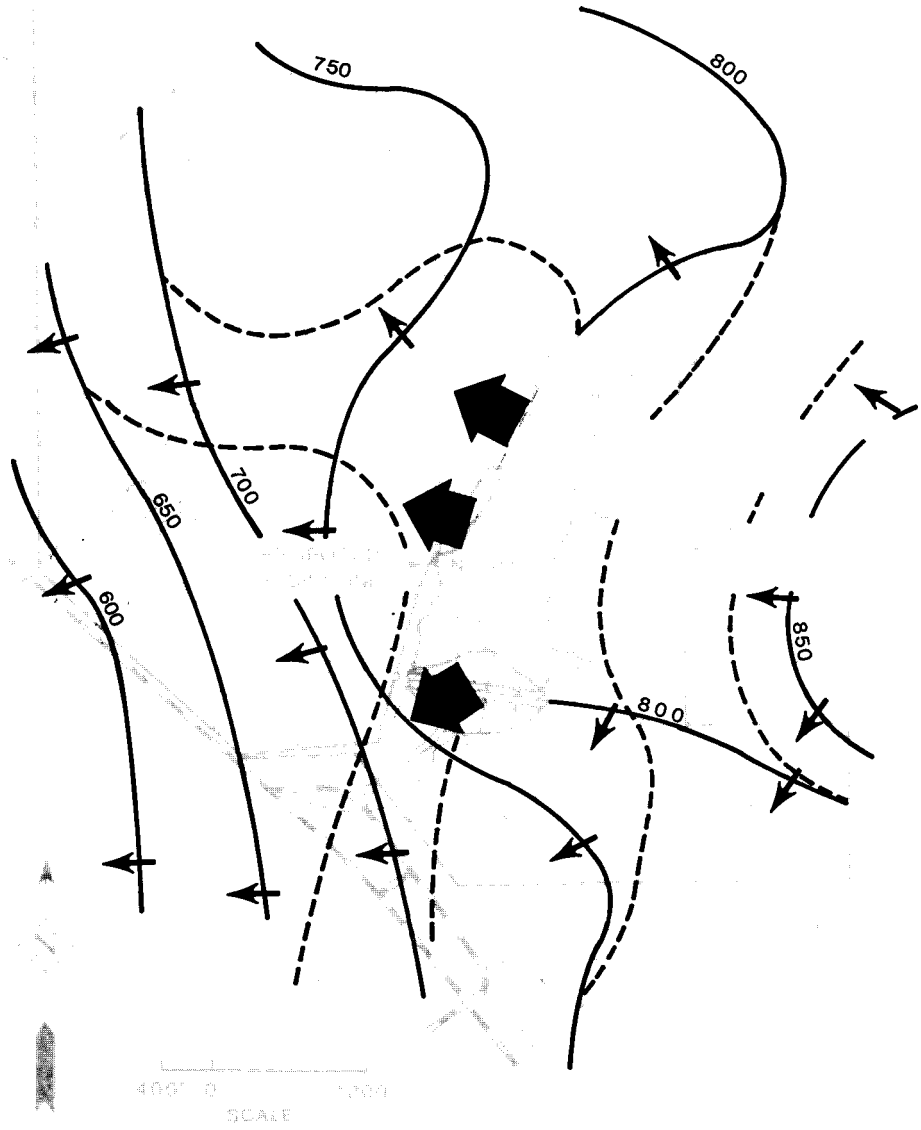


Figure 7-4. Effect of Wet Disposal Area on Groundwater System

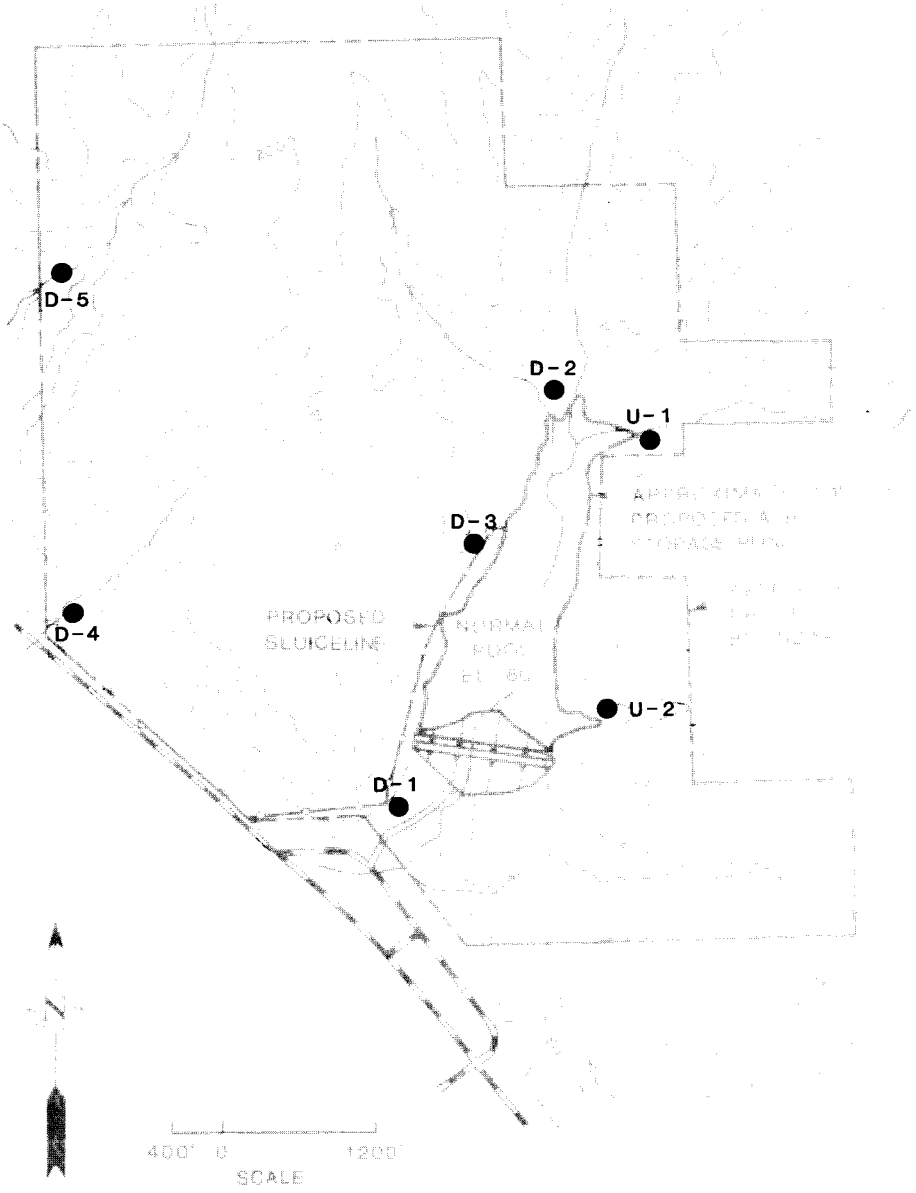


Figure 7-5. Groundwater Monitoring Points for Wet Disposal

effect of the pond. However, property lines negate the movement of these wells further away from the pond. The background data which are obtained prior to operation of the disposal area could provide significant information relative to these wells.

The 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 3 should miss the pollutant plume, due to preferential travel, poor well installation, etc., then wells D-4 and 5 would monitor 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 waterwells or environmentally sensitive areas. The decision is largely subjective and will be made on a case-by-case basis.

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, thus the monitoring well materials should be relatively inert,
- The installation of a monitoring well could be the cause of surface infiltration into the system, thus a source of contamination, and
- Due to the inability to accurately predict groundwater levels prior to drilling, experienced personnel are required 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 providing an economical installation.

The danger of surface contamination is very real in the use of monitoring wells. 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.

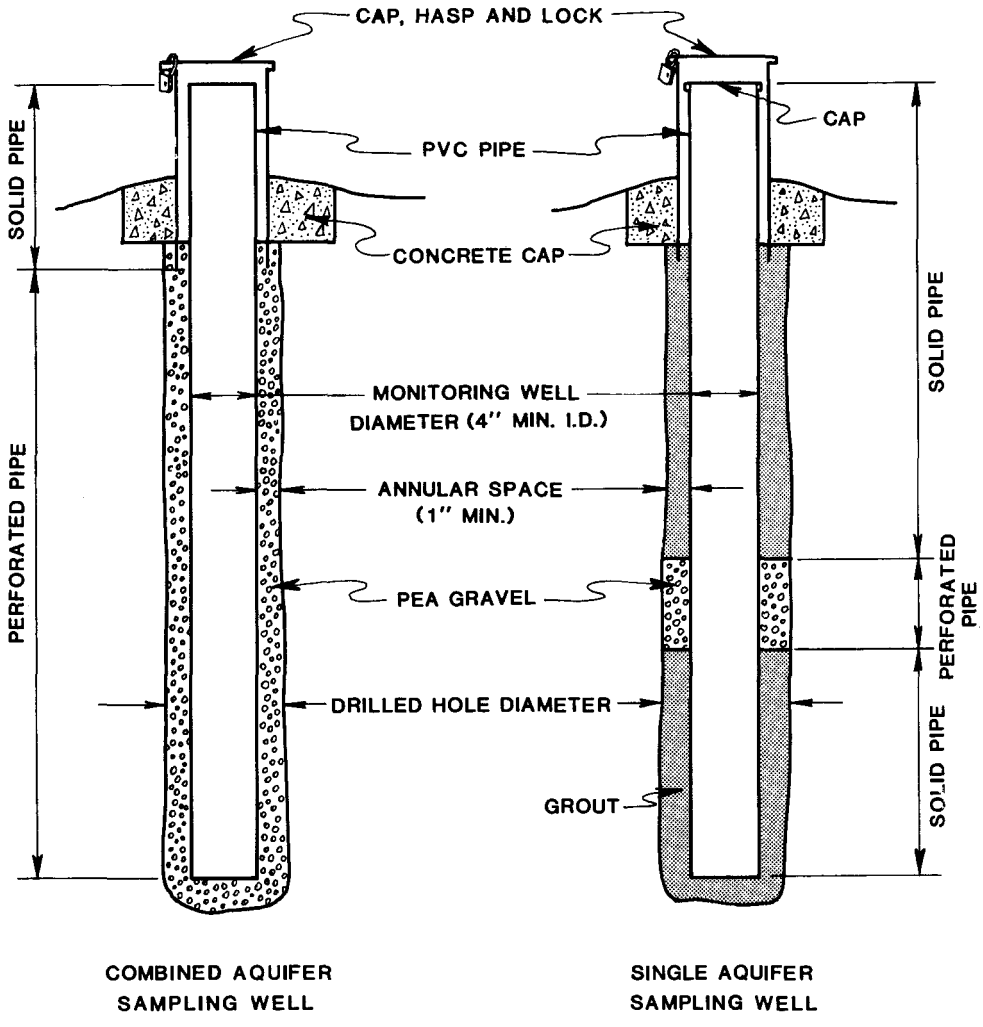


Figure 7-6. Monitoring Well Cross-Sections

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 soil or rock encountered but can be summarized as follows:

- 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 depth 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 bottom of the casing.

- With the pipe in place the annular fill material, either pea gravel or grout, is placed. If grout is being placed, 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 pumped or 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. Due to various factors, the water present in a monitoring well may not be representative of the actual groundwater. These factors are primarily due to monitoring well material contaminating the sample. The entrainment of atmospheric gases and their subsequent chemical reactions is another source of sample contamination.

To avoid sample contamination, it is therefore imperative 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 to remove the initial water. Although slow and not as effective as pumping, bailing does provide an acceptable means of removal if done with care. Bailing does have the disadvantage of suspending sediments on the bottom of the well and does not provide a mechanism for the removal of these sediments.

The most expedient and acceptable method 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 above-ground or in-well pump is utilized to remove the initial well water. 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 various scientific supply concerns. For lifts of up to 25 or 30 feet (7.6 or 9.1 meters), above ground pumps are available. These may either be electric or manually operated. The electric units may be operated with standard 12 volt current, battery operated, or attached to a vehicle electrical system. These units consist of a suction hose, pump and discharge hose. Manually operated pumps are most commonly used for lifts of up to 25 feet (7.6 meters). These pumps come in a variety of forms including peristaltic pumps, centrifugal pumps, diaphragm pumps, etc., and are readily available.

One advantage of using above ground pumps, either electric or manual, is the reduced 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 four-inch (10 centimeter) inside diameter well. In-well pumps have the disadvantage of requiring larger well diameters. Pumps are available that fit into a four-inch (10 centimeter) well; 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; however, for deeper wells, in-well pumps are the only alternative. Although more expensive, the larger diameter wells do provide added sampling capabilities. The larger wells can accommodate samplers which are capable of obtaining samples at specific depths with minimal interferences.

A final consideration in choosing a monitoring well diameter 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 temperature, conductivity, dissolved oxygen and other chemical parameters. This capability also 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, can provide a reliable groundwater sample. Bailing consists of using a bailer, which is any weighted container that may be inserted into a well, lowered, and a water sample obtained. Problems associated with bailing include the inability to adequately clean the monitoring well, suspension of deposited sediment during sampling, and the inability to obtain large samples, i.e., a series of small samples must be obtained to provide a single large water sample.

Another method of groundwater sampling is the use of a bubbler sampler. As shown in Figure 7-7, the sampler consists of two tubes and a chamber. The sampler is operated by inserting the assembly into the monitoring well. 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 identical to the sampling of surface waters. However, not only should the container be filled to the top prior to closure, but this should be done as quickly as possible and with as little turbulence as possible. 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.

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. 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

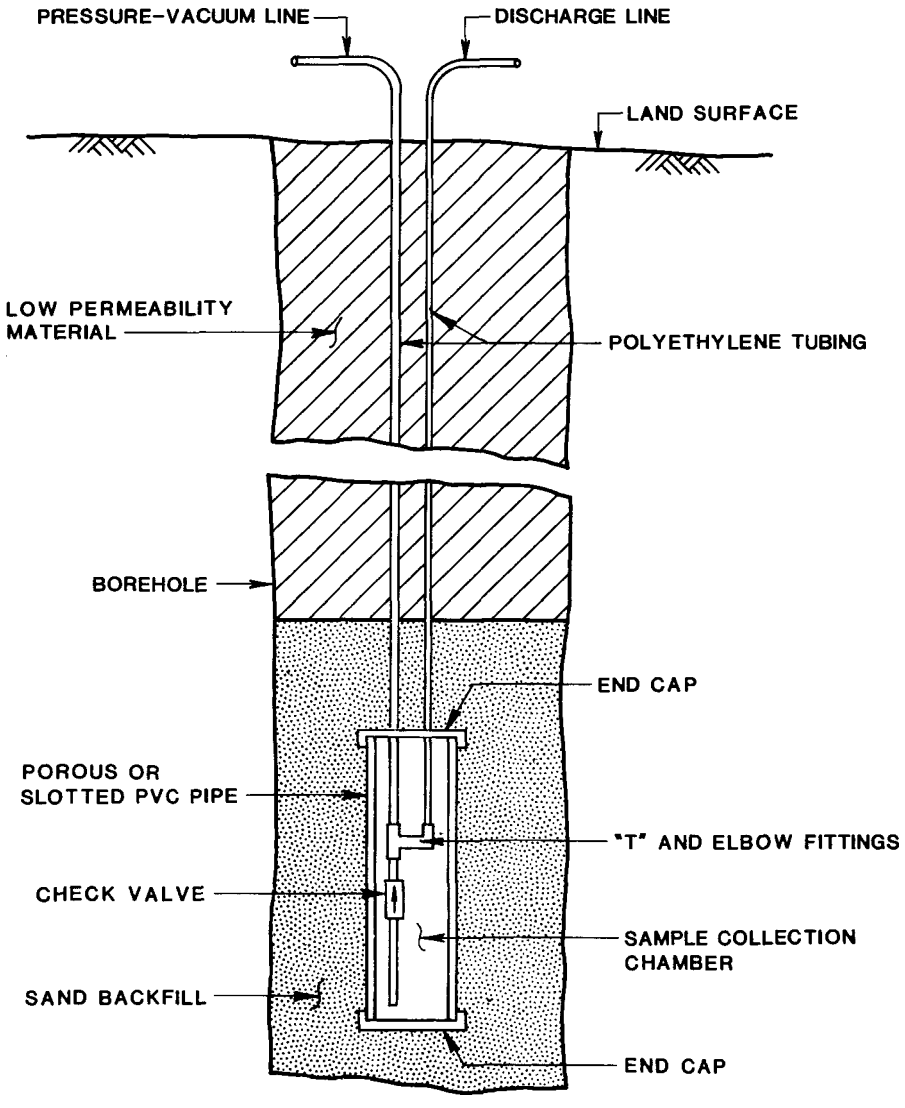


Figure 7-7. Schematic of a Bubbler Sampler

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.

include ash disposal sites as currently drafted. For those sites where leachate monitoring is required sampling frequency and analysis are similar to those for groundwater monitoring systems.

For situations where leachate monitoring is used, the simplest procedure is to sample the outflow from leachate collection systems. Leachate collection systems may include granular blankets below liners which drain to sumps or underdrain systems beneath landfills. Sampling procedures are similar to surface or groundwater sampling, as appropriate. When leachate collection systems are not included in the disposal site design, sampling is generally accomplished through pressure or vacuum lysimeters installed specifically for leachate monitoring. An alternate approach sometimes used with existing disposal sites is soil coring. In this procedure, soil samples are obtained through test borings and retained for the laboratory analysis. The use of soil sampling for leachate monitoring is normally not employed on a continuing basis because of cost. Soil borings generally cost about $10 to $15 per lineal foot of boring.

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. This 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. For 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 this case, the analysis and method of preservation should be noted such that 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 are briefly described in the section entitled Regulatory Requirements; however, these analyses are specifically related to the proposed RCRA regulations. Other federal, state, and local requirements may dictate other analyses. The most probable listing is included in Table 7-4.

Although these parameters are those water parameters which apply to ash in general, the analysis of a given sample may or may not include all of the

Table 7-4

GENERAL CHARACTERISTICS

pH	redox potential
alkalinity	total dissolved solids
conductivity	suspended solids
color	

SPECIFIC METALS OF INTEREST

Aluminum (Al)
Arsenic (As
Boron (B)
Cadmium (Cd)
Calcium (Ca)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Iron (Fe)
Lead (Pb)
Magnesium (Mg)
Manganese (Mn)
Mercury (Hg)
Molybdenum (Mo)
Nickel (Ni)
Phosphorus (P)
Potassium (K)
Selenium (Se)
Silica (Si)
Silver (Ag)
Sodium (Na)
Strontium (Sr)
Sulfur (S)
Titanium (Ti)
Zinc (Zn)

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 7-4, 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 negated 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.

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.

SAMPLE PRESERVATION

After selecting the location of the monitoring points, method of sampling, type of sample and chemical parameters to be analyzed, the next consideration is the selection of the required 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 below along with their general chemical action and general application.

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

In addition, Table 7-5 relates the method of preservation to the primary constituents normally analyzed for in environmental samples. By knowing the chemical parameters of interest and by utilizing this table, the number and types of sample bottles may be determined. In addition, this table also includes the sample size, as determined by EPA, so that the sample bottle size may also be determined for each preservative.

The initial consideration involving sample preservation is the selection of the size and type of sample container. Although not specifically a preservation technique, the sample container should not affect the sample. Plastic or glass sample bottles are generally preferred. Table 7-5 lists the type of container(s) suggested for each specific analysis procedure.

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 properly prepared prior to analysis, the ultimate water analysis, while being analytically correct, will not represent the water being sampled due to chemical

Table 7-5

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

Table 7-5 (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		50	P, G	Filter on site Cool, 4°C	24 hours(4)
Dissolved 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	--			
Tennin 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.

changes occurring within the sample container. To preclude this occurrence, procedures have been suggested for various chemical parameters. Table 7-5 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 Table 7-1). In general, the determination of chemical parameters on-site is always preferable. 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, these data are normally unacceptable to regulatory agencies who require analysis by certified laboratories. Thus, although some degree of capability exists for on-site chemical analysis, the bulk of the chemical analysis must normally be accomplished in certified laboratories.

MONITORING COSTS

The cost of implementing and conducting a monitoring program at an ash disposal site is highly site specific. 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. Similarly, the degree of analysis will depend on the ash characteristics and the frequency of sampling may depend on the rate of groundwater flow. However, to illustrate the type of costs which might be involved in a monitoring program, Table 7-6 presents a cost breakdown for the items involved in a modest groundwater monitoring program at an ash disposal site. The monitoring requirements for an actual disposal site will vary according to site conditions, size, and state or local regulations.

Table 7-6

TYPICAL COSTS FOR GROUNDWATER MONITORING PROGRAM

Installation	
Monitoring Wells - 6 @ 50 feet = 300 feet	
Drilling @ $25/lineal foot	$ 7,500
First Year Background Monitoring	
Monthly Comprehensive Analysis - 6 samples	
Labor @ $125/man-day x 12 days	1,500
Analyses @ $500/sample x 6 samples x 12 months	36,000
Total First Year Cost	$45,000
Continuing Annual Cost	
Quarterly Sampling, 1 Comprehensive, 3 Minimum Analyses	
Labor @ $125/man-day x 4 days	500
Analyses	
1 x 6 Comprehensive x $500 ea	3,000
3 x 6 Minimal x $50 ea	900
Annual Monitoring Cost	$4,400

Section 8

SITE RECLAMATION

INTRODUCTION

The advent of recently implemented, and soon to be promulgated, federal and state laws involving clean water and waste disposal standards has created a need to closely manage the progressive 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 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 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 Sections 3 and 4 of this manual. Although the promulgation of regulations under RCRA is currently incomplete, ash landfill closure criteria are tenatively stated at this time.

Proposed guidelines for regulations which could have a significant impact on erosion control, revegetation, and closure of ash disposal sites include:

- 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.
- Off-site runoff and uncontaminated on-site runoff should be routed to a sedimentation basin prior to discharge.

- 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 appears to comply with state and federal standards will more likely be permitted than the application containing a sketchy, nonspecific statement. Public opposition to the disposal of 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 solid waste 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 predomin-

ately 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 and/or local planning agencies can provide information concerning surrounding land-use and assistance in assessing possible land-use alternatives.

Proposed Site Uses(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 catagories 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 FGD Sludge Disposal Manual 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 Fly Ash Structural Fill Manual 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 sites 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, scheduling of planting, and for the design of erosion control

Table 8-1

POST-CLOSURE LAND-USE CATEGORIES FOR ASH DISPOSAL SITES

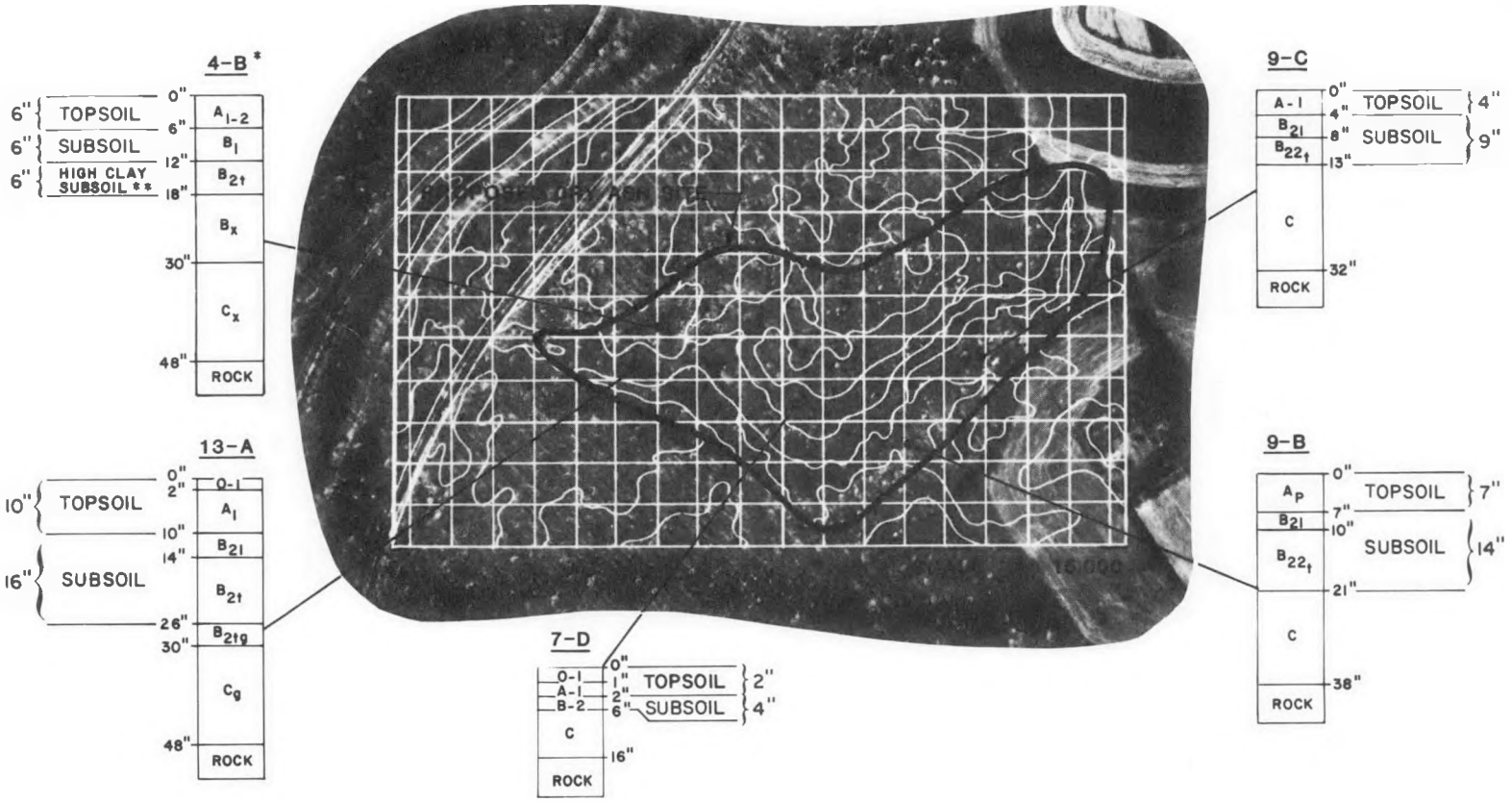
Possible Site Use After Closure	Requirements
Wildlife Habitat, Wilderness	Adequate cover and vegetation.
Limited Agriculture or Recreation grazing hunting	Adequate cover and vegetation, added protection of fill or embankment slopes to prevent erosion resulting from animal or vehicle traffic, maintenance 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.

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 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.

Figure 8-1 and Table 8-2 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 a 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 specimen. 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 TYPE DESIGNATION NUMBER AND SLOPE CLASS (A = 0-3° , B = 3-8° , C = 8-15° , D = 15-30° , E $\geq$ 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.

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 poorly	Poorly	Poorly Sour	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.

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, not to mention cost considerations involving cover material transport, soil amendments, stabilization and long term maintenance.

The primary objective of a predisturbance soils inventory is the determination of 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):

Map Units (3 to 5.99 in.)	Av. Slope of Map Unit (θ) (Degrees)	Map Area (χ) (sq. yds.)	Ground Area (χ/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	47,880

Estimated Topsoil Volume (Av.) in 3 to 5.99 Inch Cat. = 35,680 cubic yards

In a similar fashion that volume of topsoil in the other legend categories could be calculated, and when added together would provide an estimate of the strippable topsoil within the entire disposal site.

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 valley ash 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.

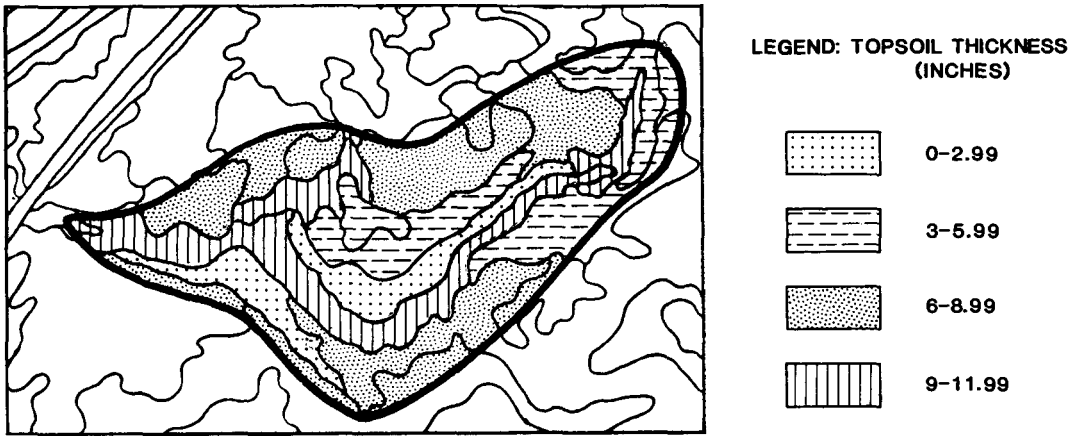


Figure 8-2. Interpretative soil map showing thickness of organic rich topsoil.

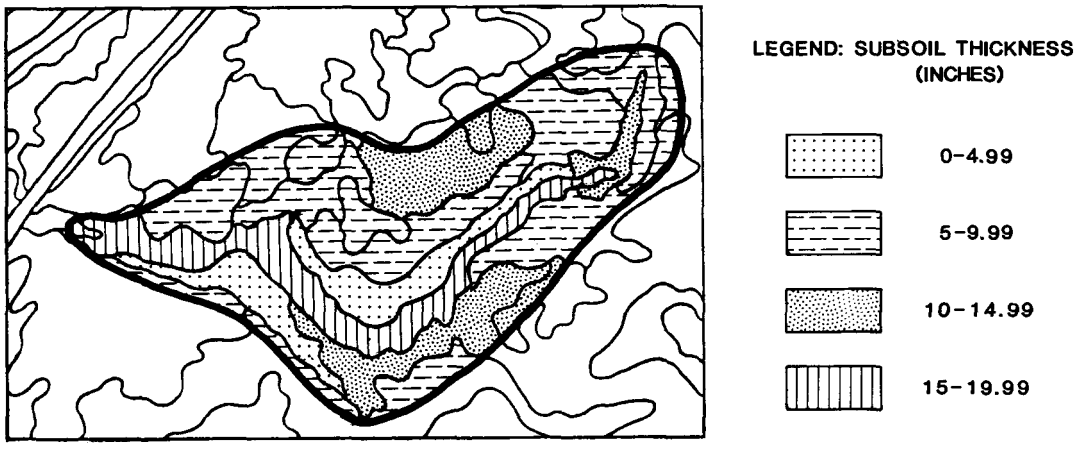


Figure 8-3. Interpretative soil map showing thickness of productive subsoil.

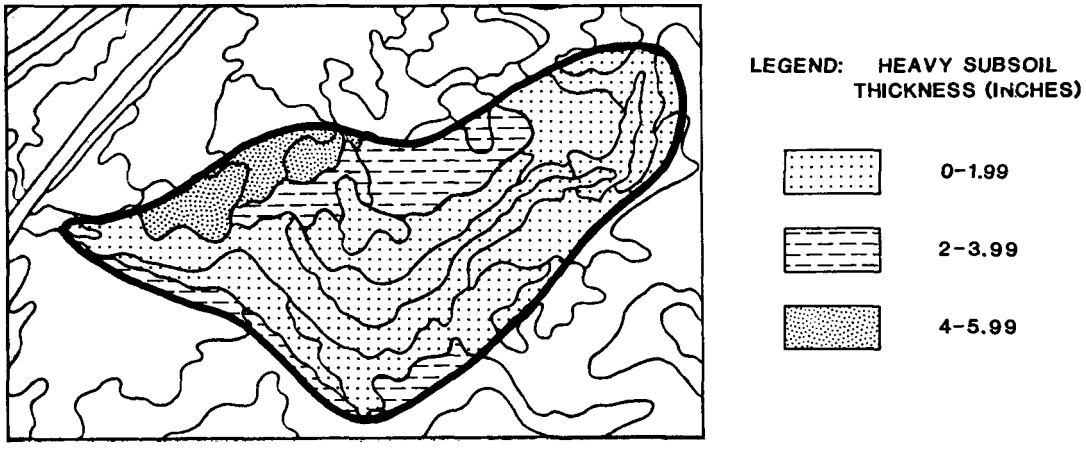


Figure 8-4. Interpretative soil map showing thickness of high clay subsoil.

EROSION AND SEDIMENT CONTROL

The detachment of soil particles from their initial resting place by of wind and 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 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 (1). 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 (2). Studies on unvegetated slopes in Arizona (3) 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 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 sediment 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

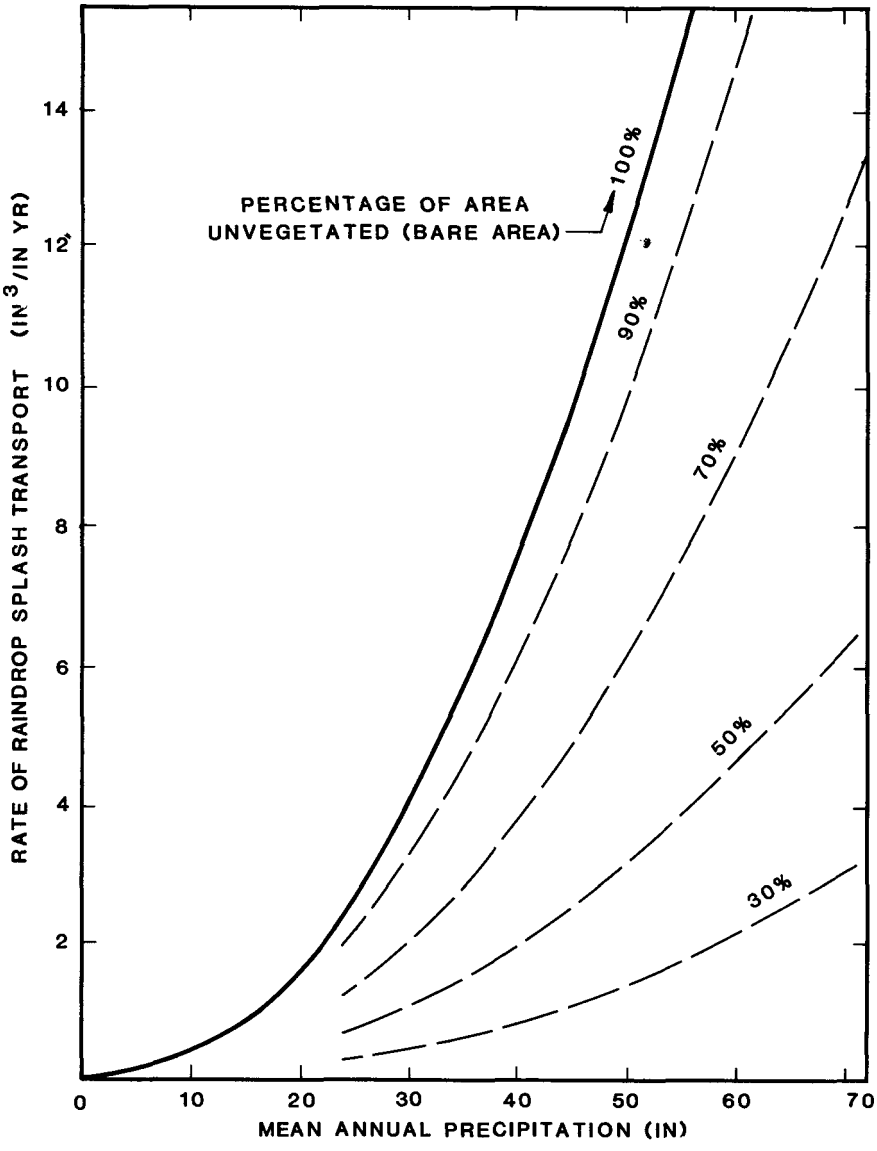


Figure 8-5. Probabilistic variation of raindrop splash erosion with extent of vegetation cover expressed in terms of mean annual precipitation.

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 of the order of 1,000 to 10,000 times (Figure 8-6), shows that the presence or absence of vegetation is the overriding 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),
- 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

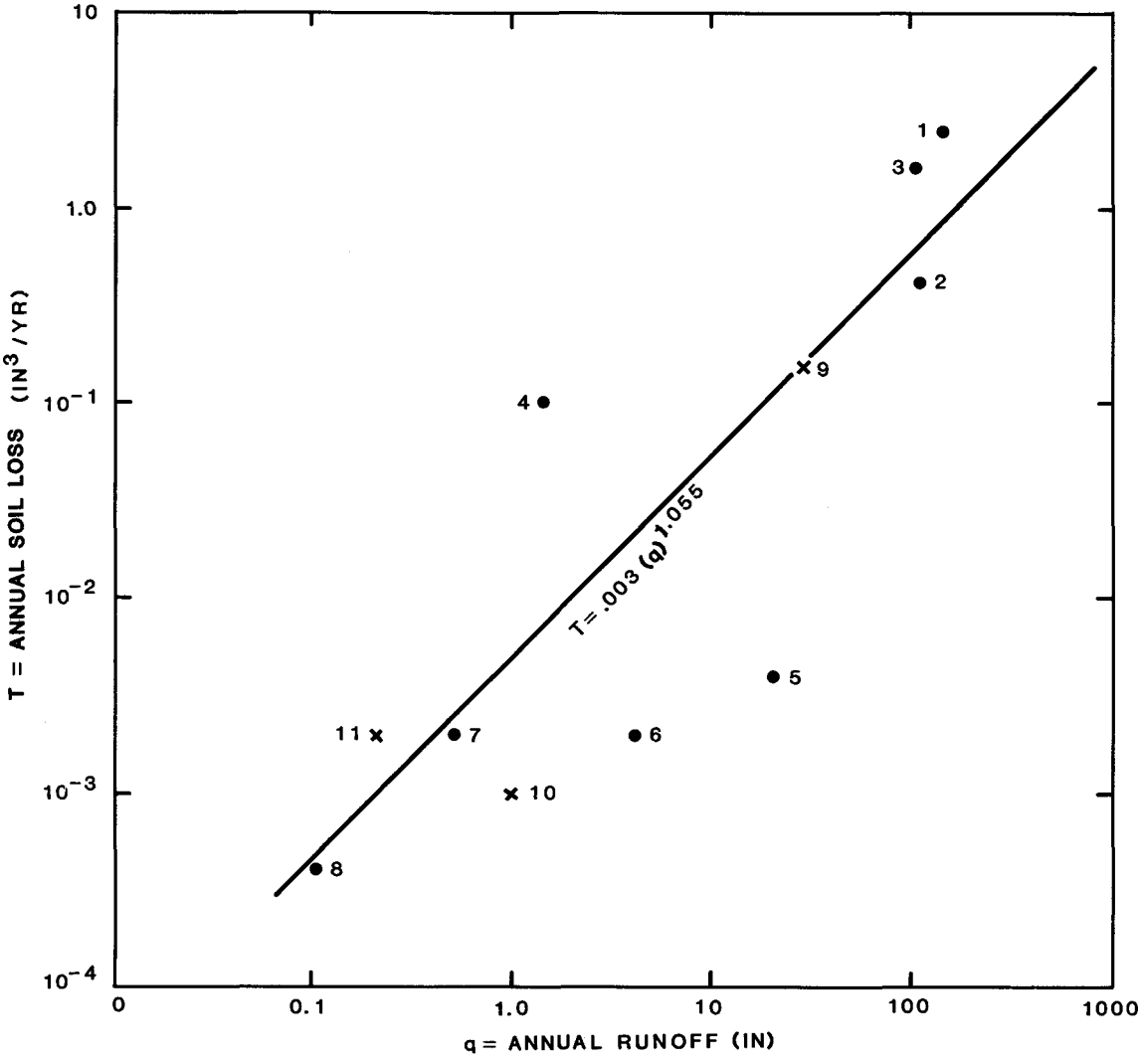


Figure 8-6. The Influence of Vegetation on Runoff and Erosion

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.

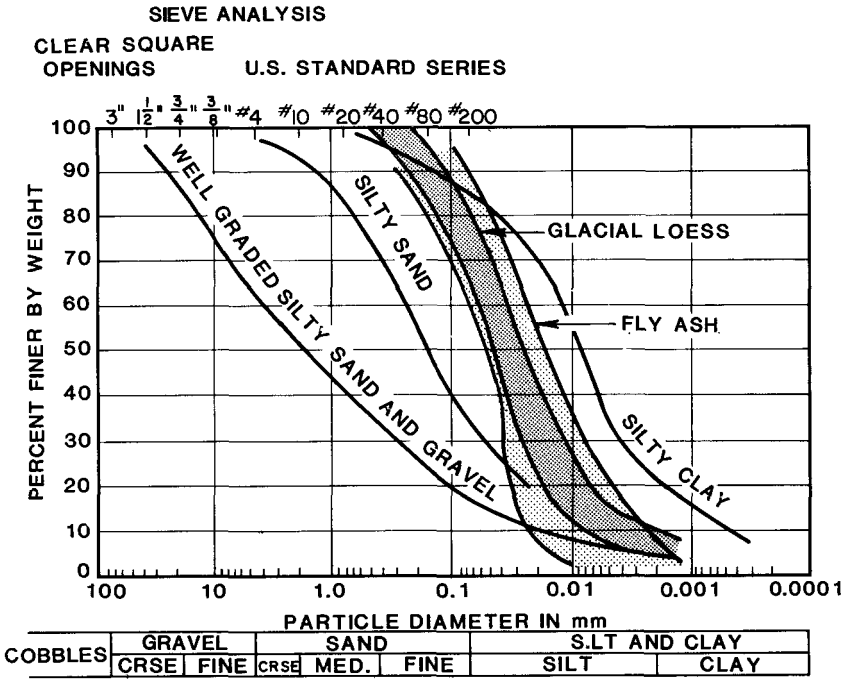


Figure 8-7. Composite of grain size distributions for bituminous fly ash and glacial loess. (Sources: Pewe, T. L. "Origin of Upland Silt Near Fairbanks, Alaska." Geological Society of America Bulletin, Vol. 66, 1955, p. 701 and Figure 2-2 of this manual.)

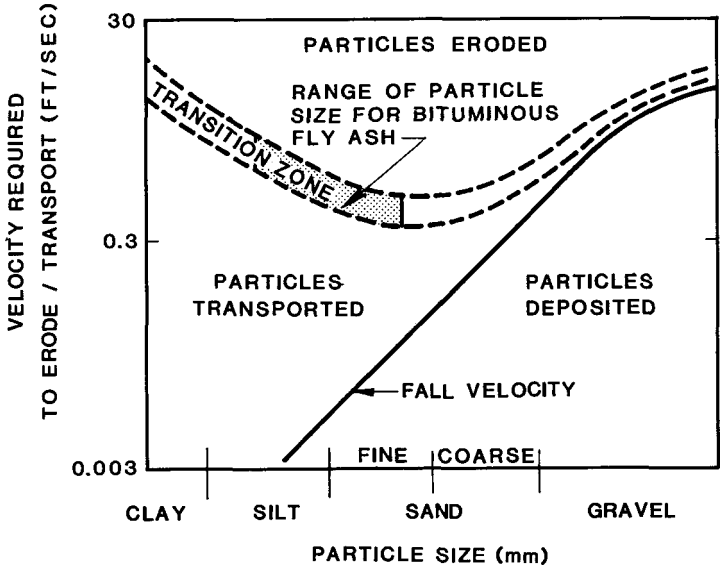


Figure 8-8. Velocities required for particle erosion, transport and deposition.

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 (4, 5). 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 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 (6).

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

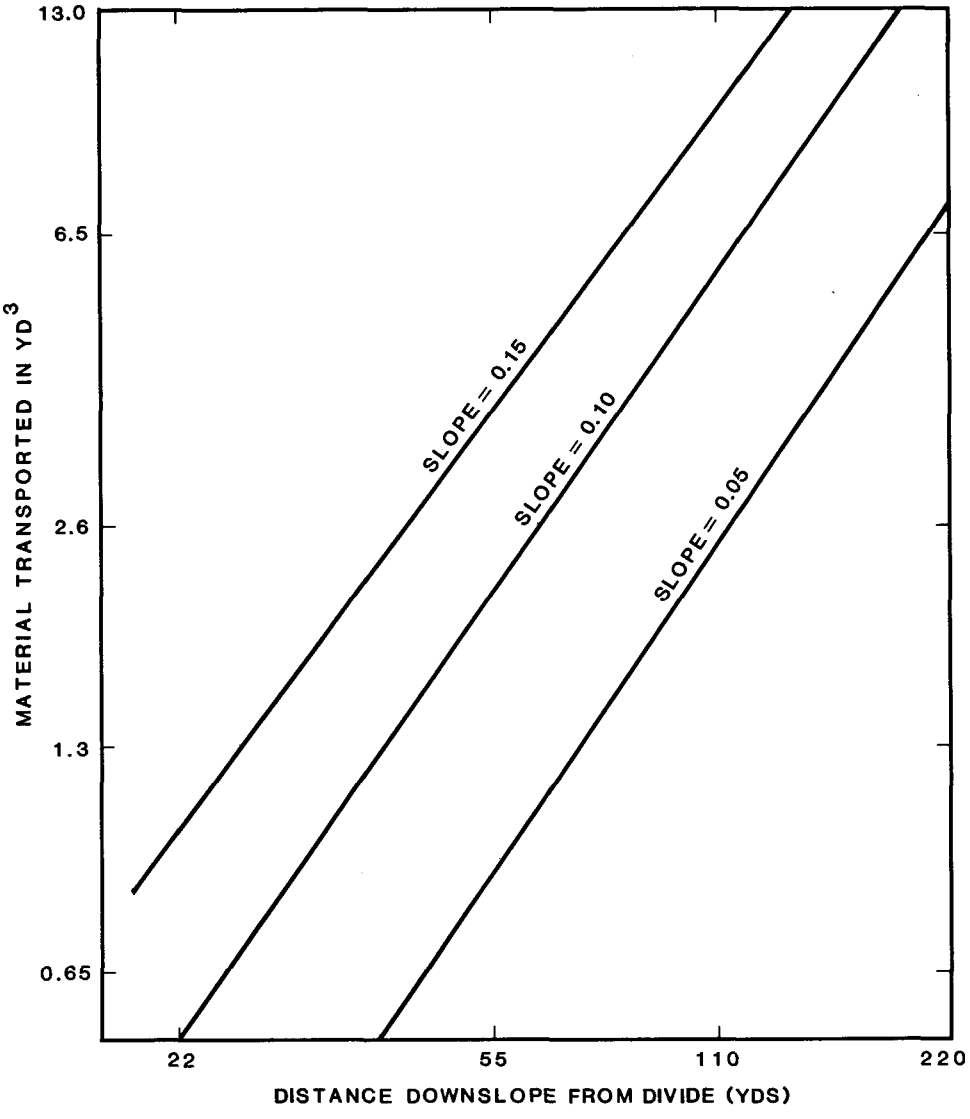


Figure 8-9. Graphic representation of empirical model: Transport $\propto$ $(\text{Distance})^{1.35}$ $(\text{Slope})^{1.35}$, for unvegetated field soils. (Source: Musgrave, G. W. "Quantitative Evaluation of Factors in Water Erosion - A First Approximation." Journal of Soil and Water Conservation, Vol. 2, 1947, p. 133.)

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 (7). 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 are 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 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 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 (8). 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.

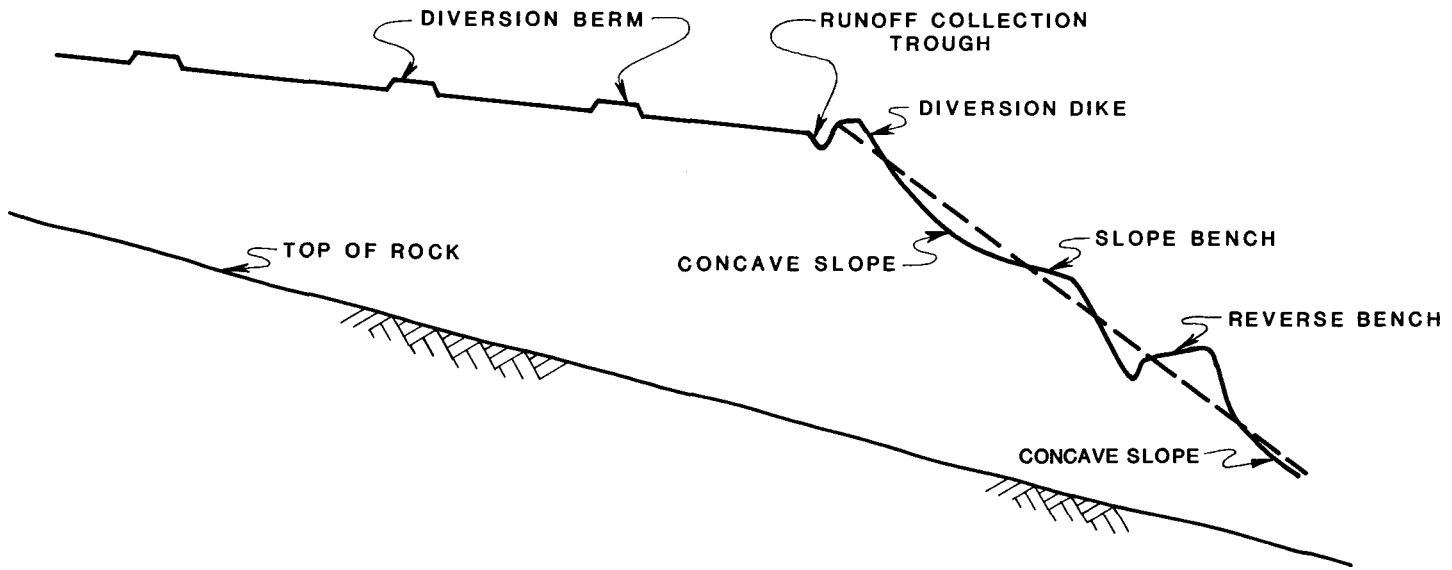


Figure 8-10. Slope Reduction Methods

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 (9).

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. Current proposed 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 in order to ascertain the most stringent prevailing criteria governing ash disposal practice.

The design of diversion and interception ditches falls under the broad topic of

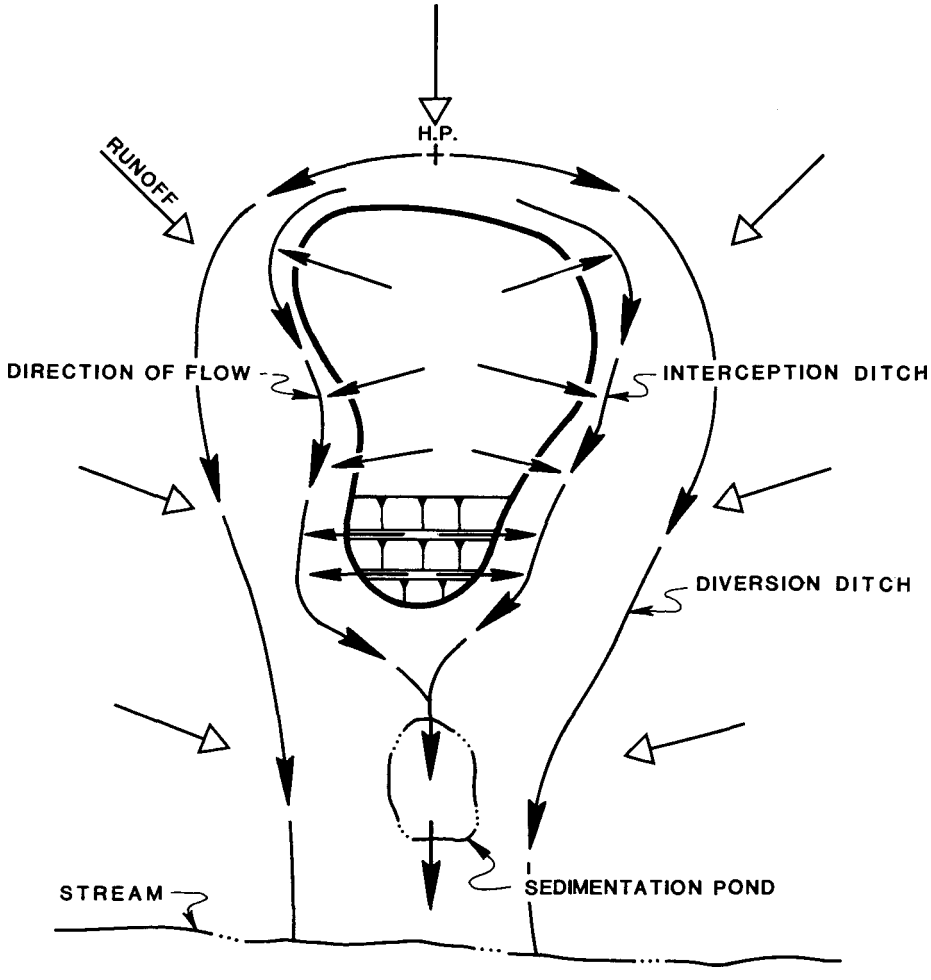


Figure 8-11. Schematic plan view of interception and diversion ditches around a valley landfill.

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. In order 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 preclude the need for frequent sediment removal. In general, the following parameters should be known or assumed in order to undertake a pond design (9).

- 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 (9):

$$\text{Required settling area} = \frac{\text{outflow rate}}{\text{critical settling velocity of the smallest particle to be retained}}$$

However, it is unlikely that ideal settling conditions will occur, due to a number of disrupting factors. These include (9):

- 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 (9):

- 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,
- Constructing a very wide overflow view 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,

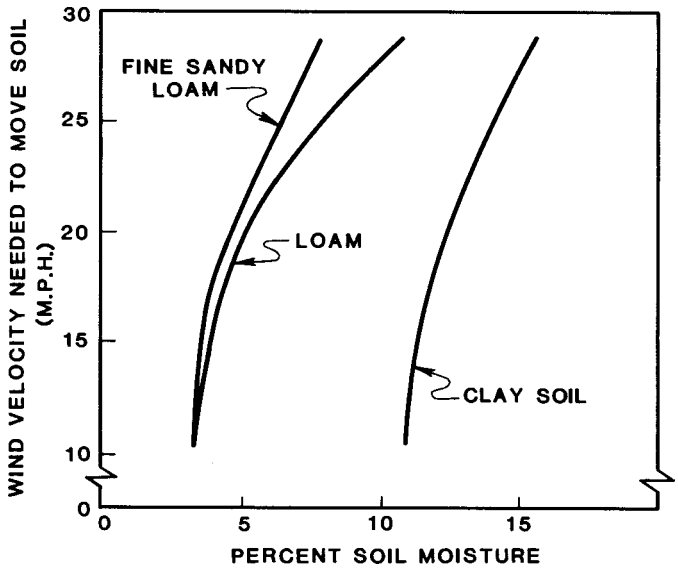


Figure 8-12. Effect of soil moisture and testure on the wind velocity required to move soils. (Source: Bisal, F., and J. Hsiek. "Influence of Moisture on Erodibility of Soil by Wind." Soil Science, Vol. 102, 1966, p. 143).

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 (10). 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 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 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 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 (11, 12). 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 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.

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.

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.

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 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.

Table 8-4

BORON PHYTOTOXICITY IN ASH LAGOONS

Concentration of Available B	No. of Samples	Degree of Phytotoxicity
ppm		
Less than 4	0	Nontoxic
4-10	5	Slightly toxic
11-20	3	Moderately toxic
20-30	3	Toxic
Over 30	1	Highly Toxic

Source: D. R. Hodgson and W. N. Townsend. The Ameliotation and Revegetation of Pulverized Fuel Ash. In Proceedings of Internal Symposium on Ecology and Revegetation of Drastically Disturbed Areas, University Park, Pennsylvania, 1969.

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. 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 (11). 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 volume of water available for plant 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 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 (4, 5) 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 steepe and desert climates.

Various other factors which will effect 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 known, the textural class can be determined using Figure 8-13. Soils having 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, dependent 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 (13).

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.

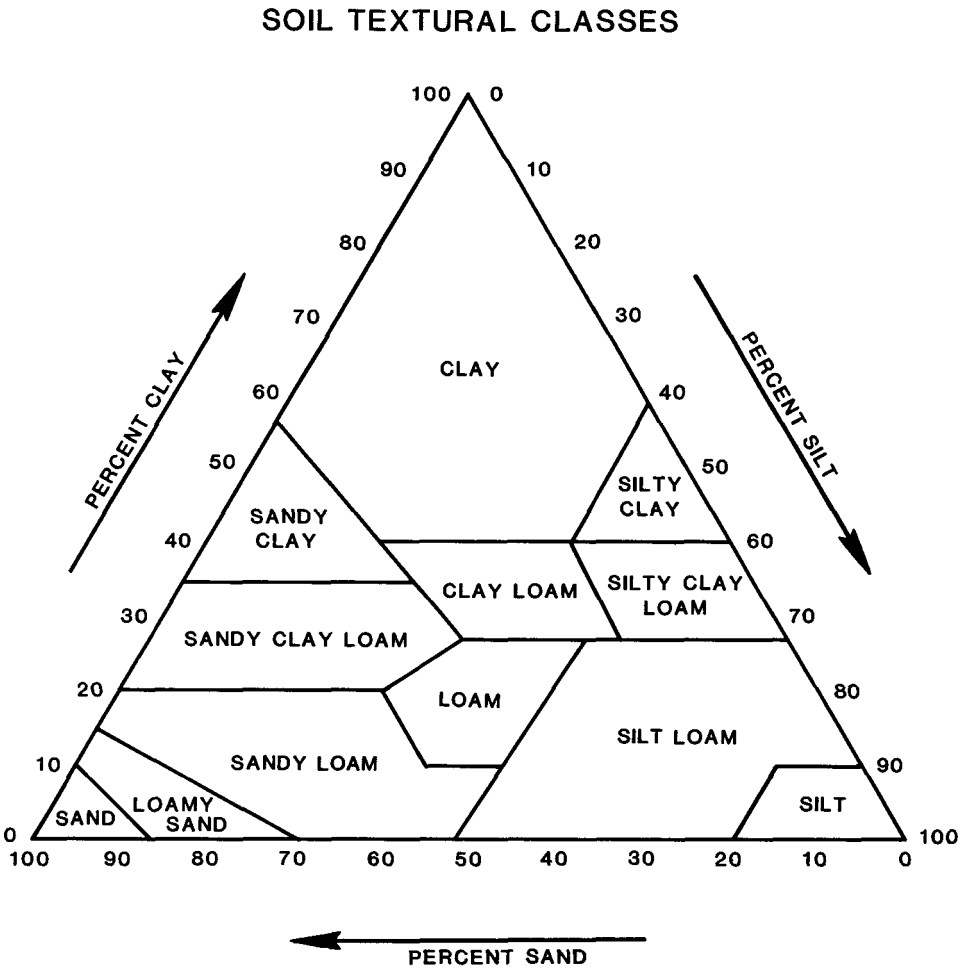


Figure 8-13. Relationship between the textural class name and particle size distribution. (Source: Soil Conservation Service. U. S. Department of Agriculture. Soil Taxonomy. Washington, D. C.: Government Printing Office, 1976. AH-436.)

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.

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. Considering the interim status of the soon to be implemented RCRA regulations, it appears prudent where possible to apply cover soil in three distinct layers as outlined in the proposed RCRA closure specification. Though the thickness of the three cover layers need not meet RCRA specifications under the present guidelines, it would be correct from an environmental and agronomic viewpoint 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

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	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.

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 reistant 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.

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.

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.

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.

Table 8-5 (Continued)

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.

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 cuneata		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.

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.

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 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 in the eastern U. S.

Plants selected must be tolerant of not only the environment normally encountered, but also of the possibility of having fly 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 fly 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.

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 (14). 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 (15) 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 and mixtures for various erosion control purposes are also indicated.

Spreading of Cover Soil

After the ash has been graded to its final form, the final soil 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 revegetation 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 lower 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

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 ryegrass	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 trefoil* †	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.

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.

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.

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 representative 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:

- 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 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. Presently proposed federal regulations for the disposal of hazardous materials indicate that post-closure care for a period of at least 20 years from the date of closure may be required. It is therefore expedient to minimize post-closure requirements through the proper operation and construction of ash disposal sites prior to closure.

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,

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.

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.

- 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 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 roadways; 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 expedient 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.

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

COST ESTIMATING

PURPOSE

This section presents a method for making an economic comparison of alternative disposal systems. 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). Although the total cost obtained using these economic premises may not be applicable to a specific facility which is being considered, the use of the methods presented should provide a valid economic comparison of alternatives. The basic assumptions used are presented so that they can be modified when required and the methodology for preparing site specific estimates is presented. In addition, some cost curves are presented for use in first order estimates of the total cost of alternate ash disposal systems.

ECONOMIC PREMISES

The assumptions and methodology presented herein are based on the economics applicable to investor-owned utilities regulated by a Public Utility Commission. Alternative disposal schemes and sites are compared on the basis of the present worth of the revenue required annually by each 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 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).

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 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 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 as well as values for several combinations of the parameters.

The following values, based on an assumed long-term inflation rate of 6 percent/year, were recommended (1) for use in long term comparisons of investment alternatives and have been used for all financial calculations:

Debt/Equity Ratio	50/50
Debt Cost	8%/year
Preferred Stock Ratio	15%
Preferred Stock Cost	8.5%/year
Common Stock Ratio	35%
Common Stock Cost	13.5%/year
Weighted Cost of Capital	10%/year
Federal + State Income Tax Rate	50%
Property Taxes and Insurance	2%/year
Investment Tax Credit	0
Book Life	30 years
Tax Life	20 years
Retirement Dispersion	Iowa Type S_1

Based on these assumptions with no tax preference allowances, the economic factors given in Table 9-1 can be computed:

Table 9-1

ECONOMIC FACTORS

Facility Life (Years)	Fixed Charge Rate	Levelizing Factors	Present-Worth Factors
5	0.34	1.182	0.8309
10	0.23	1.335	0.6904
15	0.20	1.484	0.5737
20	0.19	1.629	0.4767
25	0.18	1.763	0.3961
30	0.18	1.886	0.3291
35	0.18	1.996	0.2735
40	0.18	2.094	0.2273

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 current (Commercial Operation Date) dollars. They are based on a weighted cost of capital equal to 3.77 percent/year.

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) Royality 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 on-site facilities required for the disposal system. Included under this item are the capital

*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.

costs of transport equipment, transport pipelines, electrical equipment, excavation and site preparation. The major item in this category is 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. The pond reclamation cost is incurred primarily at the end of the site's life. Therefore, the present worth of that expense (see Table 9-1) 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.

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 9-2 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

Table 9-2

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 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.

Table 9-3

PROCESS CONTINGENCY GUIDELINES

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%

Source: Economic Premises for Power Generating Plants (2).

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 startup. The costs may be estimated as the sum of 1/12 (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 fuel andzother 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 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).

For an assumed interest rate of 8 percent per year, the AFDC can be calculated as follows:

$$AFDC = [(1.08)^{cg} - 1] \times (TPI)$$

The following sample calculation for AFDC was adapted from Reference (2).

Example of AFDC Calculation for an Assumed Construction Period Cash Flow.

The following assumptions are made:

1. Total Plant Investment (TPI) = $100 (year one dollars)

2. The construction expenditures are as follows:

Year	Construction Expenditure (in year one dollars)
1	5
2	15
3	30
4	35
5	15

3. Expenditures are uniform during a given year; the effective interest rate for the first year is 1/2 the annual interest rate. (Using annual end-of-year compounding)

4. Annual Interest Rate = 8%

CALCULATION OF AFDC

$5 \times (1.04)\ (1.08)^4$	=	$ 7.07
$15 \times (1.04)\ (1.08)^3$	=	19.65
$30 \times (1.04)\ (1.08)^2$	=	36.39
$35 \times (1.04)\ (1.08)$	=	39.31
$15 \times (1.04)$	=	15.60
Total (TPI + AFDC)		$118.02

Therefore,

AFDC	=	$118.02 - TPI
	=	$118.02 - $100
	=	$ 18.02

Calculation of Center of Gravity (cg)

$$cg = \frac{\log\left(\frac{AFDC}{TPI} + 1\right)}{\log\ (1 + \text{Annual Interest Rate})}$$

$$cg = \frac{\log\left(\frac{18.02}{100} + 1\right)}{\log\ (1.08)} = 2.153 \text{ years, say } 2.2 \text{ years}$$

Therefore, 2.2 years is the center of gravity (cg) for the construction expenditure schedule shown above. The AFDC ($18.02) can now also be calculated using the (cg) which was calculated for these expenditures:

$$AFDC = [(1.08)^{2.153} - 1] \times (\$100)$$
$$= \$18.02$$

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. Unless a specific use can be anticipated and its value estimated, the land aquisition cost should be treated as a capital cost.

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 described earlier. 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. 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. Table 9-4 presents a range of maintenance costs which is considered representative for several processing conditions (2).

Table 9-4

MAINTENANCE COSTS

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

Source: Economic Premises for Electric Power Generating Plants (2).

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 and any additional operating cost which is incurred as a function to 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 9-5 which was established by EPRI (2). An example of the calculations described above is presented in the subsection "Development of Base Case Estimates."

CLASS I - SIMPLIFIED DESIGN COST ESTIMATES

During the site selection and conceptual design stage for an ash disposal system it is often desirable to make simplified cost estimates (Class I as described in Table 9-2) for each of the alternatives being considered. Therefore, this subsection describes the development and use of a graphical method for quickly obtaining the Total Capital Requirement (TCR) and the Levelized Annual Revenue Requirement (LARR) for both wet and dry disposal of ash. This method is applicable for a Class I Simplified Design cost estimate. As the design process proceeds, detailed, site-specific, cost estimates (Class II, III or IV) will be required.

Estimates prepared for specific base cases are used as the basis for the cost estimating curves. The plant location and fuel characteristics are consistent with EPRI recommendations given in "Power Plant Design Premises" (7). Much of the additional information has been adapted from detailed estimates for FGD

Table 9-5

FORMAT FOR COMPUTING TOTAL CAPITAL REQUIREMENT, FIRST YEAR OPERATING COST, AND LEVELIZED ANNUAL REVENUE REQUIREMENT

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		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 =	1.886 x FYOC
Levelized Capital Requirement	LCR =	0.18 x TCR
Levelized Annual Revenue Requirement	LARR =	LOC + LCR

* 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.

sludge disposal prepared by TVA (3, 4, 5, 6). Additional cost and production information was obtained from References 8 through 15.

Basic Assumptions

The 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 as described below or, a more detailed cost estimate, as outlined later in this section, may be prepared.

Note that the base case disposal system does not include a site liner or provisions to monitor the groundwater. These items have not generally been required in actual systems to date. The cost of monitoring systems are relatively small and, therefore, could be accounted for as part of the Project Contingency. Liners, which can be a substantial cost, would be included as part of the Process Capital.

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. Power plant size varies from 200MW to 1500MW.

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 disposal 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 heating value is 10,500 Btu/lb (24,400 kJ/kg).

5. Coal ash content varies from 12 to 20 percent with 80 percent fly ash and 20 percent bottom ash.

6. Fly ash collection efficiency is near 100 percent.

7. Disposal cost estimates include transportation and disposal costs only.

Economics. The following economic assumptions have been made:

1. Midwestern plant location. Site is clear and level with no special problems (7).

2. Capital costs are calculated for mid-1979.

3. Paid-up Royalties amount to 0.5 percent of the Process Capital.

4. Annual operation and maintenance costs are calculated for a mid-1980 startup.

5. Annual capital and operating costs have been levelized over a 30-year period.

6. The 30-year Fixed Charge Rate is 18 percent per year (see Table 9-1).

7. The 30-year Levelizing Factor for operating and maintenance costs is 1.886 (see Table 9-1).

Base Cases. The primary assumptions which apply specifically to the base case estimates are given below. As stated earlier, systems which do not fit these assumptions can be evaluated using the more detailed cost estimating procedure described in the following section. It may be possible, however, to adapt the estimates from this section simply by adjusting the parameters. For example, differences in 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 fly ash disposal quantity. This value can then be used to enter the cost curves described below rather than the plant size and percent ash. Adjustments for different capacity factors (first year or levelized) are more complex because of their relative relationships inherent in the basic assumptions. It can be generalized, however, that the total costs (TCR and LARR) increase with increased capacity factors, but the unit cost for disposal decreases with increased capacity factors. Adjustments for several extraordinary capital expenses are discussed later in this section.

The following assumptions for the Simplified Cost Estimates were selected as typical for the type of disposal in question. Analyses have indicated, for example, that the optimum depth for pond construction on flat land is generally between 18 and 25 feet (5.5-7.6 meters) (4, 16). The 50-foot (15.2 meter) average depth for dry sites was selected as a reasonable limit based on current practice and aesthetics, although there is some indication that even greater depths are common (17). A one-mile (1.6 kilometer) distance to the disposal sites was selected as a base distance. A correction factor for the actual distance to the site can be determined graphically.

1. Sluicing to pond.

   --Slurry water recycled.

   --Pumps and transport lines have the capacity to dispose of all fly ash collected from a plant operating at 100 percent capacity factor while the disposal pond size is based on a levelized capacity factor of 48.5 percent over the 30-year life.

   --A spare pump and pipeline are included for slurry delivery. No spares are provided for recycle (4).

   --Disposal of fly ash only. All bottom ash assumed to be sold or utilized.

   --Fly ash slurry pumped at 5 percent ash by weight.

   --Pond located one mile (1.6 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.

   --Effective average depth of pond is 25 feet (7.6 meters).

2. Trucking to landfill.

   --Hauling, placing, and compaction are performed by a contractor based on a unit price bid.

   --Existing public and/or private roads are utilized in addition to the 1-1/4 miles (2 kilometers) of roads constructed.

   --Compaction by equipment and rollers, but without strict field control, results in an in-place density for dry fly ash of 80 pounds per cubic foot (1280 kilograms per cubic meter).

   --Landfill site located one mile (1.6 kilometers) from plant.

   --Effective average depth of landfill is 50 feet (15.2 meters).

Development of Base Case Estimates

The base case estimates were used to prepare the simplified cost estimating curves described later in this section. These estimates were prepared using the assumptions and methodology outlined above and are applicable to regulated investor-owned utilities. Cost estimates were made for various combinations of parameters to generate the data necessary to plot simplified cost and correction factor curves.

The scope of the base case disposal system cost estimates is limited to the

actual transportation and disposal of the fly ash. On-site ash movement and storage are not included. These costs depend on the collection operation and have been assumed to be similar in magnitude for both wet sluicing and dry trucking. Thus the estimate for wet systems begins at the slurry pumps and the estimate for dry systems begins at the discharge chute of the ash silo.

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, Tables 9-6 and 9-7 have been prepared to demonstrate a Class I - Simplied Cost Estimate for a typical wet disposal base case while Tables 9-8 and 9-9 provide the same type of cost data for a typical landfill base case.

Cost assumptions for the seven items which make up the Total Capital Requirement are given below for the two example base case estimates. The cost estimate developed for the typical wet and landfill base cases are given in Tables 9-6 and 9-8, respectively.

Total Plant Investment.

Process Capital.

1. Transport Equipment. Pumps for the sluicing system are the primary equipment which is required for wet disposal. Costs for this equipment have been adapted from the detailed estimates prepared by TVA (4). Hauling and compaction equipment purchased for dry disposal by the utility would be included in this item; however these estimates assume that those tasks are performed under contract by private companies. This allows the cost to be charged as an operating expense.

2. Transport Pipelines. The ash slurry pipeline costs were also adapted from TVA estimates (4).

3. Electrical Equipment. These costs include the required transformer equipment and power lines to all equipment as well as the feeder lines to the transformer. Also included are the individual motor control costs. These costs, based on TVA estimates (4), vary with the total horsepower connected to the system.

4. 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 item. The landfill development is the major cost item for dry disposal. Since the site in generally developed continuously over the life of the facility, only a portion of the cost must be capitalized. For these estimates the cost to develop the site sufficiently to handle one year of ash disposal is included as a capital cost ($21,600/acre x (Number of Acres)/30 years). In addition the cost for providing 1-1/4 miles of haul ($30,000) roads is included as a capital cost.

Table 9-6

TOTAL CAPITAL REQUIREMENT
SLUICING TO POND - 500 MW BASE CASE*

	Estimated Capital in Thousands of Dollars		
Plant Investment			
Process Capital			
Transport Equipment	$ 155		
Transport Pipelines	1,325		
Electrical Equipment	425		
Excavations and Site Preparation	45		
Pond Construction	1,919		
Site Reclamation	256		
Total Process Capital		$4,125	
General Facilities Capital		738	
Engineering and Home Office Fees		619	
Project Contingency		1,031	
Process Contingency		206	
Total Plant Investment (TPI)			$6,719
Royalty Allowance			206
Preproduction Costs			171
Inventory Capital			5
Initial Catalyst and Chemicals			0
AFDC			262
Land			533
TOTAL CAPITAL REQUIREMENT (TCR)			$7,897

*Base Case: New coal-fired base load plant, midwest location, 30-year design life, mid-1980 operation date, 168,175 dry tons fly ash produced at the 70 percent first year Capacity Factor, 48.5 percent average life time Capacity Factor, one mile to disposal site.

Table 9-7

LEVELIZED ANNUAL REVENUE REQUIREMENT
SLUICING TO POND - 500 MW BASE CASE

Fixed Operating and Maintenance Costs	Estimated Cost in Thousands of Dollars	
Operating Labor	$172	
Maintenance Labor	58	
Maintenance Materials	87	
Administrative and Support Labor	69	
Total Fixed O&M Cost (FOM)		$ 387
Variable Operating and Maintenance Costs		
Consumables		
Operating Electricity	$ 56	
Variable Maintenance	0	
Total Variable O&M Cost (VOM)		56
Byproduct Credit		0
Total First Year Operating Cost (FYOC)		$ 443

Levelized Operating Cost	LOC = 1.886 x $443	= $ 835
Levelized Capital Requirement	LCR = 0.18 x $7,897	= 1,421
LEVELIZED ANNUAL REVENUE REQUIREMENT (LARR)		$2,257

Unit Costs: $\frac{\$2,256,800}{168,175 \text{ dry tons}} = \$13.42/\text{dry ton}$ ($14.80/dry metric ton)

$$\frac{\$2,256,800 \times 100 \text{ mills/dollar}}{3.066 \times 10^{9} \text{ kWh}} = 0.736 \text{ mills/kWh}$$

Table 9-8

TOTAL CAPITAL REQUIREMENT
TRUCKING TO LANDFILL - 500 MW BASE CASE*

Plant Investment	Estimated Capital in Thousands of Dollars	
Process Capital		
Excavation and Site Preparation	$59	
Total Process Capital	$ 59	
General Facilities Capital	25	
Engineering and Home Office Fees	135	
Project Contingency	15	
Process Contingency	3	
Total Plant Investment (TPI)		$237
Royalty Allowance		3
Preproduction Costs		41
Inventory Capital		30
Initial Catalyst and Chemicals		0
AFDC		9
Land		202
Total Capital Requirement (TCR)		$522

*Base Case: New coal-fired base load plant, midwest location, 30-year design life, mid-1980 operation date, 168,175 dry tons fly ash produced at the 70 percent first year Capacity Factor, 48.5 percent average lifetime Capacity Factor, one mile to disposal site.

Table 9-9

LEVELIZED ANNUAL REVENUE REQUIREMENT
TRUCKING TO LANDFILL - 500 MW BASE CASE

Fixed Operating and Maintenance Costs	Estimated Cost in Thousands of Dollars	
Operating Labor	$ 61	
Maintenance Labor	1	
Maintenance Materials	1	
Administrative and Support Labor	19	
Total Fixed O&M Costs (FOM)		$ 82
Variable Operating and Maintenance Costs		
Consumables		
Site Preparation	$ 29	
Hauling	88	
Placement and Compaction	231	
Site Reclamation	10	
Variable Maintenance	0	
Total Variable O&M Costs (VOM)		358
Byproduct Credit		0
Total First Year Operating Cost (FYOC)		$440

Levelized Operating Cost	LOC = 1.886 x $440	= $831
Levelized Capital Requirement	LCR = 0.18 x $522	= 94
LEVELIZED ANNUAL REVENUE REQUIREMENT (LARR)		$925

Unit Costs: $\frac{\$924,600}{168,175 \text{ dry tons}} = \$5.50/\text{dry ton}$ ($6.05/dry metric ton)

$$\frac{\$924,600 \times 1,000 \text{ mills/dollar}}{3.066 \times 10^{9}} = 0.302 \text{ mills/kWh}$$

The number of acres required for disposal can be determined for the landfill depth (50 feet) and compacted density (80 pounds per cubic foot) to be one acre for each 87,100 tons of ash disposal.

5. Pond Construction. Detailed estimates by TVA (4) and the results from a computer model study (17) indicate that cost per acre for a disposal pond, when built at its optimum geometry, is relatively 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, excluding the land cost. For the given assumptions (25 foot pond depth and 60 pounds per cubic foot settled ash dry density) one acre of pond area is required for each 32,700 tons of ash which must be disposed of.

6. Site Reclamation. The site reclamation costs for wet disposal are assumed to be incurred at the end of 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). The present worth factor for 30 years is given in Table 9-1 as 0.3291 so the present worth of the site reclamation cost ($7400/acre) is approximately $2400/acre. The site reclamation costs for dry disposal are assumed to be incurred uniformly during the life of the site and are therefore charged as an operating expense.

General Facilities Capital. The off-site facilities included under this item were assumed to cost about 1-1/2 percent of the Process Capital excluding the pond construction cost (4). The additional expense resulting from construction was estimated (in millions of dollars) from the following formula (4):

$$\text{Construction Expense} = 0.25 \times (PC - P)^{0.83} + 0.13 \times (P)^{0.83}$$

where:

PC = the Process Capital excluding the pond construction cost (millions of dollars)

P = the pond construction cost (millions of dollars)

The sum of these items make up the General Facilities Capital.

Engineering and Home Office Fees. These costs were taken as 15 percent of the Process Capital. For the dry disposal estimates, these fees were

estimated as 15 percent of the total site development cost rather than only the first year cost reflected in the Process Capital total. This more realistically estimates the level of engineering effort which is required.

Project Contingency. A contingency of 25 percent of the Process and General Facilities Capital was included because these estimates were made for general site and plant conditions (Class I as defined by Table 9-2).

Process Contingency. A contingency of 5 percent of the Process Capital was included since the technology for ash disposal is fairly well developed (see Table 9-3).

Royalty Allowance. An allowance of 0.5 percent of the Process Capital is made for prepaid royalty items (2).

Preproduction Costs. This cost was estimated as the sum of 1/12 (one month) of the estimated First Year Operating Cost and 2 percent of the Total Plant Investment.

Inventory Capital. The estimated cost for 1/12 (one month) of the Variable Cost item labeled "Consumables" is included as Inventory Capital.

Initial Catalyst and Chemicals. This item does not apply to the disposal alternatives considered.

Allowance for Funds During Construction. The center of gravity (cg) for construction expenditures has been assumed to be 1/2 year. Therefore:

$$AFDC = [(1.08)^{0.5} - 1] \times (TPI) = 0.039 \times (TPI)$$

Land Aquisition. A cost of $5,000 per developed acre is assumed in accordance with Reference (2). The land requirements, discussed above, are one acre per 87,100 tons (79,000 metric tons) of ash for dry disposal and one acre per 32,700 tons (29,600 metric tons) of ash for wet disposal.

The First Year Operating Costs for the two 500 MW base case examples which are presented in Tables 9-7 and 9-9, are described below.

Fixed 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 at least two people are required full time for operation and supervision 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.

The recommended labor rate of $12.50/hr for mid-1978 (2) was adjusted to $14.05/hr to reflect the mid-1980 operation date using the 6 percent inflation rate.

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).

Variable Operating and Maintenance Costs.

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 a price of $0.030/kWh. The operating contracts for dry disposal were estimated using References 8, 9, 10, and 14. The site preparation costs are estimated to be $21,600/acre which amounts to about $720/acre each year during the 30-year life of the site. The hauling unit price varies with the transport distance while the placement and compaction unit price was estimated at $1.60/dry ton ($1.48/compacted c.y.). 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. 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.

Variable Maintenance. Since there is no basis for estimating variable maintenance costs, none were assigned.

Byproduct Credit. The net revenue from the sale of byproducts has been assumed to be zero.

30-Year Levelized Costs

The First Year Operating Costs (FYOC) should be levelized using the 30-year levelization factor which was computed for the assumptions discussed earlier (1.886) 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. A fixed charge rate of 18 percent/year is appropriate. Thus:

Levelized Operating Cost, LOC = 1.886 x FYOC
Levelized Capital Requirement, LCR = 0.18 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, mills/kWh, and dollars/dry-ton of ash disposed. These calculations are shown on Tables 9-7 and 9-9 for the base case disposal system examples.

Simplified Cost Curves

The simplified cost estimating procedure utilizes a series of curves to quickly obtain an estimate. Variables which have a significant impact on the overall

costs are given below with the range of values considered.

1. Sluicing to pond.

   --Plant size is 200 to 1500MW.

   --Percent of ash in coal is 12 to 20 percent.

   --Distance to pond is 1 to 10 miles (1.6 to 16 kilometers).

   --Availability of land is 50 to 100 percent of optimum. Land availability and topography may limit the pond to less than its optimum size. One hundred percent optimum represents enough land to construct the pond at its minimum cost. The combination of excavation costs, dike construction costs, and land purchases is minimized at 100 percent optimum.

2. Trucking to landfill.

   --Plant size is 200 to 1500 MW.

   --Percent of ash in coal is 12 percent to 20 percent.

   --Distance to disposal site is 1 to 10 miles (1.6 to 16 kilometers).

The Total Capital Requirement (TCR) and Levelized Annual Revenue Requirement (LARR) for the base system are first determined from Figures 9-1 and 9-2, respectively. Figures 9-3 through 9-5 are then used to determine correction factors to be applied to the TCR and LARR for distance and for optimum land availability. The corrected costs are obtained by multiplying the base costs by these correction factors. Table 9-10 shows which figure should be used to obtain the appropriate costs and correction factors.

Table 9-10

FIGURES TO OBTAIN CORRECTION FACTORS
FOR SIMPLIFIED COST ESTIMATES

Correction Factors For	Sluicing to Pond		Trucking to Landfill	
	TCR	LARR	TCR	LARR
Transport Distance	9-3	9-4	9-3	9-4
Land Availability	9-5	9-5	-	-

TCR = Total Capital Requirement
LARR = Levelized Annual Revenue Requirement

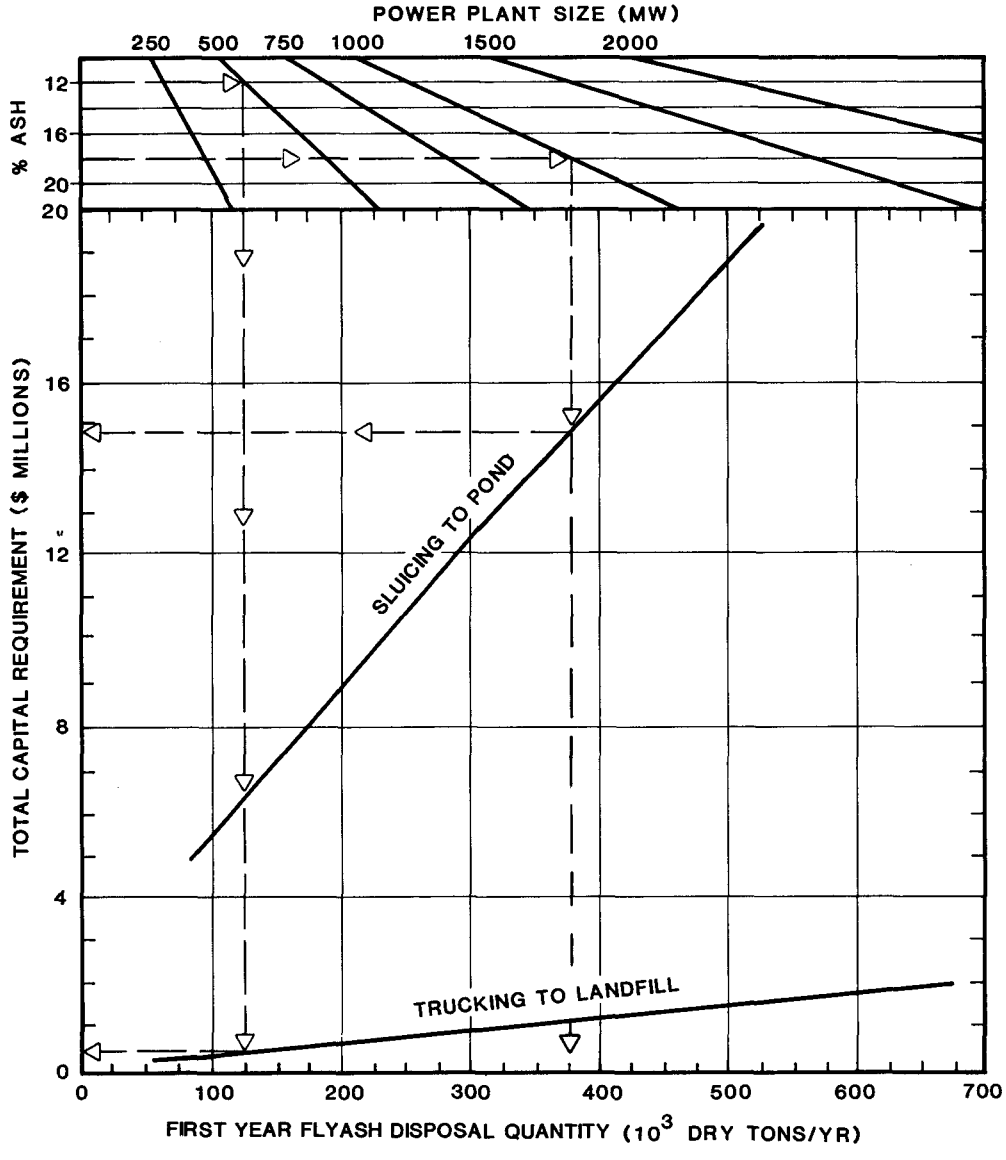

Figure 9-1. Total capital requirement vs first year fly ash disposal quantity.

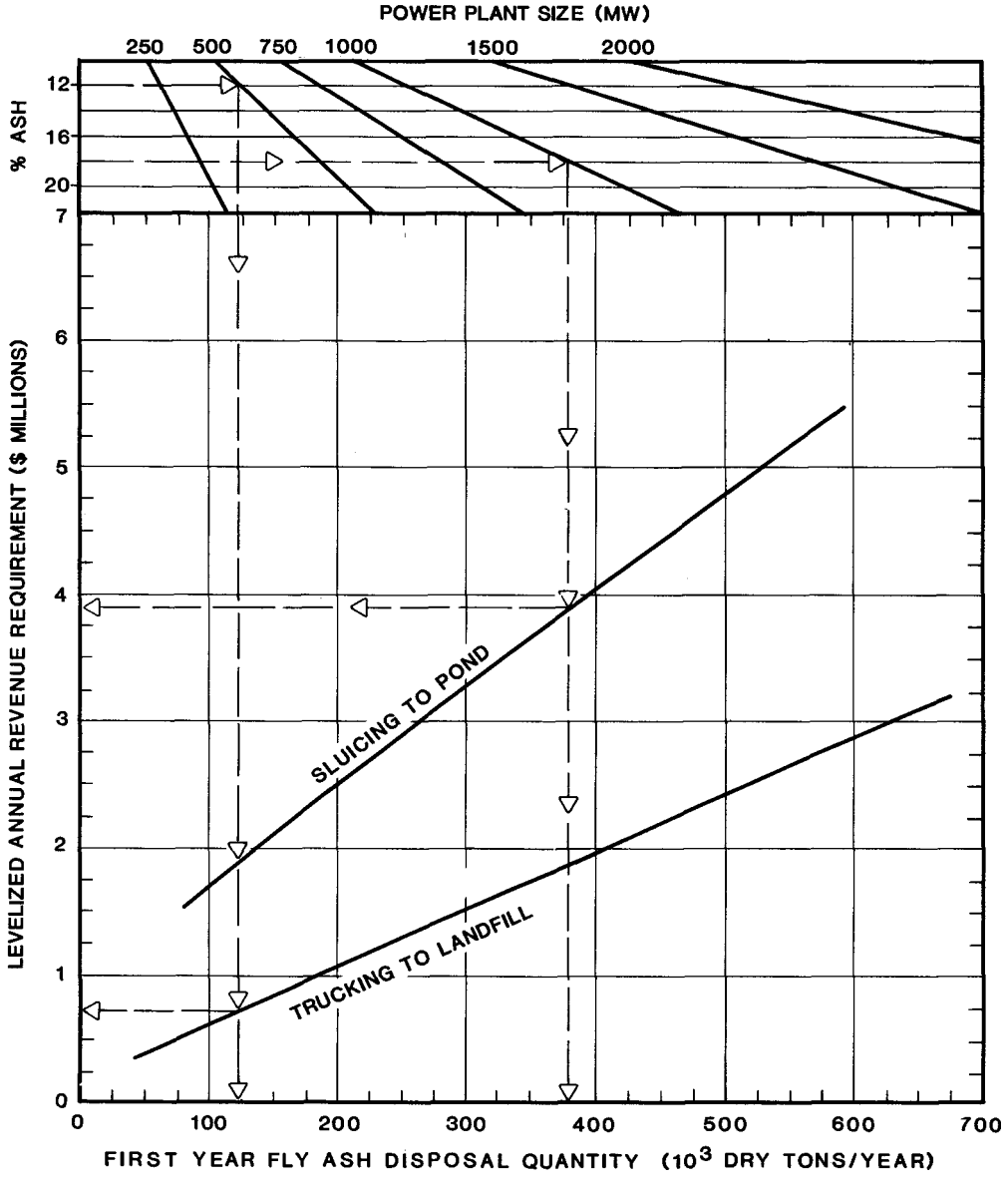

Figure 9-2. Levelized annual revenue requirement vs first year fly ash disposal quantity.

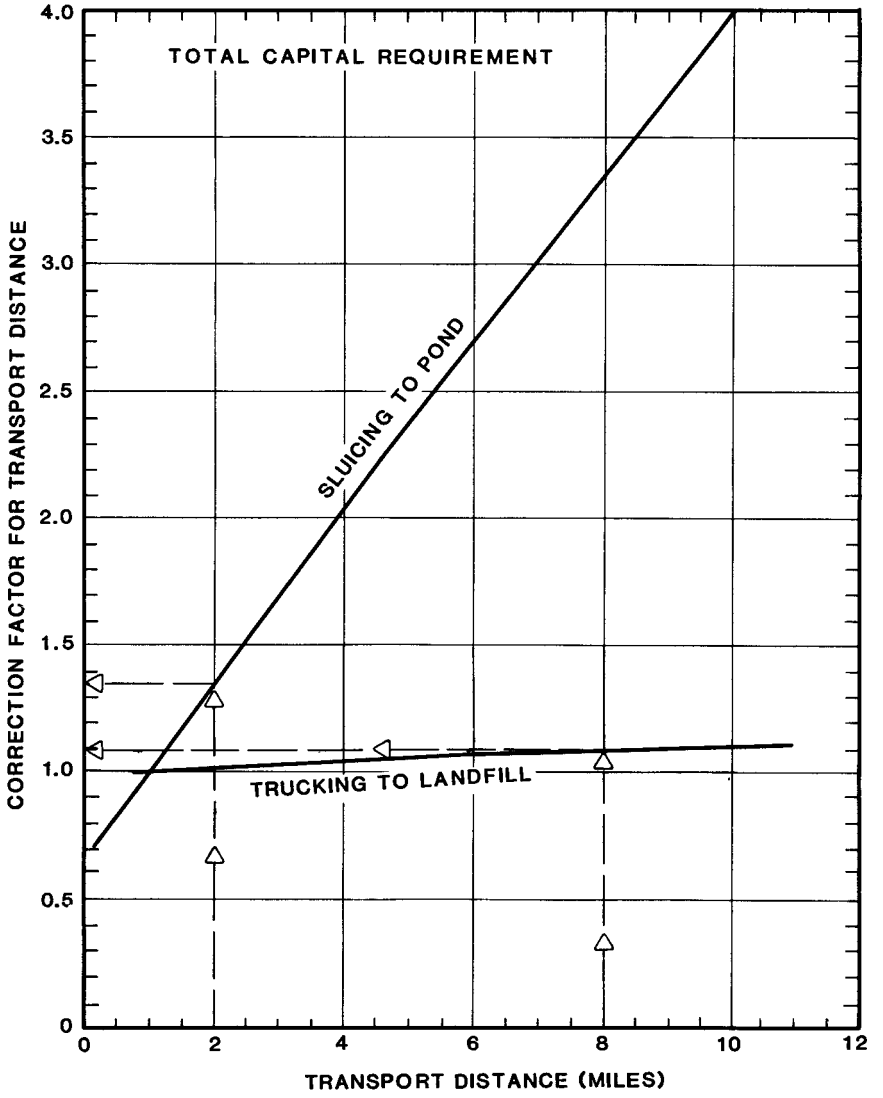

Figure 9-3. Total capital requirement correction factors for transport distance.

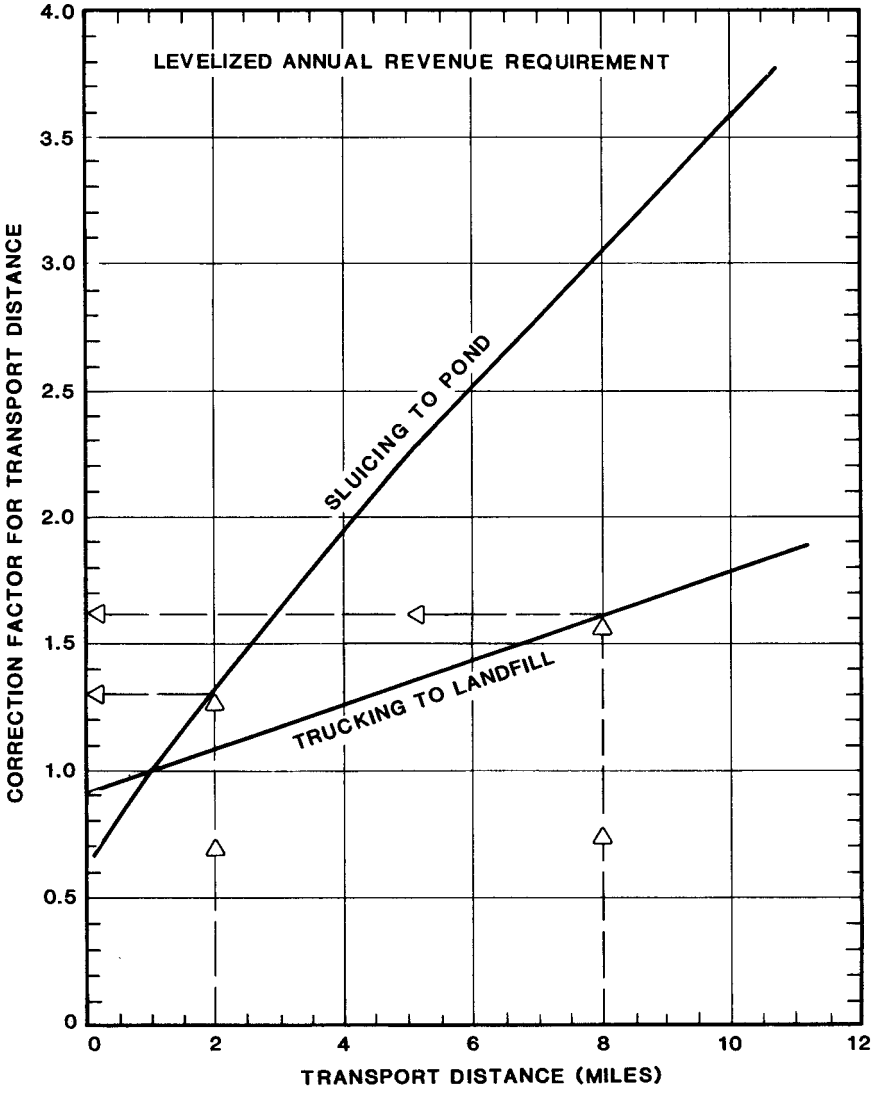

Figure 9-4. Levelized annual revenue requirement correction factors for transport distance.

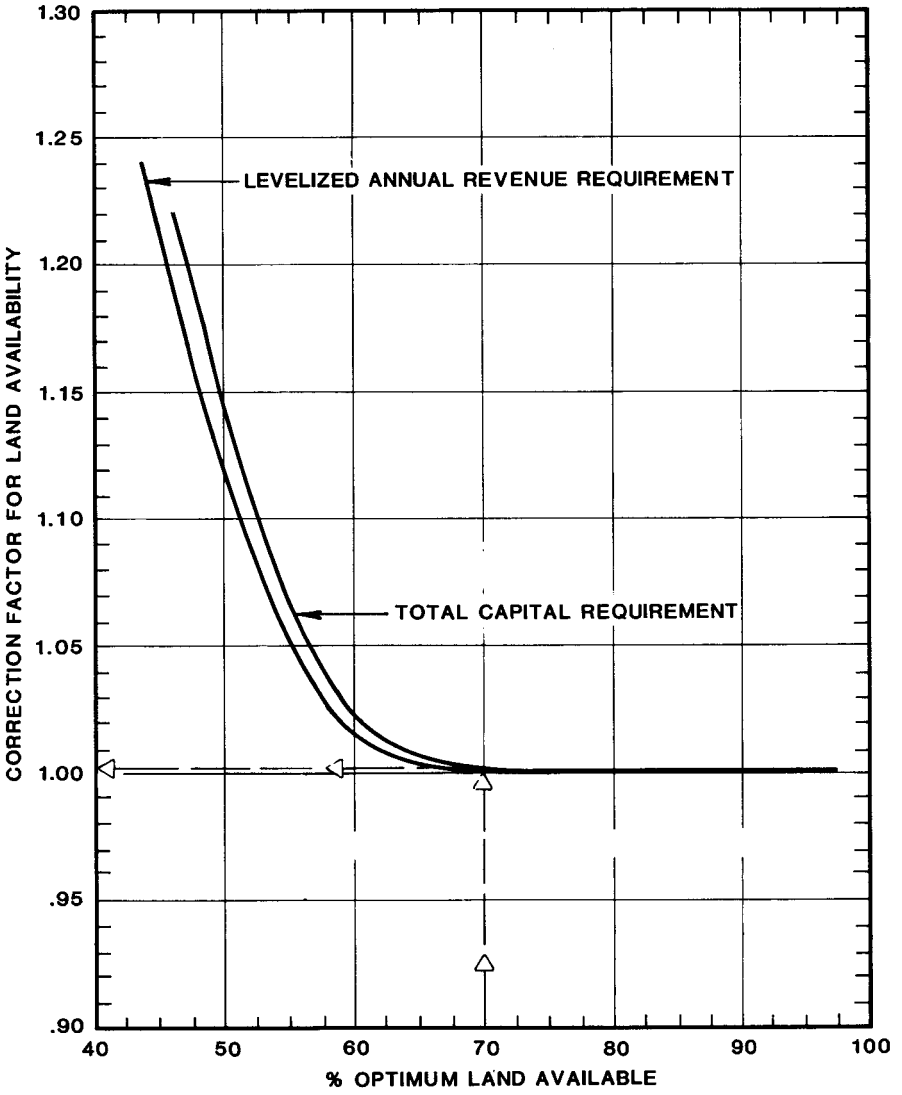

Figure 9-5. Total capital requirement and levelized annual revenue requirement correction factors for land availability.

Figures 9-1 and 9-2 plot the TCR and LARR versus the first year fly ash disposal quantity. As mentioned earlier, this quantity is dependent on many parameters. For the base case systems with the assumptions previously stated, the fly ash disposal quantity is directly related to the plant size and the percent ash in the coal burned. Therefore, the scale presented at the top of each figure allows the direct determination of costs when given the plant size and the percent ash in the coal. The diagonal lines represent a given plant size, while the horizontal lines correspond to a particular percent ash in the coal. To determine the base TCR or LARR from these curves, enter the figure at the percent ash and locate its intersection with the line representing the appropriate plant size (interpolation may be required). From the intersection of these lines, move vertically down to the appropriate cost curve and then horizontally to the dollar value.

Naturally, if the quantity of fly ash to be disposed of is known or calculated using the methods described in Section 5 of this manual, the First Year Fly Ash Disposal Quantity scales at the bottom of Figures 9-1 and 9-2 may be used. The following two examples illustrate the use of the simplified method. They are not, however, intended to be typical cases or to be used to compare wet and dry disposal alternatives. Comparison of alternatives should be made for the site and plant parameters which are appropriate.

Sluicing to Pond Example. The problem is to determine the TCR, the LARR, and the cost per dry ton of fly ash disposed of by sluicing to a pond.

1. Basic Parameters.

   --Plant Size is 1000 MW.

   --Percent of ash in coal is 18 percent.

   --Distance to pond is two miles (3.2 kilometers).

   --Land Availability is 70 percent.

2. Base Case Costs. The base costs are read directly from Figures 9-1 and 9-2. Note that the example has been highlighted on each of the figures. Enter the figure in the upper scale at 18 percent ash and move across to the 1000 MW line. Next drop vertically to the curve labeled "sluicing to pond". The total cost (millions of dollars) can be read from the scale at the left.

   --Figure 9-1 Total Capital Requirement = $14,800,000

   --Figure 9-2 Levelized Annual Revenue Requirement = $3,860,000

3. Correction Factors.

	Total Capital Requirement	Levelized Annual Revenue Requirement
--Transport Distance - Figure 9-3	1.34	
Figure 9-4		1.32
--Land Availability - Figure 9-5	1.002	1.000

4. Corrected Costs:

--TCR = Base Cost x Correction Factors

= $14,800,000 x (1.34) x (1.002)

= $19,872,000

--LARR = Base Cost x Correction Factors

= $3,860,000 x (1.32) x (1.000)

= $5,095,000

5. Cost Per Ton. The quantity of fly ash that is produced during the first year of operation by the system which has been estimated can be determined from Figure 9-2. Following the vertical line used earlier from the top scale to the lower scale of Figure 9-2, the fly ash quantity can be read directly.

First year fly ash disposal quantity = 378,000 dry tons/year.
(343,000 dry metric tons/year)

$$\text{Cost/dry ton} = \frac{\text{Levelized Annual Revenue Requirement}}{\text{dry tons/year}}$$

$$= \frac{\$7,095,000}{378,000} = \$13.48/\text{dry ton } (\$14.85/\text{dry metric ton})^*$$

Trucking to Landfill Example. The problem is to determine the TCR, the LARR, and the cost per dry ton of fly ash disposed of by trucking to a landfill.

1. Basic Parameters.

--Plant Size is 500 MW.

--Percent of ash in coal is 12 percent.

--Distance to site is 8 miles (12.8 kilometers).

*Remember that the first year ash disposal volume is based on a load factor of 70 percent while the 30-year storage volume requirement is based on a 48.5 percent load factor.

2. Base Case Costs. Using the procedure described in the previous example, the base case costs are determined from Figures 9-1 and 9-2. Note that this example is also highlighted on these figures.

   --Figure 9-1 Total Capital Requirement = $4,000,000

   --Figure 9-2 Levelized Annual Revenue Requirement = $730,000

3. Correction Factors.

	Total Capital Requirement	Levelized Annual Revenue Requirement
--Transport Distance - Figure 9-3	1.09	
Figure 9-4		1.62

4. Corrected Costs.

   --TCR = Base Cost x Correction Factor

   = $400,000 x (1.09)

   = $436,000

   --LARR = Base Cost x Correction Factor

   = $730,000 x (1.62)

   = $1,183,000

5. Cost Per Ton. The quantity of fly ash that is produced during the first year of operation by the system which has been estimated can be determined from Figure 9-2. Following the vertical line used earlier for base case costs down to the bottom scale, the quantity of fly ash can be read directly.

   First year fly ash disposal quantity = 125,000 dry tons/year. (113,000 dry metric tons/year)

$$\text{Cost/dry ton} = \frac{\text{Levelized Annual Revenue Requirement}}{\text{dry tons/year}}$$

$$= \frac{\$1,183,000}{125,000}$$

   = $9.46/dry ton ($10.47/dry metric ton)

These five steps can be used to quickly obtain Class I cost estimates for many disposal systems. These estimates are useful for comparison of alternatives, but should not be substituted for higher level estimates as the system design progresses.

Simplified Cost Curve Capital Adjustments

In some cases, actual capital costs may vary significantly from those assumed in the base case. The curves presented in Figures 9-1 and 9-2 can also be used to generate simplified cost estimates for cases with site specific capital costs. Capital costs which may be corrected are excavation and site preparation, pond construction, site reclamation and land.

In order to adjust the cost estimates, obtained from Figures 9-1 and 9-2 the following procedure is used:

1. Calculate the Total Capital Requirement (TCR) and the Levelized Annual Revenue Requirement (LARR) with the appropriate correction factors.

2. Calculate the capital cost differential due to the site specific capital cost.

3. Adjust the capital cost differential to account for additional capital costs dependent upon the change. An adjustment factor of 1.85 should be applied to excavation and site preparation, pond construction and site reclamation cost changes. A factor of 1.0 should be applied to land cost changes.

4. Multiply the adjusted capital cost differential by the Fixed Charge Rate (Table 9-1) to levelize it.

5. Add (subtract) the levelized adjusted capital cost differential to the Levelized Annual Revenue Requirement.

This procedure is illustrated in the following two examples. The costs determined for Site 3 - Wet of the case study presented in Section 1 are adjusted for the significant difference between capital costs for dam construction in a valley and diked pond construction on flat land. The second example demonstrates the adjustment of costs for Site 3 to account for land costs incurred as a result of the extra acreage which had to be purchased since the owner did not want to subdivide his land.

Example 1 Adjustment to Process Capital Cost. The problem is to adjust the LARR and unit cost of ash disposal to reflect the reduced capital costs which result from construction of a dam in a valley rather than the diked pond construction which is assumed for the simplified cost curves.

1. Corrected TCR and LARR. Site 3 is located approximately 2-1/2 miles (4 kilometers) from the plant.

Base Costs: TCR = $5,200,000 (Figure 9-1)

LARR = $1,600,000 (Figure 9-2)

Corrections for Distance: TCR = 1.51 (Figure 9-3)

LARR = 1.48 (Figure 9-4)

Corrected Costs: TCR = $5,200,000 x 1.51 = $7,852,000

LARR = $1,600,000 x 1.48 = $2,368,000

2. Capital Cost Differential (CCD). The capital cost for construction of a dam in a valley may be in the neighborhood of 1/3 the cost for dike construction on flat land. The simplified cost curves assume that the dike construction costs are $18,000/acre. Since it has been assumed that wet disposal accomodates approximately 32,700 tons/acre of pond, the 2,226,000 tons of ash which must be disposed of at Site 3 of the case study require 68.1 acres. Therefore, the diked pond construction cost, P is:

   P = $18,000/acre x 68.1 acres = $1,226,000

   Assuming that dam construction costs, D, are 1/3 the diked pond cost the capital cost differential, CCD, is calculated:

   CCD = D - P = ($1,226,000/3) - $1,226,000 = -$817,000

3. Adjusted Capital Cost Differential. The CCD adjustment is taken as 1.85.

   Adjusted CCD = 1.85 x (-$817,000) = -$1,511,000

4. Levelized Adjusted Capital Cost Differential. The fixed charge rate from Table 9-1 is 0.18. Therefore:
   Levilized Adjusted CCD = 0.18 x (-$1,511,000) = -$272,000.

5. Adjusted LARR. Adding the levelized adjusted CCD to the corrected LARR gives the adjusted LARR.

   Adjusted LARR = $2,368,000 - $272,000 = $2,096,000

   The unit cost for first year disposal of 91,800 tons of ash is:

$$\frac{\$2,096,000}{91,800 \text{ tons}} = \$22.82/\text{dry ton} \ (\$25.10/\text{dry metric ton})$$

Example 2 - Adjustment to Land Cost. The problem is to adjust the LARR and unit cost of ash disposal to reflect the additional capital cost due to the extra land which must be purchased to obtain the disposal acres.

1. Corrected TCR and LARR. The corected costs, computed in Example 1 are:

   TCR = $7,852,000

   LARR = $2,368,000

2. Capital Cost Differential (CCD). The ash disposal land requirement was calculated to be 68.1 acres. The tract of land in which Site 3 of the case study is located is approximately 780 acres. Since land costs are assumed to be $5,000/acre, the CCD is the difference in computed land costs:

   Cost for 68.1 acres = 68.1 acres x $5,000/acre = $340,000

   Cost for 740 acres = 740 acres x $5,000/acre = $3,900,000

   CCD = $3,900,000 -$340,000 = $3,560,000

   Note that an actual cost for the purchase of a tract of land could be used for this computation rather than the cost at $5,000/acre.

3. Adjusted Capital Cost Differential. No adjustment is made for costs which are not part of TPI.

4. Levelized Adjusted Capital Cost Differential. The Fixed Charge Rate from Table 9-1 is 0.18. Therefore:

   Levelized Adjusted CCD = 0.18 x $3,560,000 = $641,000

5. Adjusted LARR. Using LARR Calculated in Example 1:

   Adjusted LARR = $2,368,000 + $641,000 = $3,009,000

   The unit cost for first year disposal of 91,800 tons of ash is:

   $$\frac{\$3,009,000}{91,800 \text{ tons}} = \$32.78/\text{dry ton } (\$36.06/\text{dry metric ton})$$

CLASS II, III and IV COST ESTIMATES

The preparation of Class II, III and IV cost estimates will be necessary to properly evaluate the several disposal alternatives which, on the basis of simplified cost estimates and the various other non-economic considerations, 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 9-2 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 (7)" 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. 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 fly ash disposal requirement. This value depends on 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 fly ash collection and handling. The collection and handling system must be known to insure a compatible disposal alternative. The estimates described in this manual are limited to transportation and disposal of the ash.

Step 2. Establish the Disposal System

Table 9-2 outlines the design information required and the cost estimating basis for Class II, III and IV designs. For example, in order 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 were described earlier in this section. The Detailed Cost Estimate should be prepared in this standard format, an outline of which is given in Table 9-5.

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 have been discussed in detail. The format given in Table 9-5 should be used for presenting these costs.

Step 5. Determine the Levelized Annual Revenue Requirement

The Levelized Annual Revenue Requirement (LARR) is the sum 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, while the LOC is determined by multiplying the First Year Operating Costs (FYOC) by a levelization factor. For the economic assumptions described in this section, the 30-year Fixed Charge Rate is 18 percent per year and the corresponding 30-year levelization factor for operating costs is 1.866. Thus, as shown in Table 9-5:

$$\text{Levelized Capital Requirement (LCR)} = (0.18) \times \text{TCR}$$
$$\text{Levelized Operating Costs (LOC)} = (1.886) \times \text{FYOC}$$

By adding these two levelized annual costs, the Levelized Annual Revenue Requirement is established. Although the LARR is an annual cost ($/year), it is often informative to express the cost as mills/kilowatt-hour or dollars/dry-ton of fly ash. These unit revenue requirements are determined by dividing the LARR by the annual production (kWh and dry tons of fly ash, respectively). Naturally the former must be multiplied by 1000 mills/$ to obtain the correct units.

SUMMARY

The cost estimating procedures presented in this section are appropriate for investor-owned, regulated utilities. Different accounting systems will probably result in different calculated disposal costs and may even alter the relative costs of alternatives considered. Therefore, disposal estimates to be prepared for other than investor-owned, regulated utilities must be altered to reflect any differences in the accounting systems.

The simplified cost estimating curves are 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 9-2 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 9-5 so that it can readily be compared with other estimates.

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