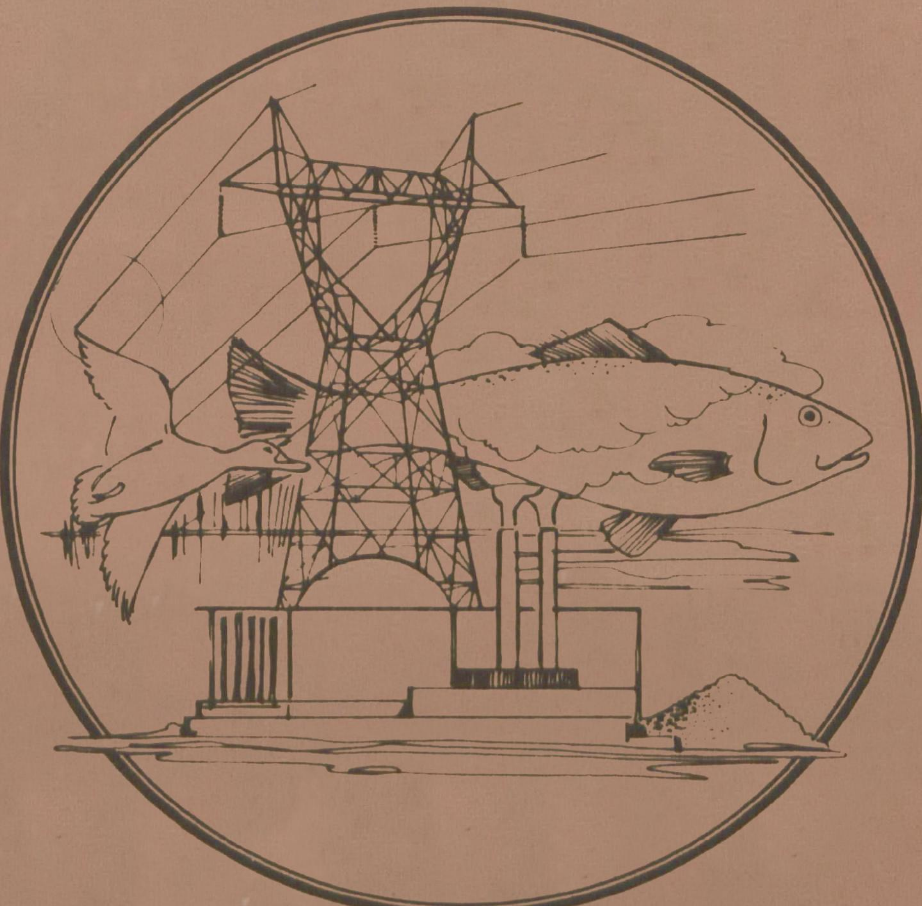
Biological Services Program

FWS/OBS-81/05
AUGUST 1981

Coal Combustion Waste Manual: Evaluating Impacts to Fish and Wildlife



Office of Research and Development
U.S. Environmental Protection Agency

Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; mineral development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; environmental contaminants; National Wetland Inventory; habitat classification and evaluation; inventory and data management systems; and information management.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for development of information and technology by contracting with States, universities, consulting firms, and others; Regional Teams, which provide local expertise and are an important link between the National Teams and the problems at the operating level; and staff at certain Fish and Wildlife Service research facilities, who conduct inhouse research studies.

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

EASTERN ENERGY AND LAND USE TEAM
Route 3, Box 44
Kearneysville, West Virginia 25430

September 25, 1981

Dear Colleague:

The Eastern Energy and Land Use Team, Office of Biological Services, is pleased to provide you with a copy of the enclosed publication. This report is intended to assist the biologist, planner, manager, and public in making decisions affecting the Nation's fish and wildlife resources.

The goal of this manual is to provide quantitative guidelines, where possible, for evaluating the potential extent of habitat disturbances from waste constitutent dispersal. Criteria are also provided for evaluating the potential for impact from trace elements in the waste.

This manual is designed to be used in conjunction with the technical report entitled "Handling of Combustion and Emission-Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources" (FWS/OBS-80/33 9/30/81).

We are interested in your thoughts and comments concerning this publication and the kinds of information materials you would like to see the Team produce in the future. We invite you to write us at your convenience.

Sincerely,

Edgar A. Pash

Edgar A. Pash, Team Leader
Eastern Energy and Land Use Team

Enclosure

FWS/OBS-81/05
August 1981

COAL COMBUSTION WASTE MANUAL: EVALUATING IMPACTS TO FISH AND WILDLIFE

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Preface

The National Power Plant Team of the U. S. Fish and Wildlife Service, and Argonne National Laboratory cooperated in producing this manual to provide the reader with tools for evaluating specific situations which may be encountered in reviewing plans for the handling and storage of coal combustion wastes.

The manual is designed to be used with the technical report "Handling of Combustion and Emission - Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources," FWS/OBS-80/33. The technical report provides more detailed information on the nature of wastes and their potential impacts to fish and wildlife resources. This manual is cross-referenced to the technical report by the bracketed numbers in the right-hand margins of the manual. The numbers refer to pages of the technical report relevant to the manual topics.

On April 3, 1981, the National Power Plant Team was transferred to the Eastern Energy and Land Use Team (EELUT) and renamed the National Power Development Group. Requests for information should be directed to:

Information Transfer Specialist
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Acknowledgements

The authors are grateful for the guidance and support of the National Power Plant Team, U.S. Fish and Wildlife Service. Dr. James Bennett and Dr. R. Kent Schreiber of the Team provided many useful comments and ideas. The authors also appreciate the helpful reviews by personnel of the Fish and Wildlife Service regional offices and the U.S. Soil Conservation Service. Dr. Lee Martin of BlueBird Enterprises, Fresno, California, provided useful background information on discouraging wildlife from using impoundments.

Mr. William Hallett, Dr. Bernard Jaroslow, Dr. Elizabeth Stull, and Dr. Jack Zapotosky from the Division of Environmental Impact Studies, Argonne National Laboratory, and Dr. Barbara-Ann Lewis of Northwestern University provided helpful reviews of early drafts of the manual. Ms. Alice Packard of the Division of Environmental Impact Studies provided able technical information support.

Introduction

Increased use of coal in the generation of electricity has become national policy. With the anticipated accelerated use of coal as an energy source, a concomitant increase can be expected in the potential for impacts to fish and wildlife resources. Current new source performance standards promulgated by the U.S. Environmental Protection Agency (USEPA) require restriction of atmospheric emissions at virtually all coal-fired electric generating stations. However, disposition of both the pollutants extracted from flue gases and the reagents used in the extraction process poses a problem that has only recently received much attention.

Personnel of the U.S. Fish and Wildlife Service are responsible for assessing the impact of these flue-gas control wastes upon the nation's fish and wildlife resources. These responsibilities are met through consultation with other agencies and through review of environmental assessment documents. The goal of this manual is to provide quantitative guidelines, where possible, for evaluating the potential extent of habitat disturbance and waste constituent dispersal. Criteria are also provided for evaluating the potential for impact from trace elements in the waste. Much impact assessment will be of a qualitative nature because of the innate imprecision of both the input data and the assessment tools. Evaluating the significance of coal combustion wastes to fish and wildlife resources will require the biologist to rely heavily on his or her own expertise in assessing the nature of fish and wildlife populations and their interactions with their habitat.

This manual is designed to be used in conjunction with the technical report entitled "Handling of Combustion and Emission-Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources" (FWS/OBS-80/33). The technical report provides more detailed information on the nature of the wastes and their potential impacts to fish and wildlife resources. The manual is cross-referenced to the report (FWS/OBS-80/33) by the bracketed numbers in the right-hand margin of the manual pages. These numbers refer to the pages in the report relevant to the topics discussed in the manual.

The scope of this manual is restricted to the combustion and emission-abatement waste-handling systems and the impacts of wastes upon fish and wildlife resources. Discussion has been limited to the period following collection of the wastes, and the mechanisms for extracting flue-gas pollutants have not been described in detail. However, the reader may find descriptions of flue-gas control systems in other documents, including "Air Pollution. Vol. IV, Engineering Control of Air Pollution," edited by Stern (1976). For general background information about the operation of a coal-fired electric generating facility, the reader is referred to "Impacts of Coal-Fired Power Plants on Fish, Wildlife, and Their Habitats" (FWS/OBS-78/29).

The waste stream from a coal-fired electric generating station contains a number of materials that are potentially harmful to fish and wildlife resources. These materials can include flue-gas-desulfurization (FGD) sludges, collected fly ash, and boiler ash residue or aggregate (Figure 1). The FGD sludges are derived from flue-gas sulfur removal systems (scrubbers) and contain varying proportions of sulfates, sulfites, scrubbing reagent (currently lime and limestone are most commonly used), and trace elements derived primarily from ash impinged by the scrubber sludge. Fly ash is that portion of coal ash which passes up the flue with the combustion gases; it is commonly removed from the flue gases by means of electrostatic precipitators, bag houses, or wet scrubbers. Aggregate consists of ash that has not been entrained by the flue gases; it may occur as slag, in which the ash has melted and fused into a solid mass, or simply as particulate bottom ash. The ashes contain a variety of trace elements, some of which may be toxic to fish and wildlife resources.

This manual provides the reader with tools that can be used for evaluating specific situations which may be encountered in reviewing plans for the handling and storage of coal combustion wastes. The approach taken is outlined in Figure 2. The first chapter presents criteria for evaluating the suitability of a site as a locale for a waste-storage facility. The next two chapters contain a brief description of waste-handling options and the regulatory context for the handling of coal combustion wastes. Impacts from waste-handling systems are divided into two aspects: (1) disturbance of habitat and (2) release of potentially toxic materials to the environment. Techniques are presented for estimating the magnitude of these two aspects and for evaluating their impacts upon fish and wildlife resources. To help the reader learn how this manual can be used, data for four model 2100-MWe electric generating stations are presented as examples.

The International System of Units (SI) is used in this manual with a few exceptions (e.g., Btu/lb). Definitions and conversion factors (Appendix A) follow the "Standard for Metric Practice" of the American Society for Testing and Materials (1976). A glossary of technical terms and acronyms is provided in Appendix B.

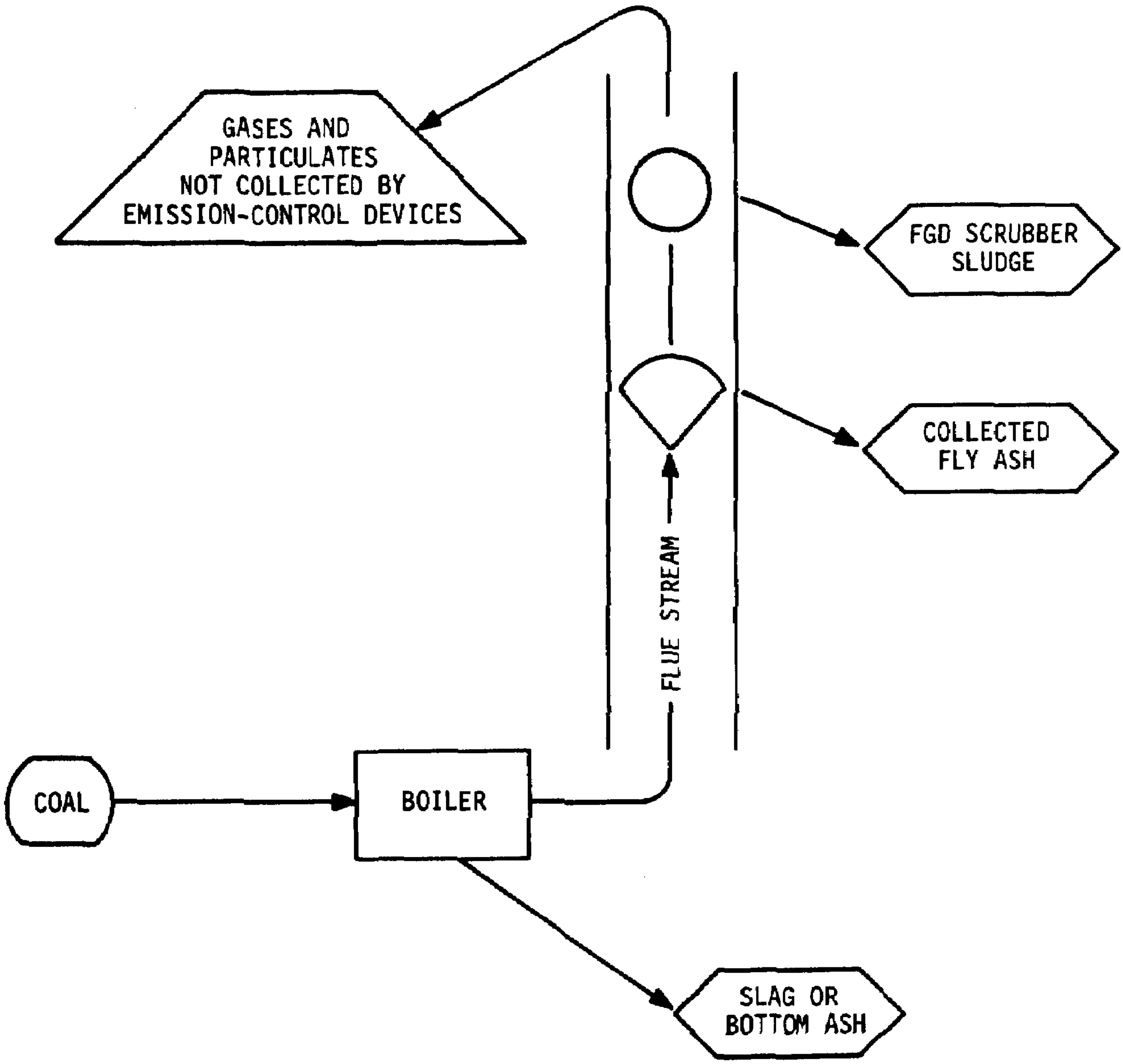


Figure 1. Schematic Representation of Production of Coal Combustion and Emission-Abatement Wastes.

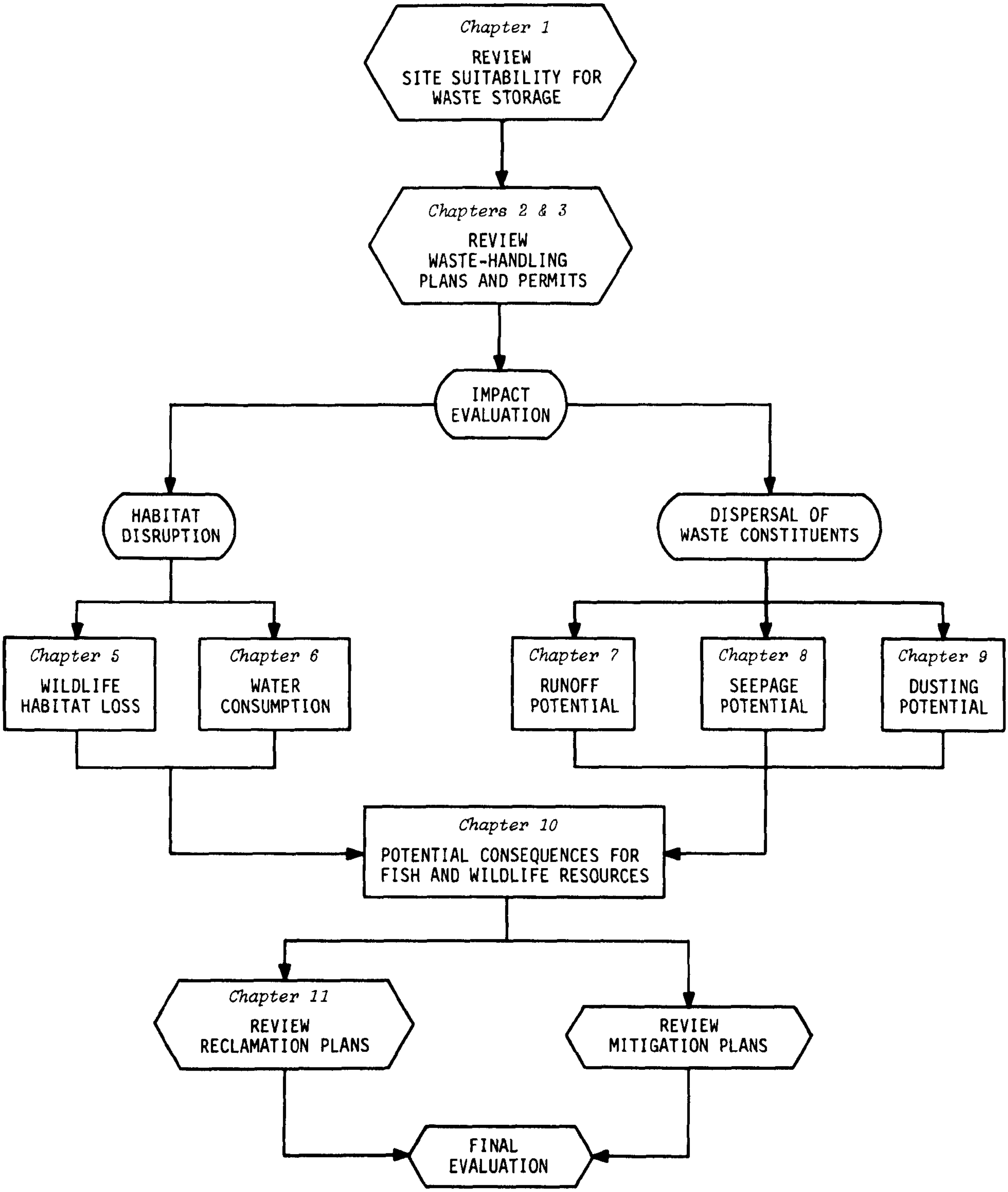
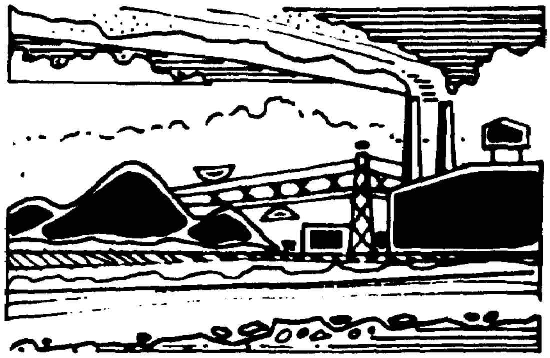


Figure 2. An Outline of the Evaluation of a Coal Ash and FGD Sludge Waste-Handling Plan.



Chapter 1
Siting Considerations

INTRODUCTION [98-100]

In reviewing plans for locating a waste-handling facility, the biologist must consider those nonbiological factors that determine the ability of the waste-management operation to contain and/or immobilize the wastes. This involves consideration of many individual factors, the relative importance of which varies among sites. The factors (evaluation criteria) that may influence the selection of a storage site can be divided into environmental and nonenvironmental categories (Figure 3). Evaluation criteria are interdependent and, thus, fish or wildlife biologists must keep all factors in mind, although their primary responsibilities center upon the environmental factors.

Additionally, the biologist must recognize that the ecological factors are closely tied to the other environmental siting criteria. For example, a site located in a geologically hazardous area (e.g., floodplain) could pose a threat to fish and wildlife resources should there be catastrophic release of waste materials.

Selection of a proper site can be a major factor in the mitigation of impacts from a waste-storage facility.

ENVIRONMENTAL CRITERIA [98]

Most of the environmental criteria are not directly related to fish and wildlife resources, but they do affect the future use of a site and the capability of a site to support a waste facility without adverse impacts to the environment. The following questions should be considered in evaluating the potential for environmental impacts from the siting of a waste-handling facility. These questions are not definitive but are a sample of the questions that may be asked. Proper siting of the facility is an important factor in mitigating impacts from a waste operation. Impacts can be lessened by siting facilities in areas that are not ecologically sensitive or in areas where the release of the wastes is unlikely.

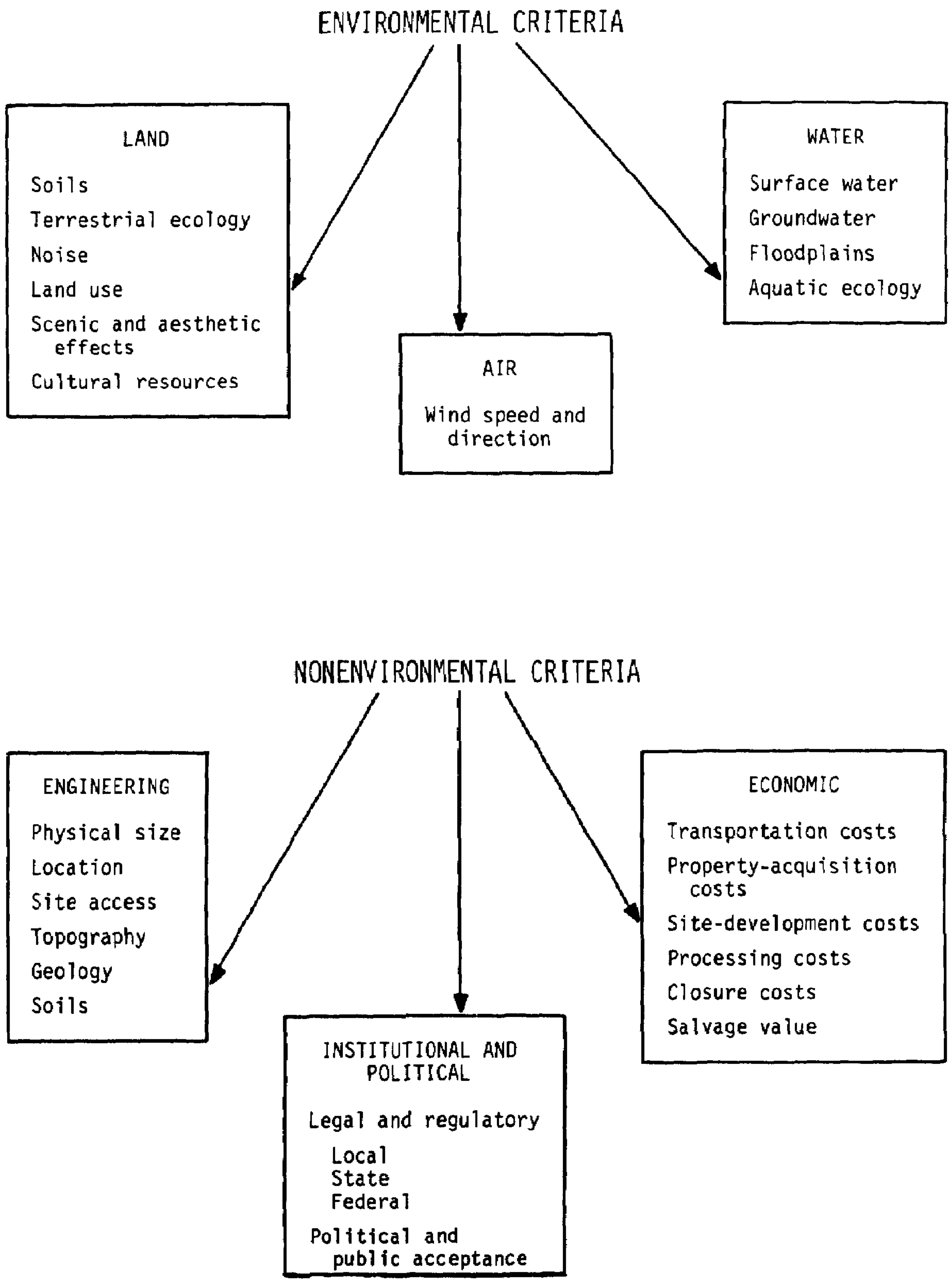


Figure 3. Evaluation Criteria for Selection of Waste-Storage Sites.

Land

- Does the site contain important or unique agricultural soils?
- Are the soils of the site suitable for supporting a waste-storage facility with minimal dispersal of waste constituents?
- Does the area around the site contain unique or sensitive terrestrial habitats?
- Does terrestrial habitat on the site support populations of rare, endangered, or commercially valuable species?
- Is terrestrial habitat at the site of high quality or is it the best quality of that habitat in the region?
- Will wildlife use of the area around the site be affected by noise generated during waste-handling operations?
- Does current land use of the area around the site conflict with use of the site as a waste-storage facility?
- Can the site be restored to its current land use after closure of the waste-handling operation?
- Will storage facilities on the site cause scenic or aesthetic effects such as visible intrusion into the scenic view?
- Will a waste-storage operation disturb cultural resources such as unique archeological, historical, or paleontological areas?
- Can these cultural resources be studied prior to construction of a storage facility?

Air (Wind Speed and Direction)

- Is the site susceptible to wind erosion and resulting fugitive dust from the stored waste?
- Could downwind habitat be affected by fugitive dust?

Water

- Can surface waters safely accept discharges from the site while maintaining adequate water quality?
- Is sufficient surface water available to support consumptive uses of waste handling without degradation of surface water biota?
- Will construction of a storage facility result in diversion of surface water flows?

- Will new impoundments attract wildlife, possibly delaying migrating waterfowl or resulting in toxic effects to wildlife?

- Is the underlying groundwater susceptible to contamination from the waste-storage site?

- Will the site comply with USEPA guidelines for maintaining a minimum distance of 150 m between storage sites and groundwater supplies?

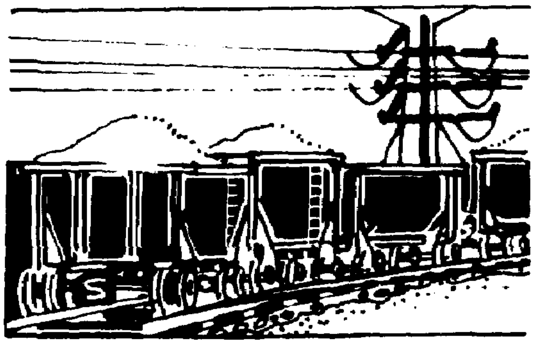
- Is the water table more than 1.5 m below the storage area?

- Is the site located in the 100-year floodplain and/or coastal zone?

- Will the facilities or practices at the storage site restrict the flow of the 100-year flood, reduce the temporary water storage capacity of the floodplain, or result in washout of solid waste?

- Will use of the site for waste storage alter or destroy unique aquatic habitat, e.g., wetlands?

- Is there potential for detrimental effects to populations of rare, endangered, or commercially valuable aquatic species?



Chapter 2
Handling Wastes

Handling of coal ash and flue-gas-desulfurization (FGD) wastes for ultimate disposal involves three steps: processing, transport, and storage. As shown in Figure 4, the combinations of methods used may vary widely and the choice is a function of the characteristics of the waste, method of storage, land availability, cost, and potential for environmental disturbance.

PROCESSING [29-31]

Coal ash processing is usually unnecessary but may be appropriate for some waste-handling methods. For example, water must be added to the ash for pond storage and slurry pipeline transport. The ash may also be blended with FGD sludge to act as a sludge stabilizer.

For convenient handling, processing of FGD sludge is necessary because its thixotropic nature (i.e., it tends to become fluid when disturbed) makes sludge difficult to handle. As a result, the sludge must be stabilized, or fixed, so that it does not flow prior to disposal. The available stabilization methods are dewatering, underdraining impoundments, chemical fixation, and forced oxidation. A comparison of these methods is given in Table 1.

Dewatering [29-30]

Dewatering reduces the moisture content of the ash or FGD sludge slurry and, thus, the land area requirements for waste storage. Water removed from the sludge during dewatering may be recycled to the scrubber, resulting in decreased consumptive water use. Water removal also results in reduced potential for seepage of soluble trace elements into the surrounding environment. Pond settling and thickening are used almost universally to concentrate sludge or slurry solids. Chemical dewatering aids may be added to the sludge to cluster colloidal suspensions, allowing them to settle out of suspension. Following primary dewatering by one of the steps discussed above, the FGD sludge may undergo secondary dewatering by vacuum filtration or centrifugation.

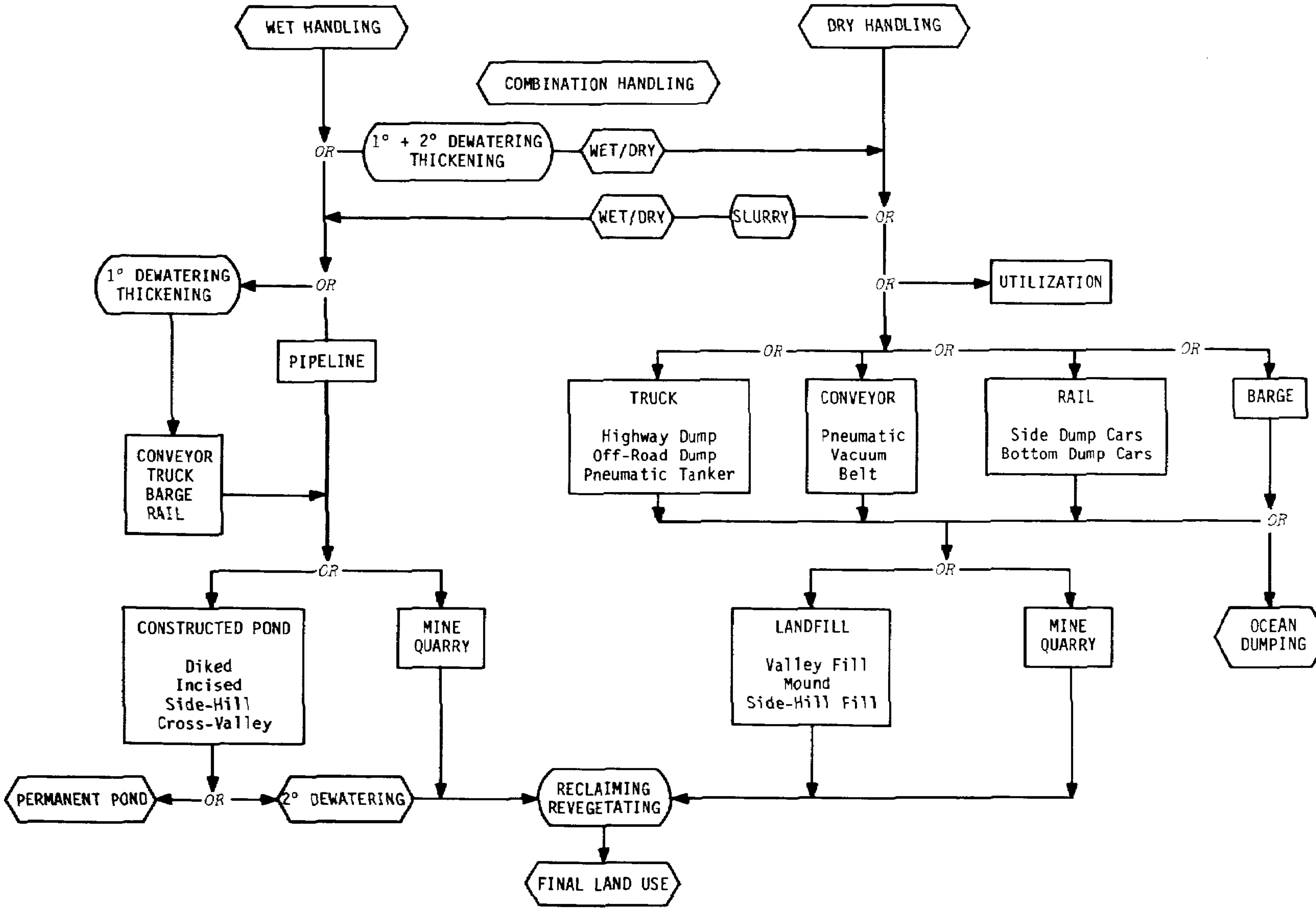


Figure 4. Potential Waste-Handling Schemes for Coal Ash and FGD Sludge. Modified from GAI Consultants (1979).

Table 1. Comparison of FGD Scrubber Sludge Stabilization Methods[a]

	Dewatering				Underdraining impoundment	Chemical fixation	Forced oxidation
	Settling pond	Thickener	Vacuum filter	Centrifuge			
Sensitivity to flow variations and solids content	Low	High	High	Medium	Low	Low	Low
Maintenance required	Low	Medium	High	High	Low	Medium	High
Land commitments for process	High	Low	Low	Low	High	Low	Low
Energy requirements	Low	Medium	High	High	Low	Medium	Medium
Percent reduction in sludge volume	10 to 90%	10 to 93%	10 to 77%[b]	10 to 75%[b]	n.a.[c]	n.a.	n.a.
Seepage potential	High	Low to high	Low	Low	Low	Low	Low
Ease of sludge removal	Low	High	High	High	n.a.	High	High

[a]Based on personal communication and data from U.S. Environmental Protection Agency (1980b), Metcalf & Eddy (1972), and Fair et al. (1966-1968).
[b]Percent reduction following primary dewatering.
[c]n.a. = not applicable because water is not withdrawn from the waste.

Underdrained Impoundments [30]

Underdrained impoundments contain a drainage bed in the floor of the impoundment. The drainage bed collects seepage, which is removed and may be reused as makeup water in the scrubber. This method allows the pond to be used as an acceptable landfill because collection of the seepage greatly reduces infiltration of waste constituents into the soil and groundwater. However, pond liners may be required where soils are highly permeable or where there is a high water table.

Chemical Fixation [30-31]

Chemical fixation involves treatment of the FGD sludge with chemical additives or coal ash, resulting in a solidified waste that can be handled much more readily than the original sludge. The permeability of the waste is decreased, and the amount of material leached from the waste is reduced. However, the addition of ash to FGD sludge results in higher concentrations of potentially mobile elements than are found in the sludge alone.

Forced Oxidation [30]

Forced oxidation involves forcing air through the sludge, thereby accelerating the oxidation of calcium sulfite to calcium sulfate. Calcium sulfate sludge has a higher solids settling rate, is easily dewatered, and is less thixotropic than calcium sulfite. Calcium sulfate may also be marketable, lessening the need for long-term storage. In addition, forced oxidation reduces the potential for sulfite contamination of the environment.

TRANSPORT

There are five methods that can be used for transportation of wastes to disposal sites: belt conveyors, rail, barge, truck, and pipeline. The design and selection of an ash or scrubber sludge transport system depends primarily on whether the transported material is handled as solids (dry) or as a slurry (wet).

Belt Conveyors

Belt conveyors are limited to disposal of dry wastes. They may be used for transport of dewatered FGD sludge as well as ash. Short conveyors have a high degree of flexibility and can be moved to different locations, whereas long conveyors (several hundred meters or more) are usually permanent installations. Impacts from this mode of transport would be localized because conveyors are not used for long distance (several kilometers) hauling.

Rail

Rail can be used to transport dry ash and fixed sludge. Dry ash disposal using conventional side-dumping or bottom-dumping cars has been shown to be effective. However, there are problems in handling wet sludge, and specially designed cars have not yet been developed. It is possible to use existing commercial rail-haul routes or to haul on tracks and rights-of-way controlled by the utility. Hauling by commercial routes is not economically competitive at distances less than 80 km. Fugitive dust in transit could be a problem and might require that the cars be covered or that dust-suppressant sprays be used.

Barge

Barge transport may accommodate wet or dry sludges and has high system reliability and very low unit costs. However, it does not promise wide applicability because of limited transport routes and required special loading and unloading facilities. Except for ocean disposal, barging alone would not get the wastes to the disposal site.

Truck

Truck transport may be used for wet or dry ash and sludge hauling, but is preferred for dry hauling. Trucking is the most flexible and most widely used mode of dry ash and sludge transportation. A principal disadvantage of truck transport is high public visibility. The quantity of materials produced at a fully operational station require a nearly continuous flow of truck traffic in and out of the station site. Fugitive dusting problems from open trucks can require the use of dust-control measures.

Pipelines

Pipelines are used to transport wet ash and sludge slurries for distances up to 15 km. A typical pipeline transport facility consists of a single pumping station, although more than one may be required for long distances or uphill traverses. Two full-size pipelines are often required--one pipeline for transporting the slurry to the storage site, the other for returning supernatant to the station. Conventional pumping and piping materials are generally suitable if the pH is near neutral, but the abrasive character of the sludge and ash may lead to pipeline failure resulting from erosion.

STORAGE [31-37]

There are two basic types of storage for coal ash and FGD sludge wastes: wet (ponding) and dry (landfilling). Two other options are deposition of the wastes in mines or in the ocean. A comparison of these methods is given in Table 2.

Wet Storage

The four wet storage pond configurations used most often are the diked pond, incised pond, side-hill pond, and cross-valley pond. The following illustrations (Figures 5 through 8) are reproduced from Duvel et al. (1979). The arrows in the illustrations indicate the position and direction of view for the cross section of each configuration.

Table 2. Comparative Summary of Waste Storage/Disposal Options[a]

	Wet storage	Dry storage	Mine disposal	Ocean disposal
Method	Ponding of waste	Landfilling of waste	Backfilling mines with waste	Depositing waste in the ocean
Applicability	Most wastes and handling systems except double alkali	Dry or fixed waste	Mainly dry or fixed wastes	Dry or fixed wastes
Advantages	Simple	Low land requirement	Sites available	No new land preempted
	Versatile	No impoundment required	No new land pre-empted	
	Low traffic potential	Low seepage potential	Aids in mine stability	
	Low dust potential	Reclamation practicable		
		No attraction for biota		
Disadvantages	High land requirement	Sludge fixation required	High leaching potential	Limited to coastal areas
	Impoundment construction	High dust potential	Potential for acid mine drainage synergisms	May be legally unacceptable
	High potential for seepage	High traffic potential	May require that mine be dewatered	
	Sludge instability	Requires diversion of runoff	Plant must be near mine site	
	Reclamation uncertain	May require further processing of waste		
	Liners may be required			
	Ponds may attract biota			

[a]Sources: Frascino and Vail (1976), Ansari et al. (1979), and Duvel et al. (1979).

The diked pond is the most common pond in use, requires a nearly level site, and is contained within a perimeter embankment or dike.

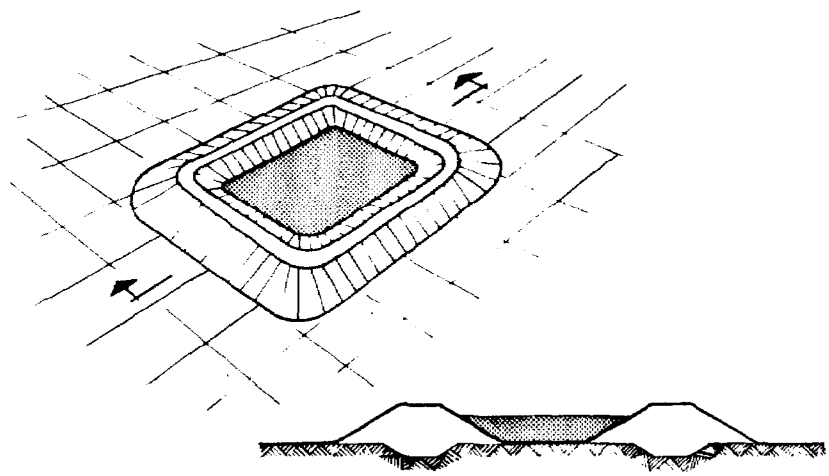


Figure 5. Diked Pond Constructed Above-Grade.

An incised pond is contained in an excavation below the existing grade and is most appropriate for use where the bedrock and water table are deep. The incised pond is preferable where space is limited for dikes or where excavated materials are unsuitable for dike construction.

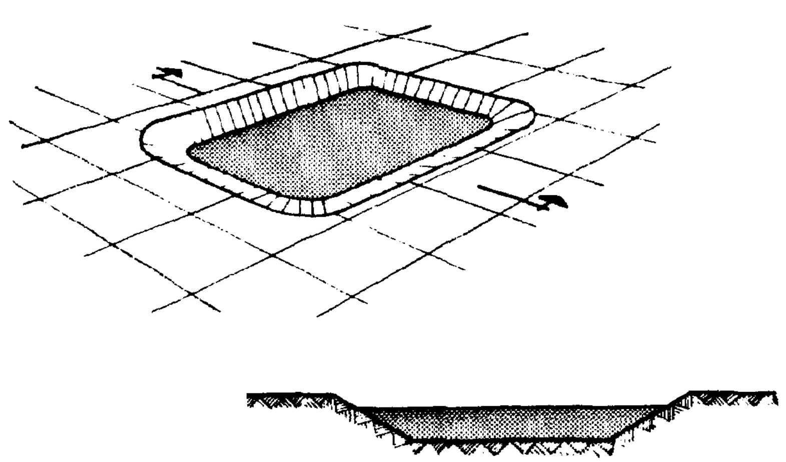


Figure 6. An Incised Storage Pond.

The side-hill pond takes advantage of local hilly terrain to provide one or two sides of an impoundment. However, it may be difficult to safely construct a large side-hill pond on steeply sloping sides.

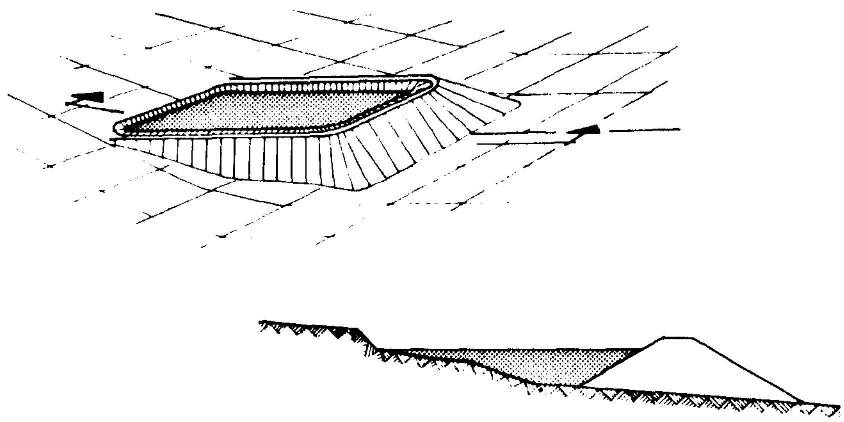


Figure 7. A Side-Hill Storage Pond.

A cross-valley pond is formed by constructing a dam across a portion of a natural valley between the valley walls. The design is critical because, in addition to waste storage, it must provide for controlled storage and discharge of the natural water flow in the valley.

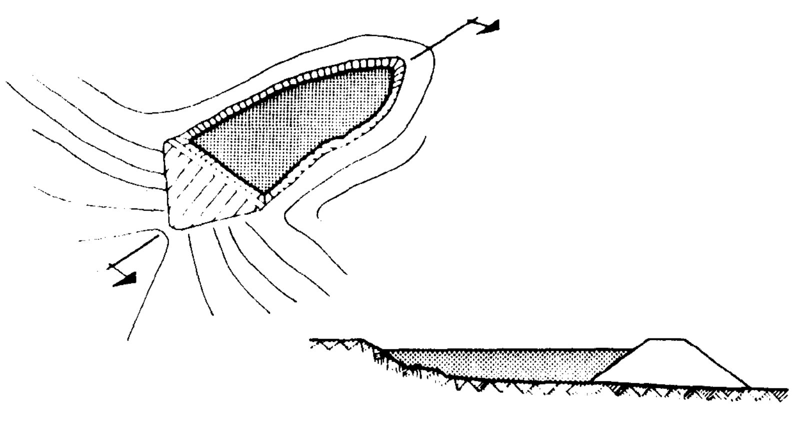


Figure 8. A Cross-Valley Pond Configuration.

Dry Storage

Dry storage, or landfilling, of sludge requires blending of dry material (e.g., ash) with sludge to aid in reducing the moisture content. Dry storage usually requires construction of facilities to divert runoff from landfill areas. The following illustrations of landfill configurations (Figures 9 through 11) are reproduced from Duvel et al. (1979). The arrows in the illustrations indicate the position and direction of view for the cross section of each configuration.

The heaped fill is the simplest landfill configuration and is typically used in areas with level terrain. Groundwater pollution, slope stability, and site preparation problems are minimal when the site is properly managed. However, the landfill has a high visibility.

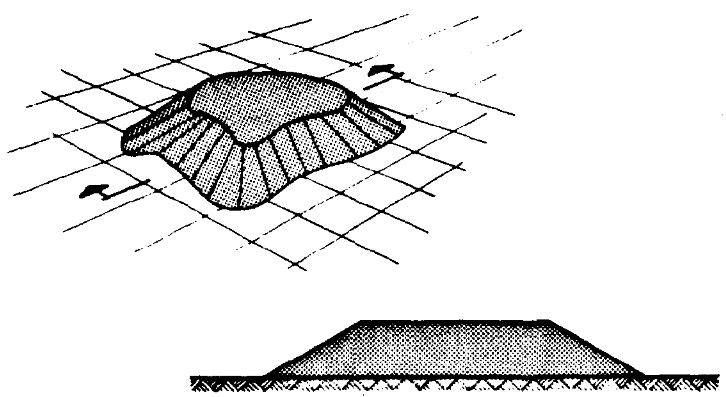


Figure 9. A Heaped Landfill Configuration.

The side-hill construction is often used in hilly or gently sloping terrain. Properly constructed, side-hill landfills may blend well with the existing terrain.

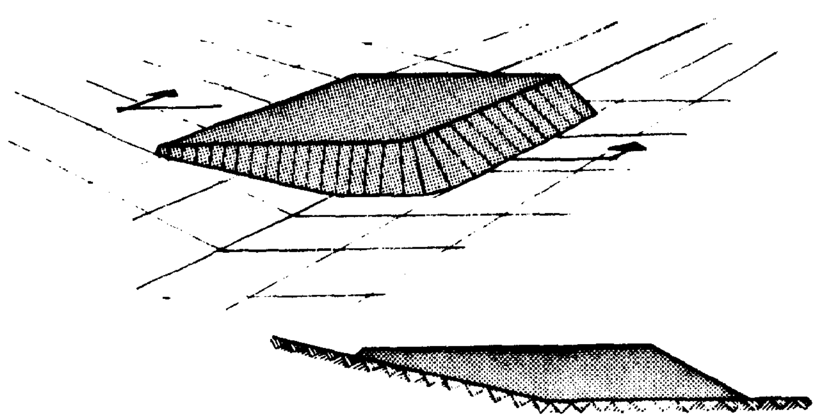


Figure 10. A Side-Hill Landfill Configuration.

The valley-fill is the most common type of landfill in areas of hilly terrain. Control of surface water and groundwater is necessary since valleys are natural avenues of surface runoff and, in some cases, of springs along side slopes.

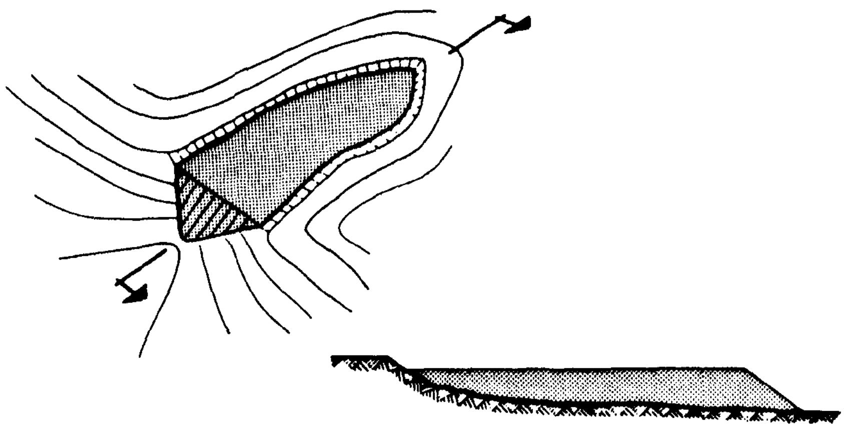


Figure 11. A Valley-Fill Storage Configuration.

Mine Disposal

Mine disposal of coal ash has been practiced at a number of mines, but no full-scale operation of FGD sludge disposal in surface or deep mines has been developed. Mine disposal has a potential for impacts on groundwater or surface waters by dispersal of soluble materials from wastes deposited in the mines. Mine disposal of coal ash or FGD sludge may be dependent on guidelines for the use of toxic materials as backfill in both surface and deep mines (30 CFR 816.103, 817.103).*

Ocean Disposal

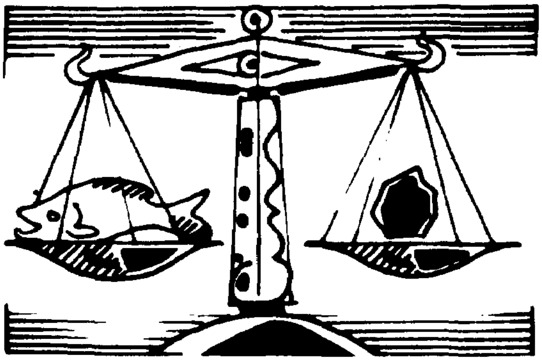
Ocean disposal of waste sludge may be an available alternative for some coastal utilities. However, ocean dumping is being discouraged by government agencies. Certain compounds contained in waste sludge may not be disposed of in the ocean. These toxic pollutants are listed in 40 CFR 401, and control of these pollutants would be required if an ocean dumping permit were granted. Because of potential sulfite toxicity effects, ocean disposal is not applicable to untreated, sulfite-rich FGD sludges.

*Title 30, Code of Federal Regulations (CFR), Sections 816.103 and 817.103. Such citations are usually abbreviated as indicated.

UTILIZATION OF COAL ASH AND FGD SLUDGE [37-39]

Coal ash can be recycled for such uses as cement additive, fill material for road construction sites, stabilizer in pavement, and filler in asphalt mix. Ash utilization is also under study for agricultural and land reclamation applications, water treatment, grouting mixes, and fire abatement in landfills or coal mine refuse piles. Currently, less than 25% of the coal ash being produced is recycled.

The prospects for large-scale utilization of FGD sludge are minimal. On a small scale, it appears feasible to use sludge as a soil additive to improve soil porosity or nutrient enrichment, for blending with coal ash in landfill and surface reclamation, as fill in pavement, as liners in waste ponds, and as a source of gypsum.



Chapter 3
Standards and Criteria

IMPLICATIONS FOR FISH AND WILDLIFE RESOURCES [97]

The U.S. Congress has passed statutes regulating solid waste handling in order to protect human health and the environment from deleterious effects of hazardous solid wastes. Implicit in protection of the environment is protection of the nation's fish and wildlife resources. The primary thrust of the regulations, promulgated and proposed, is to contain toxic wastes in the storage area. In general, this should lead to a reduction in the amounts of hazardous material reaching areas where they might affect fish and wildlife resources. The regulations do not, however, require recovery of wildlife habitat that may be preempted by the waste-storage facility, nor do they ensure that wildlife will not use potentially toxic drinking waters in impoundments.

An outline of the federal statutes as they pertain to various aspects of the waste-handling process is presented in Table 3. The three major federal laws affecting coal ash and FGD wastes are the Clean Air Act, Resources Conservation and Reclamation Act (RCRA), and Clean Water Act. In addition to federal regulations, local and state regulations will also place constraints upon the manner in which ash and sludges wastes may be handled.

CLEAN AIR ACT [97]

The Clean Air Act (Public Law 90-148, as amended) was passed in response to increasing concern for maintaining air quality at a level compatible with human health and environmental integrity. This act has a direct impact upon the amount of disposable waste produced because, under regulations promulgated in response to the act, coal-fired generating stations must employ emissions-control technology. Thus, most of the particulates (fly ash) and sulfur compounds must be removed from the flue-gas stream, thereby producing the bulk of the solid wastes to be handled by the utility. For coal-fired steam electric generating plants, the standards (40 CFR 60) presented in Table 4 must be met.

Table 3. Federal Statutes That May Affect the Handling and Release of Coal Ash and FGD Sludge Wastes[a]

Affected process/legislation	Administrative authority	Permits required
PRODUCTION		
Clean Air Act of 1973 and Amendments of 1977	Environmental Protection Agency	Prevention of Significant Deterioration (PSD); New Source Review
HANDLING		
Resource Conservation and Recovery Act of 1976	Environmental Protection Agency	Hazardous Waste
Dam Safety Act of 1972	Army Corps of Engineers	Not applicable
Surface Mining Control and Reclamation Act of 1977	Office of Surface Mining, Reclamation and Enforcement	Not applicable
Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration	Not applicable
Federal Coal Mine Health and Safety Act of 1969	Mining Enforcement Safety Administration	Not applicable
AERIAL RELEASES		
Clean Air Act of 1973 and Amendments of 1977	Environmental Protection Agency	Not applicable
Hazardous Materials Transportation Act of 1969	Department of Transportation	Not applicable
Federal Coal Mine Health and Safety Act of 1969	Mining Enforcement Safety Administration	Not applicable
Occupational Safety and Health Act of 1970	Occupational Safety and Health Administration	Not applicable
GROUNDWATER CONTAMINATION		
Resource Conservation and Recovery Act of 1976	Environmental Protection Agency	Hazardous Waste
Safe Drinking Water Act of 1974	Environmental Protection Agency	Underground Injection
SURFACE WATER CONTAMINATION		
Clean Water Act of 1977	Environmental Protection Agency	National Pollutant Discharge Elimination System; Dredge and Fill
Resource Conservation and Recovery Act of 1976	Environmental Protection Agency	Hazardous Waste
MARINE WATER CONTAMINATION		
Clean Water Act of 1977	Environmental Protection Agency	National Pollutant Discharge Elimination System
Resource Conservation and Recovery Act of 1976	Environmental Protection Agency	Hazardous Waste
Marine Protection Research and Sanctuaries Act of 1972	Environmental Protection Agency	Ocean Dumping

[a]Data from GAI Consultants (1979).

CLEAN WATER ACT [97]

The Federal Water Pollution Control Act (Public Law 92-500) as amended by the Clean Water Act has an established goal of eliminating the discharge of pollutants into the nation's water bodies. The act has expressly declared

Table 4. New Source Performance Standards for Coal-Fired Steam Electric Generating Plants

Emissions product	Plant built: Between 12 August 1971 and 18 September 1978	Plant built: After 18 September 1978
Particulates	≦ 43 ng/J (0.10 lb/Btu)	≦ 13 ng/J (0.03 lb/Btu) and ≦ 1% of potential combustion concentration
SO_2	≦ 520 ng/J (1.2 lb/Btu)	≦ 520 ng/J (1.2 lb/Btu) and ≦ 10% of potential combustion concentration or 260 ng/J (0.6 lb/Btu) with a maximum release of 30% of potential combustion concentration
NO_2	≦ 300 ng/J (0.7 lb/Btu)	≦ 210 ng/J (0.5 lb/Btu)

Source: 40 CFR 60.

that regulations be promulgated so as to protect the biota of freshwater and marine systems. Under the authority of this act, the U.S. Environmental Protection Agency (USEPA) has issued standards for discharges from coal ash and FGD sludge waters. Current effluent standards for discharges from steam electric generating stations are presented in Table 5. For new sources, there may be no discharge that contains suspended solids from fly ash transport waters. Unless the operator of a waste-handling site can show extenuating circumstances, runoff from waste-storage sites cannot contain in excess of 50 mg suspended solids per liter of water. These effluent standards may be changed in the near future.

RESOURCE CONSERVATION AND RECOVERY ACT [93-96]

The Resource Conservation and Recovery Act (Public Law 94-580) has a major impact upon the handling of coal ash and FGD sludges as solid waste. This act is intended to prohibit open, uncontrolled dumping and promote waste-handling techniques that will reduce adverse effects to health and environment. The USEPA (1979a, 1979b, 1980a) has promulgated standards and criteria for carrying out these goals. To date, utility wastes have not been labeled as hazardous, but some data suggest that they may occasionally exceed the USEPA criteria for toxicity hazard. Current USEPA criteria for classifying wastes as toxic hazards are listed in Table 6.

Table 5. Effluent Standards for Discharges from Coal-Fired Steam Electric Generating Plants

Parameter	Standards for ash and FGD sludge liquors
pH	6-9
Total suspended solids	100 mg/L (daily maximum) 30 mg/L (30-day average)
Oil and grease	20 mg/L (daily maximum) 15 mg/L (30-day average)

Source: 40 CFR 423.

Table 6. USEPA Toxicity Criteria for Classifying Waste as Hazardous[a]

Contaminant	Criterion concentration in leachate (mg/L)
Arsenic	5.0
Barium	100.0
Cadmium	1.0
Chromium	5.0
Lead	5.0
Mercury	0.2
Selenium	1.0
Silver	5.0
Endrin	0.02
Lindane	0.40
Methoxychlor	10.0
2,4-Dichlorophenoxyacetic acid (2,4-D)	10.0
2,4,5-Trichlorophenoxypropionic acid (2,4,5-TP)	1.0
Toxaphene	0.5

[a]From U.S. Environmental Protection Agency (1980a). Criteria are 100 times the USEPA National Interim Primary Drinking Water Regulations. The USEPA (1980a) requires a standard method for testing a waste for toxic hazard. If leachate from this test contains any of the above contaminants in excess of the criteria in this table, the waste is to be classified as hazardous.

Under RCRA, the USEPA (1979a, 1979b) has also issued regulations and guidelines for locating and designing nonhazardous waste sites, including sites for coal ash and FGD sludge. These regulations and guidelines indicate that:

A site may not be located in:

- Environmentally sensitive areas, such as 100-year floodplains, wetlands, or permafrost

- Critical habitat for endangered species

- Seismically active areas

- Recharge zones of sole-source aquifers

Additionally, the waste-handling facility must not discharge pollutants into surface waters in violation of the requirements of the National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act. The facility should be designed such that mobilization of waste constituents is minimized by incorporating the guidelines in Table 7 and Figure 12. These USEPA guidelines are not mandatory at this time but should be considered by the states in developing waste-handling regulations. Site monitoring is required to assess the success of containment during the lifetime of the facility.

Table 7. USEPA Guidelines for Controlling Mobilization of Waste Constituents from Containment[a]

Leachate control

- Unless the groundwater in the area is already unusable, the bottom of the landfill should be maintained at least 1.5 m above the seasonal high water table.
- Runoff diversion structures should be constructed which are capable of diverting all runoff from a 10-year, 24-hour storm.
- 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% so that erosion and infiltration are minimized.
- Terraces should be included at 6-m 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 permeability coefficient of 1 v 10-7 cm/s or less.
- Minimum thickness for in-place or constructed soil liners is 30 cm, and for synthetic membranes is 20 mils.
- Synthetic liners should be covered and rest on sufficient granular material to prevent puncture.
- Liner grades of 1% or more are required.
- Collected leachate must be treated before discharge.

Runoff control

- The landfill should be located in an area where drainage from adjacent lands onto the site is minimal.
- Suitable runoff diversion ditches should be constructed surrounding the site.
- Landfill surface should be sloped to grades not in excess of 30%.
- Well-compacted, fine-grained soil should be used for final cover.
- Offsite runoff and uncontaminated onsite runoff should be routed to a sedimentation basin prior to discharge. Contaminated onsite runoff must be collected and decontaminated prior to discharge.

[a]Adapted from GAI Consultants (1979).

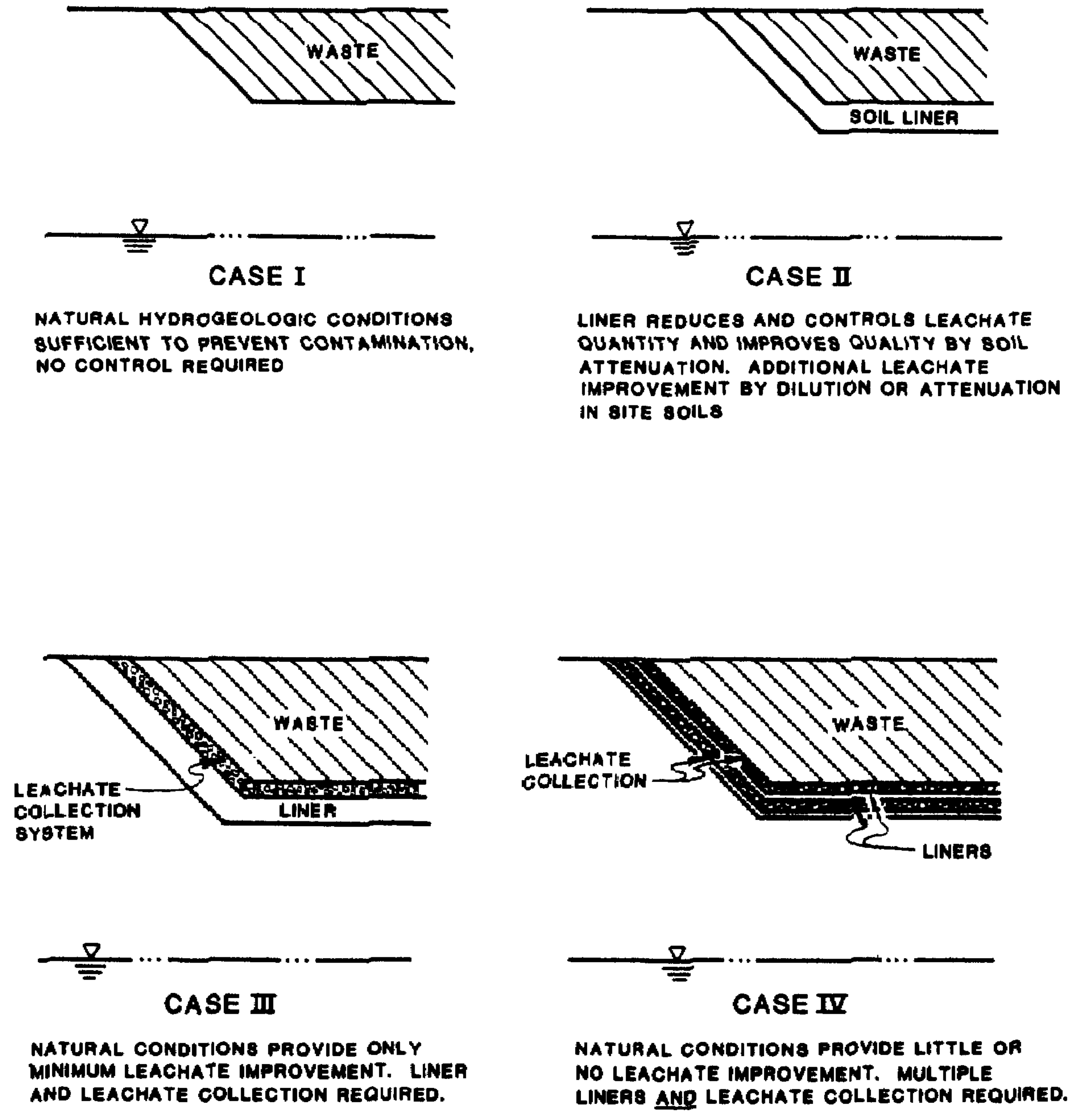
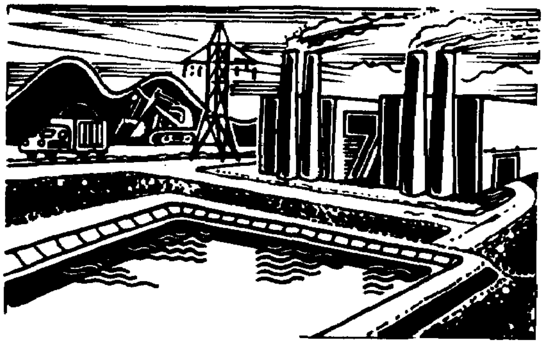


Figure 12. Leachate Control Methods for Nonhazardous Waste-Disposal Sites. The lines at the bottom of the drawings represent the water table. From GAI Consultants (1979).



Chapter 4
Description of Model Facilities

Data on four model 2100-MWe coal-fired power plants are presented to illustrate how to use the guidelines given in this manual for assessing proposed coal combustion waste-storage sites, management of active sites, and reclamation of former sites. Each plant has a nominal operating lifetime of 40 years. Values presented for quantification purposes are approximate values and, due to rounding, recalculation will not result in the exact values presented here. [Numbers are rounded in accordance with the rules outlined in the style manual of the Council of Biology Editors (1978)]. Model plant locations and coal characteristics are presented in Table 8. Coal types reflect regionally observed variations in coal composition. Operating parameters of the four plants, which are characteristic of current power plants coming on line, are presented in Table 9. Waste-handling practices are summarized in Tables 10 and 11.

WESTERN PLANT [135-139]

At the Western plant (Figure 13), ash residues are stored in a large upland surface coal mine 8 km (5 miles) from the plant, near the Powder River in Wyoming. The sludge storage site, a diked pond, is located in an alluvial area more than 300 m from the river and meets applicable state and federal specifications. The soil type of the storage pond area is Kim loam, an Entisol, with 0 to 3% slope. The area is currently managed for range and wildlife habitat but has potential for being managed for irrigated hay, small grain, and pasture. Natural vegetation is dominated by plains grassland, but range conditions have deteriorated slightly--allowing annual invaders, prickly pear cactus, and short grasses to appear. Forage value of the area is higher than most habitat types in the region, and similar habitats available for wildlife are in limited supply. Endangered and threatened species have not been reported in the area.

Table 8. Ash, Sulfur, and Heat Values of the Coals Utilized by the Four Model 2100-MWe Coal-Fired Power Plants[a]

Model plant	Coal type	Ash (%)	Sulfur (%)	Heat value (Btu/lb)	Sulfur[b] ($lb/10^6$ Btu)
Western	Low-sulfur	6.0	0.48	8,200	0.58
Ohio River valley	High-sulfur	10	3.5	11,400	3.07
Texas	Lignite	10	0.8	7,705	1.04
Southeastern coastal	High-sulfur	12.4	1.6	13,135	1.22

[a]The model plants are designated as 2100-MWe plants, the MWe indicating units of electric power as opposed to, for example, thermal power (MWt). All model plants are assumed to operate at 70% of capacity over one year (i.e., the plant factor = 0.7).
[b]Sulfur ($lb/10^6$ Btu) = sulfur (%) ÷ [heat value (Btu/lb) × 10^6].

Table 9. Emission-Control Characteristics of the Four Model Coal-Fired Power Plants

Model plant	SO_2 control: FGD reagent	SO_2 control: % SO_2 removal[a]
Western	Lime	70
Ohio River valley	Lime	90
Texas	Limestone	74
Southeastern coastal	Limestone	90

Particulate control for all model plants

- 85% of ash is fly ash.
- Electrostatic precipitators are used.
- 99.5% of the ash is removed from the flue stream.
- About 0.1% of the fly ash is removed from the flue gas by impingement on FGD reagent.

[a]From Figure 19, using the data for sulfur ($lb/10^6$ Btu) from Table 8.

Table 10. Ash Handling at the Four Model 2100-MWe Coal-Fired Power Plants

Model plant	Storage option	Design	Transport	Water content of thickened waste
Western	Deposited dry in surface mine	Not applicable	Truck	Not applicable
Ohio River valley	Slurried with sludge to impoundment	Diked pond	Pipeline	65%
Texas	Dry-mixed with sludge in landfill	Heaped landfill	Truck	Not applicable
Southeastern coastal	Slurried with sludge to impoundment	Above-grade diked pond	Pipeline	65%

Table 11. Flue-Gas Desulfurization Sludge Handling at the Four Model 2100-MWe Coal-Fired Power Plants

Model plant	Storage option	Design	Transport	Water content of thickened waste
Western	Slurried to impoundment	Incised, diked pond	Pipeline	65%
Ohio River valley	Slurried with ash to impoundment	Above-grade diked pond	Pipeline	35%
Texas	Mixed with dry ash in landfill	Heaped landfill	Truck	50%
Southeastern coastal	Slurried with ash to impoundment	Above-grade diked pond	Pipeline	35%

Ash is used as fill material in the surface coal mine providing coal for the Western plant. Scrubber sludge from the power plant contains 15% solids and is mechanically thickened to 35% solids by weight; water from the thickening process is recycled in the scrubbing system. Supplementary water is pumped from the Powder River. Thickened sludge is piped to the partially incised, diked storage pond. The storage site has been excavated to a depth of 3 m, and the excavated soil material is used in the construction of restraining dikes to allow scrubber sludge to be deposited 9.1 m deep. The above-grade restraining dike is 7.6 m high and 65.5 m wide at the base. The outer slope of the dike has a 5:1 grade, the inner slope a 3:1 grade. The storage site occupies approximately 53 ha (130 acres), including the area occupied by waste, restraining dikes, and associated pipelines and access roads. This area is sufficient to hold the waste produced over the 40-year lifetime of the plant. The pond is lined with clay having a hydraulic conductivity of 7.5×10^{-7} cm/s. The pond has an effluent discharge facility. As individual cells of the storage pond are filled, they will be stabilized for reclamation by natural evaporation, and the stabilized storage area will be graded, covered, and revegetated.

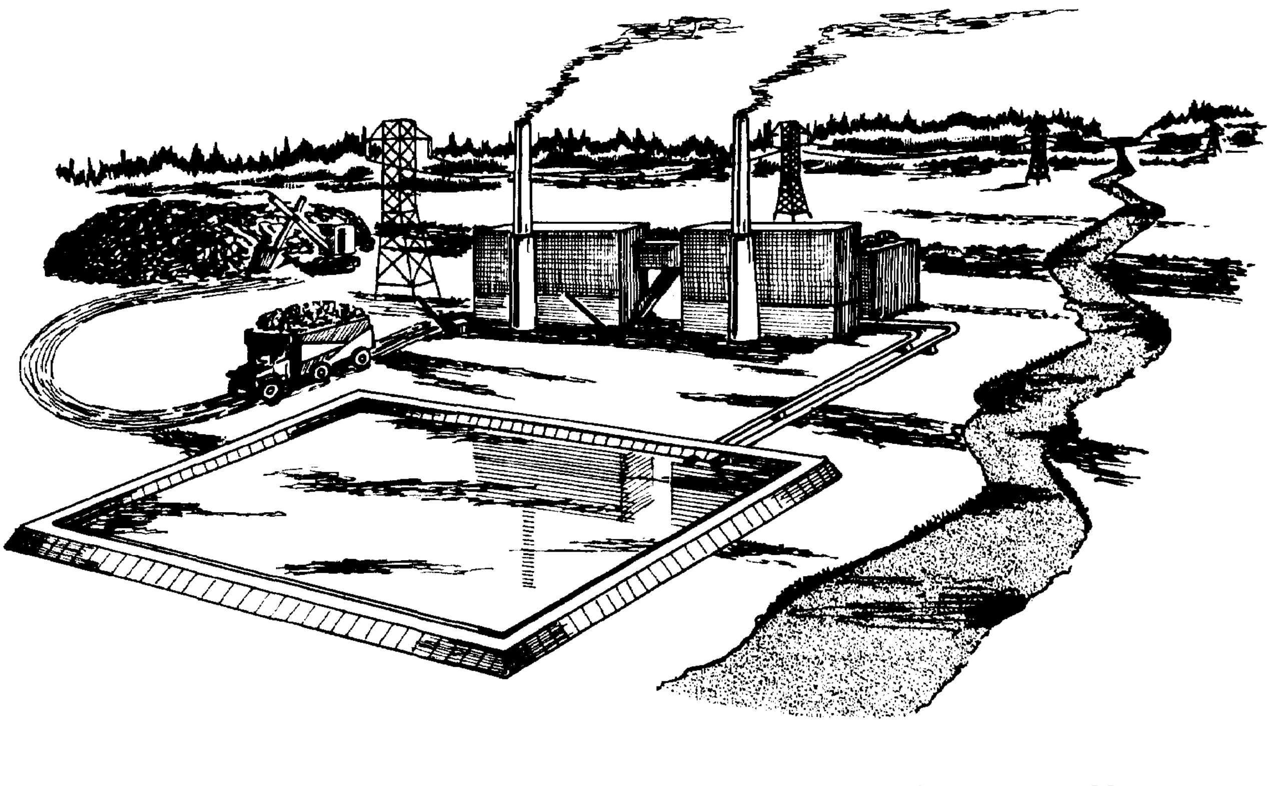


Figure 13. Illustration of the Western Model Coal-Fired Power Plant.

The Ohio waste-storage site (Figure 14) is located in an alluvial area adjacent to the Ohio River. The diked storage pond is 300 m or more from the river and meets all applicable state and federal specifications. Levees will be constructed as needed to protect the area from flooding. The storage pond area soil type is Huntington silt loam, a Mollisol, which is nearly level. Approximately 50% of the area is currently used for row crops (corn and soybeans); the other 50% was formerly cultivated but has been abandoned and is reverting to woodland. Huntington silt loam is well suited for corn and small grain crops, grasses and legumes, wild herbaceous upland plants, and hardwood plants--making habitat for open-land wildlife or woodland wildlife. Wetland wildlife are also found in the area due to the proximity of satisfactory habitat along the Ohio River. Bald eagles (Haliaeetus leucocephalus), a threatened species, and Virginia big-eared bats (Plecotus townsendii virginianus), an endangered species, have been reported in the area.

Ash at the Ohio plant is deposited with scrubber sludge in a diked storage pond. The diked pond is completely above-grade because of the shallow water table. Restraining dikes are 10.7 m high and 89.9 m wide at the base. The outer slope of the dike has a 5:1 grade, the inner slope a 3:1 grade. The combined ash and sludge is deposited to a depth of 9.0 m. The square storage site, including a 30.5-m buffer zone (with the deposited waste, restraining dikes, and associated access roads, etc.), will occupy about 670 ha (1700 acres) at the end of plant operations. The pond is lined with clay having a hydraulic conductivity of 5×10^{-7} cm/s. The combustion wastes are stabilized to 65% solids by weight in the storage pond by natural evaporation and by removal of excess supernatant through a controlled-flow effluent discharge after the suspended solids have settled. The stabilized storage area will be graded, covered, and revegetated.

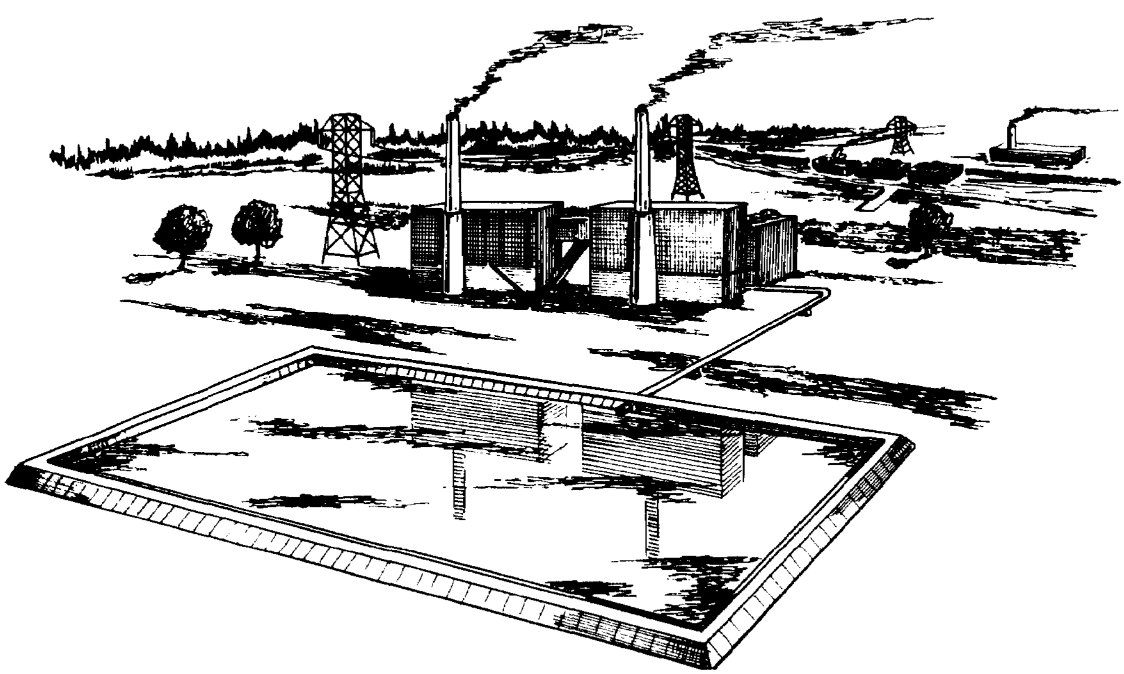


Figure 14. Illustration of the Ohio River Valley Model Coal-Fired Power Plant.

The Texas waste-storage site (Figure 15) is located near Sam Houston National Forest. The storage site soil type is Tuckerman loam-heavy sub-stratum, an Alfisol, with less than 0.3% slope. The area is currently managed for loblolly pine (Pinus taeda) and slash pine (Pinus elliottii) timber and woodland grazing. The most important forage plants are sedges, which make up 80% of the herbaceous understory. Although the area is managed in part as woodland, equipment limitations, plant competition, and seedling mortality are severe. Wildlife species are abundant, and red wolves (Canis rufus), an endangered species, have been reported in the area.

At the Texas plant, scrubber sludge is mechanically thickened to 50% solids by weight. Thickened sludge is mixed with ash residues and landfilled to a thickness of 4.6 m. Prior to deposition of the wastes, 0.6 m of topsoil is removed from the storage site. The completed storage site will occupy approximately 730 ha (1800 acres). The landfill site will not be lined. As the site is filled, it will be capped with a clay liner, covered with stored topsoil, and revegetated.

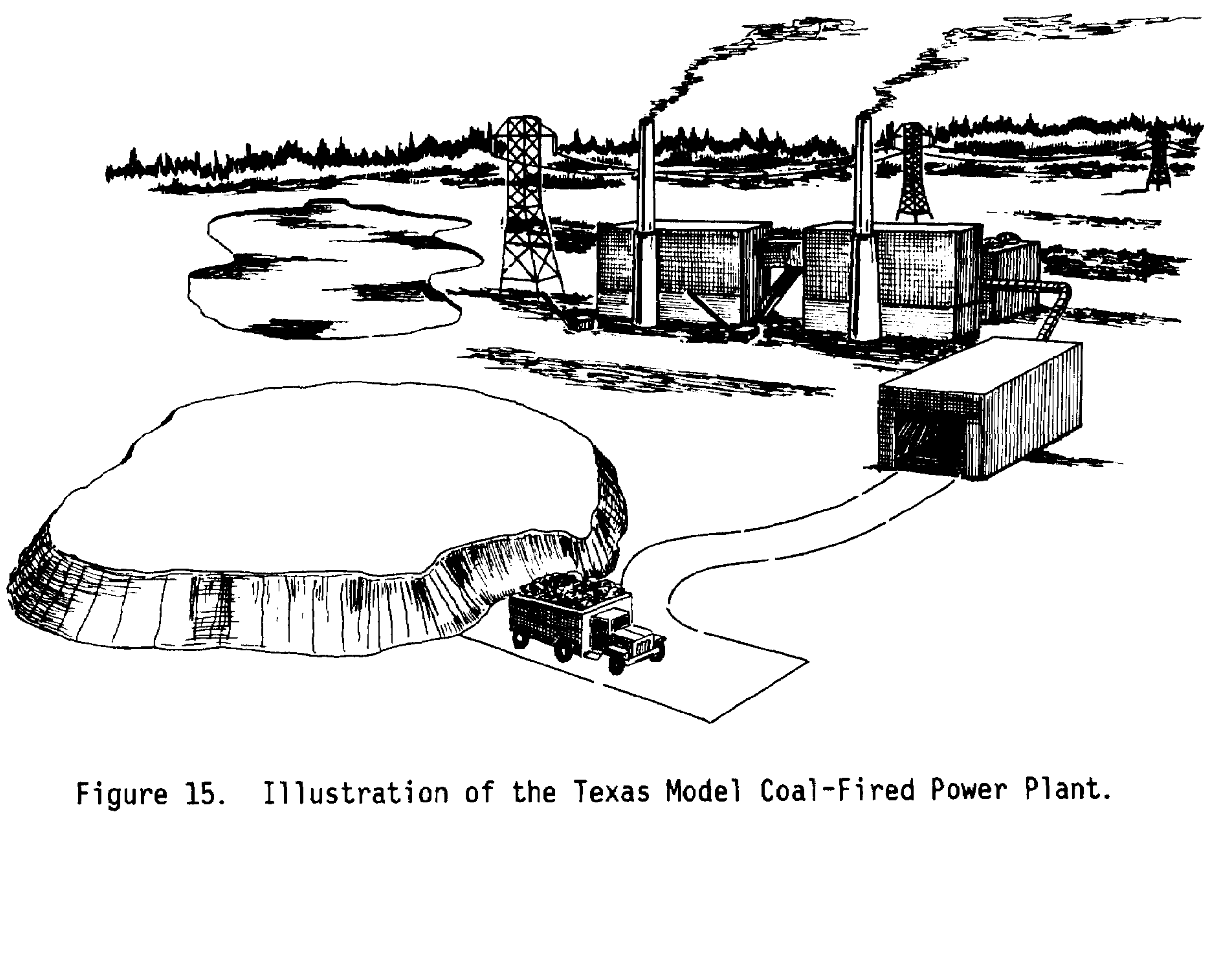


Figure 15. Illustration of the Texas Model Coal-Fired Power Plant.

The Southeastern coastal waste-storage site (Figure 16) is located on the North Carolina coastal plain. The diked storage pond is 300 m or more from the nearest stream and meets all applicable state and federal specifications. The soil type of the storage pond area is a sandy loam, an Ultisol, which is nearly level. Approximately 50% of the area is currently used for row crops (corn and soybeans); the other 50% is in the early stages of old-field succession. Natural vegetation types for the area are oak-pine (Quercus-Pinus) and tupelo-sweet gum-bald cypress (Nyssa sp.-Liquidambar styraciflua-Taxodium distichum). A number of wildlife species use the site. Bald eagles (Haliaeetus leucocephalus), a threatened species, and American alligators (Alligator mississippiensis), an endangered species, have been reported in a nearby small stream and large estuary.

Scrubber sludge and ash from the Southeastern coastal plant are stored in an above-grade, diked storage pond with an underdrain system. Underdrainage is recycled to the scrubber system. Excess supernatant is removed through a controlled effluent discharge after adequate settling of suspended solids has occurred. Restraining dikes are 7.6 m high and 65.5 wide at the base, with the outer slope of the dike at a 5:1 grade, the inner slope at 3:1. Combus-

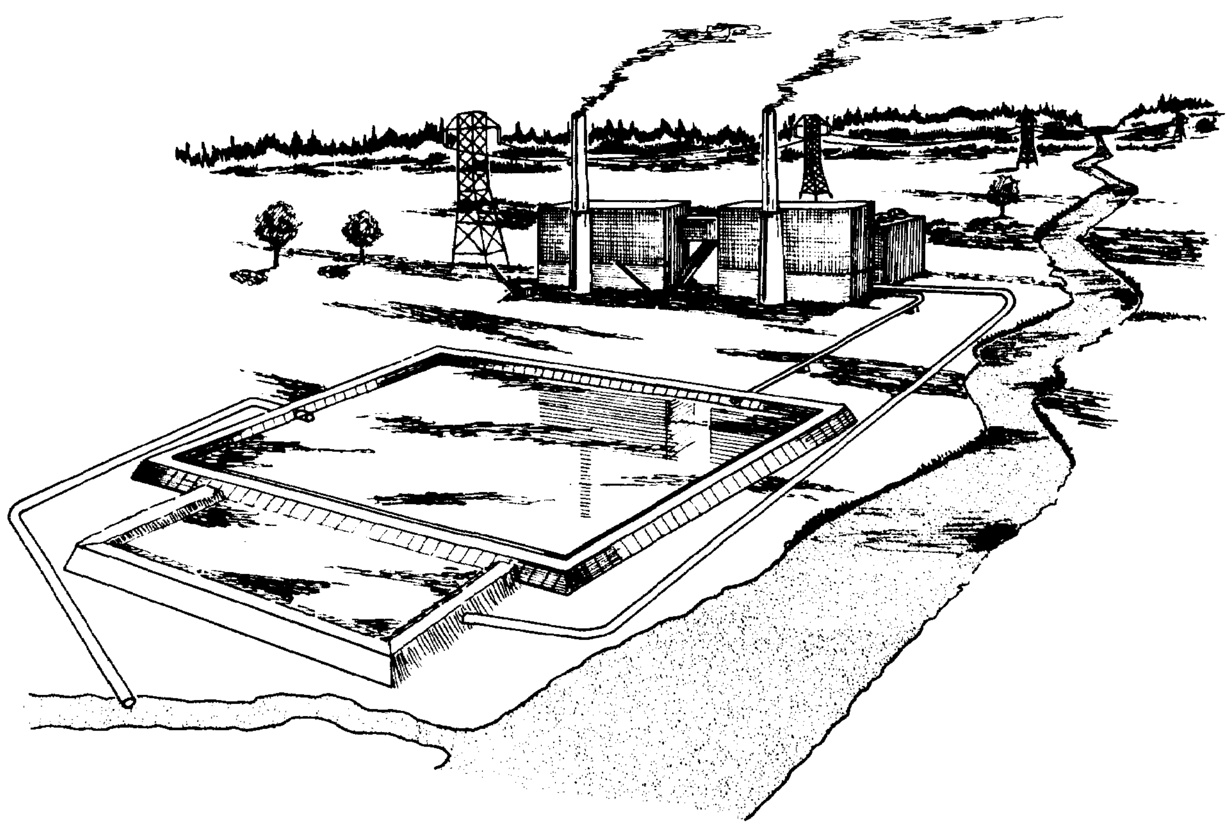
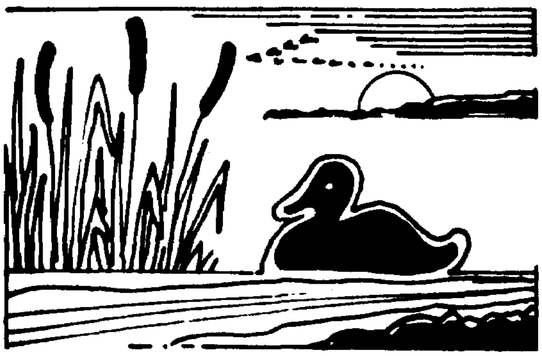


Figure 16. Illustration of the Southeastern Coastal Model Coal-Fired Power Plant.

tion wastes are deposited to a depth of 6.0 m. The storage site is surrounded by a 30.5-m buffer zone and occupies 730 ha (1800 acres). The pond is lined with clay, having a permeability of 1×10^{-7} cm/s, below the underdrain system. When the storage pond is filled and stabilized to 65% solids, the storage area will be graded, covered, and revegetated.



Chapter 5
Wildlife Habitat Loss

POTENTIAL IMPACTS [41-42]

Withdrawal of land from use by wildlife may have marked impacts upon local faunal populations. Members of the less mobile species may be killed by clearing and construction activities. Although mobile species can move into adjacent habitats, the resulting increased competitive pressures may prove to be detrimental to the population as a whole. Because of the complex network of interactions influencing a population's success, it is difficult to assess the potential magnitude and impact of increased competition pressures due to displacement of individual wildlife. Available information is largely anecdotal, and predictions of adverse impact are based upon the assumptions that habitats are normally at carrying capacity and increased competition is detrimental to a population. These assumptions have not been rigorously tested.

Of particular concern is the displacement of wildlife populations from habitat that is important to their life history, e.g., winter foraging, nesting, or breeding areas. If such areas are rare in a given locale, their removal from use by wildlife may markedly reduce wildlife abundance. This is especially important if rare, endangered, or other sensitive wildlife populations are involved. Therefore, in assessing the impact of land preemption due to storage of coal ash or FGD sludge wastes, one must first evaluate the kinds, extent, and value of habitat available to local wildlife resources and the degree to which habitats are being exploited by wildlife populations.

QUANTIFICATION [18-26]

The initial steps in quantifying the amount of habitat to be lost to waste-storage facilities is to quantify the amount of wastes that will be produced during operation of the coal-fired utility. Often, the amount of waste produced and land requirements can be obtained from the utility. In some instances, this information may be incomplete or one may wish to check utility estimates. A predominantly graphic method for estimating waste production and land requirements for waste storage is presented below. Estimates derived from this approach will provide approximations for the quantities in question.

The initial step in quantifying waste production is determining the rate of coal consumption by the operating plant (Figure 17). The rate of coal consumption is a function of the operating capacity (rated capacity × percent of time the plant is in operation [plant factor]), heat capacity of the coal being consumed, and the heat rate of the plant (amount of heat required to produce a given amount of electricity). For Figure 17, it is assumed that a heat rate of 8930 Btu/kWe is representative of a typical coal-fired electric generating facility. If another heat rate is to be used, the results from Figure 17 must be multiplied by the new heat rate value and divided by 8930.

The ash produced is simply:

$$\text{Amount/year} = \text{Amount/year coal burned} \times \text{proportion of ash in coal} \quad (1)$$

The ash collected is calculated in two steps:

$$\text{Amount of fly ash/year} = \text{Amount of ash/year} \times \text{proportion of fly ash in ash} \times \text{percent collection efficiency} \quad (2)$$

$$\text{Amount of aggregate/year} = \text{Amount of ash/year} \times \text{proportion of aggregate in ash} \quad (3)$$

Using the information in Tables 8 and 9 and Equations 1-3, one can calculate the following coal consumption and ash production for the four model 2100-MWe plants, each operating at 70% of rated capacity:

	Coal (10^9 kg/yr)	Fly ash (10^9 kg/yr)	Aggregate (10^9 kg/yr)	Volume ash collected (10^4 m^3/yr)
Western	6.4	0.3	0.1	28
Ohio River valley	4.0	0.3	0.1	33
Texas	6.8	0.6	0.1	49
Southeastern coastal	4.0	0.4	0.1	36

The volume of ash handled can be determined from Figure 18.

A sample calculation for the Western plant is presented in Box 1.

BOX 1

SAMPLE CALCULATION OF VOLUME OF ASH COLLECTED

STEP 1: Rated capacity of plant (from Table 8) = 2100 MWe.

STEP 2: Plant factor (from Table 8) = 0.7.

STEP 3: Operating capacity of plant = Step 1 × Step 2 = 0.7 × 2100 MWe = 1470 MWe.

STEP 4: Heat value of coal to be used (from Table 8) = 8200 Btu/lb.

STEP 5: Rate of coal consumption (using Step 3 and Step 4 in Figure 17) ≅ 6.4×10^9 kg/yr.

STEP 6: Percentage ash in coal (from Table 8) = 6.0.

STEP 7: Rate of ash production (from Equation 1) = Step 5 × Step 6 ÷ 100 = 4.0×10^8 kg/yr.

STEP 8: % Fly ash produced (from Table 9) = 85.

STEP 9: Fly ash produced (from Equation 2) = Step 7 × Step 8 ÷ 100 = 0.3×10^9 kg/yr.

STEP 10: % Fly ash collected (from Table 9) = 99.5.

STEP 11: Fly ash collected = Step 9 × Step 10 ÷ 100 = 0.3×10^9 kg/yr.

STEP 12: % Aggregate produced = 100 - Step 8 = 15.

STEP 13: Aggregate produced and collected (from Equation 3) = Step 7 × Step 10 ÷ 100 = 0.1×10^9 kg/yr.

STEP 14: Total ash collected = Step 11 + Step 13 = 0.4×10^9 kg.

STEP 15: Volume of ash collected (using Step 8 and Step 14 in Figure 18) = 0.3×10^6 m^3/yr.

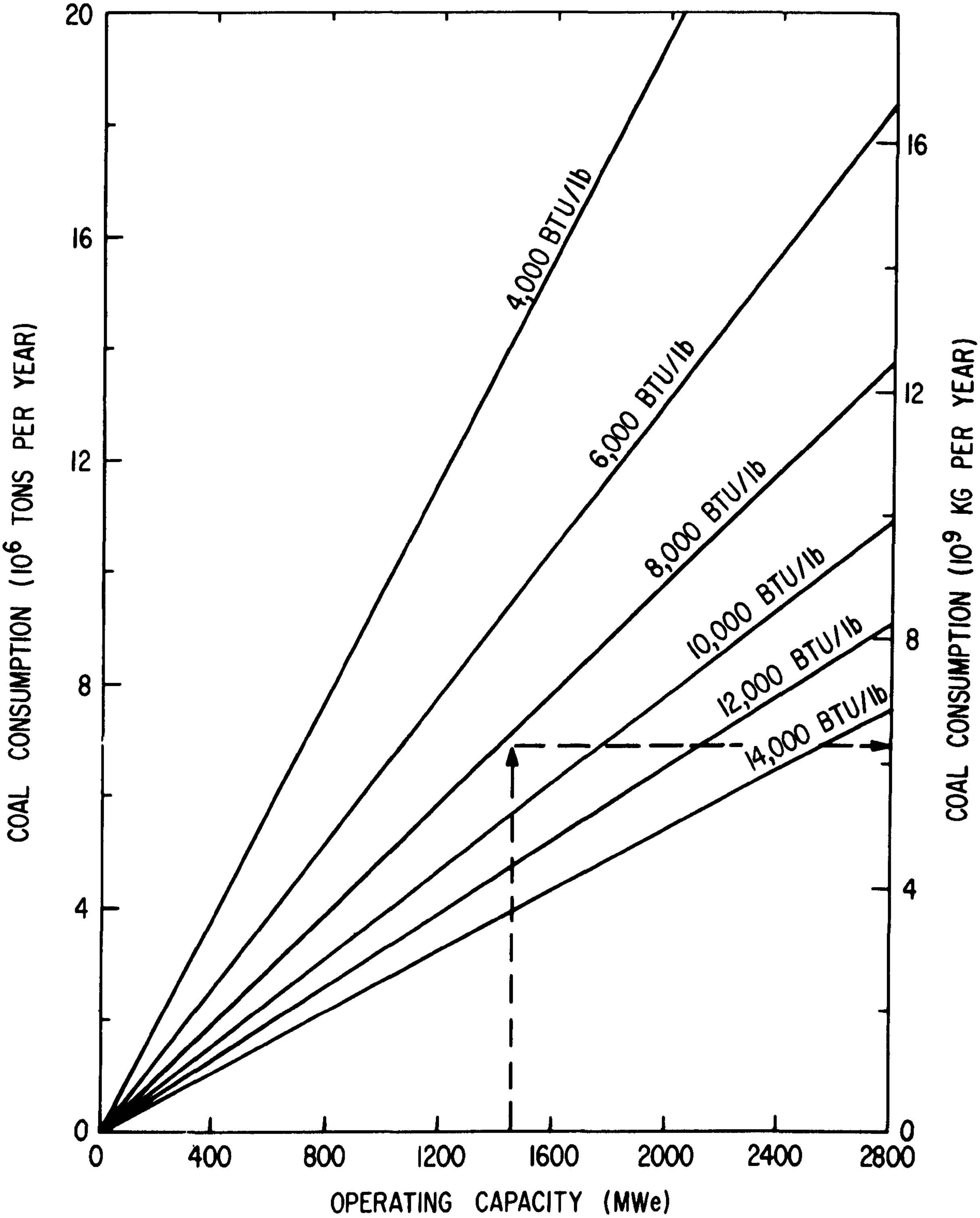


Figure 17. Coal Consumption as a Function of Operating Capacity of an Electric Generating Station. A heat factor of 8930 Btu/kWe has been assumed. The dashed line illustrates the example in Box 1.

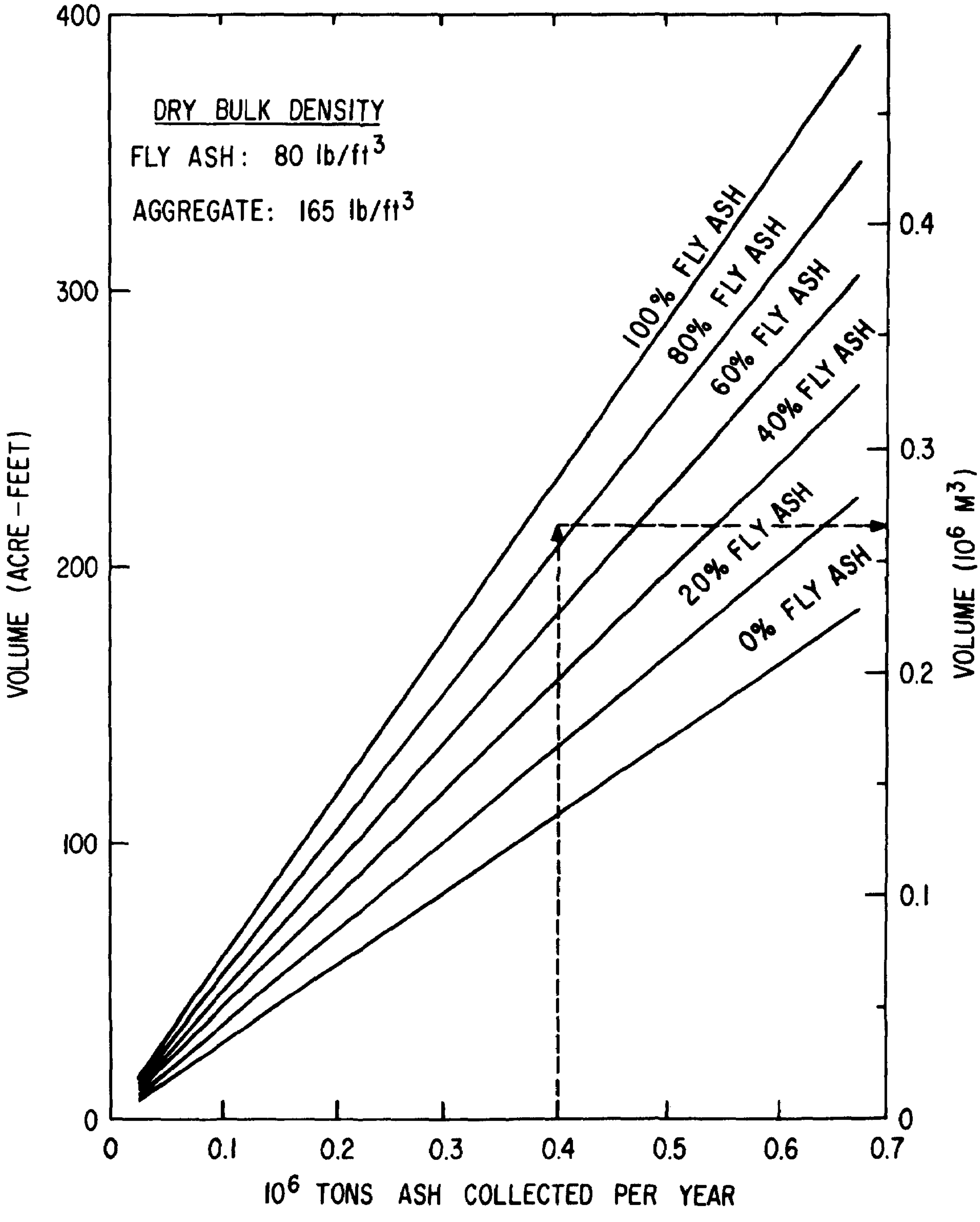


Figure 18. Volume of Ash as a Function of Weight and Percentage of Fly Ash and Aggregate. The dashed line illustrates the example in Box 1.

FGD scrubber sludge volumes can be calculated from the data on coal consumption rates (Figure 17), sulfur content of the coal (Table 8), SO_2 removal efficiency of scrubbers (Figure 19), and scrubbing reagent (Table 9). The reagent used in the FGD scrubber influences the sulfate:sulfite ($SO_4:SO_3$) ratio of the waste scrubber sludge. Limestone reagents yield sludges with sulfate:sulfite ratios of about 8:2, lime reagents yield a ratio of about 2:8, and lime/limestone reagents yield a ratio of about 1:1. As can be seen in Figure 20, this sulfate:sulfite ratio influences the weight of waste solids produced in an FGD scrubber system.

For the Western plant, the parameters of the sulfur removal system are presented in Box 2.

BOX 2

SAMPLE INFORMATION
FOR
SULFUR EMISSIONS CONTROL

STEP 1: Sulfur content of coal (from Table 8) = 0.48% or 0.6 lb/Btu.

STEP 2: % SO_2 removal required (using Step 1 in Figure 19) = 70%.

STEP 3: Scrubbing reagent (from Table 8) = Lime (2 SO_2:8 SO_2).

The weight of sludge solids can be estimated from Figures 20, 21, 22, or 23. Figure 20 is used for situations where the coal contains 2% or less of sulfur; Figures 21, 22, and 23 are used for coals containing 2% or more sulfur and for limestone, lime, or lime/limestone scrubbing, respectively. The volume of sludge produced is dependent upon the proportion of dry solids in the sludge suspension (Figure 24).

For example, at the Western plant--with 0.48% sulfur in the coal, a lime scrubbing reagent (2 SO_4:8 SO_3), and a final dry solid percentage of 65%--the calculations proceed as presented in Box 3.

BOX 3

SAMPLE CALCULATION OF AREA REQUIRED FOR STORAGE OF SLUDGE

STEP 1: Coal consumption (Step 5 from Box 1) ≅ 6.4×10^9 kg/yr.

STEP 2: Weight of dry solids (using Steps 1, 2, and 3 from Box 2 in Figure 20) ≅ 14×10^3 kg per 10^6 kg coal combusted.

STEP 3: Total solids produced = Step 1 × Step 2 = $(14 \times 10^3) \times (6.4 \times 10^3) \div 10^6 = 9.0 \times 10^7$ kg/yr.

STEP 4: Volume of sludge (using Step 3 in Figure 24) ≅ 1.0×10^3 m^3 per 10^6 kg dry solids.

STEP 5: Volume of sludge produced annually = Step 3 × Step 4 $= (9.0 \times 10^7) \times (1.0 \times 10^3) \div 10^6 = 9.0 \times 10^4$ m^3/yr.

STEP 6: Minimum area required for storage (from Figure 25 using depth of 9.1 m and Step 5) ≅ 9.0×10^3 m^2/yr = 0.9 ha/yr.

The minimum area needed to handle this sludge can be obtained from Figure 25. If the ash at this site were impounded with the sludge, the area could also be estimated from the volume produced by using Figure 24 and Step 15 in Box 1.

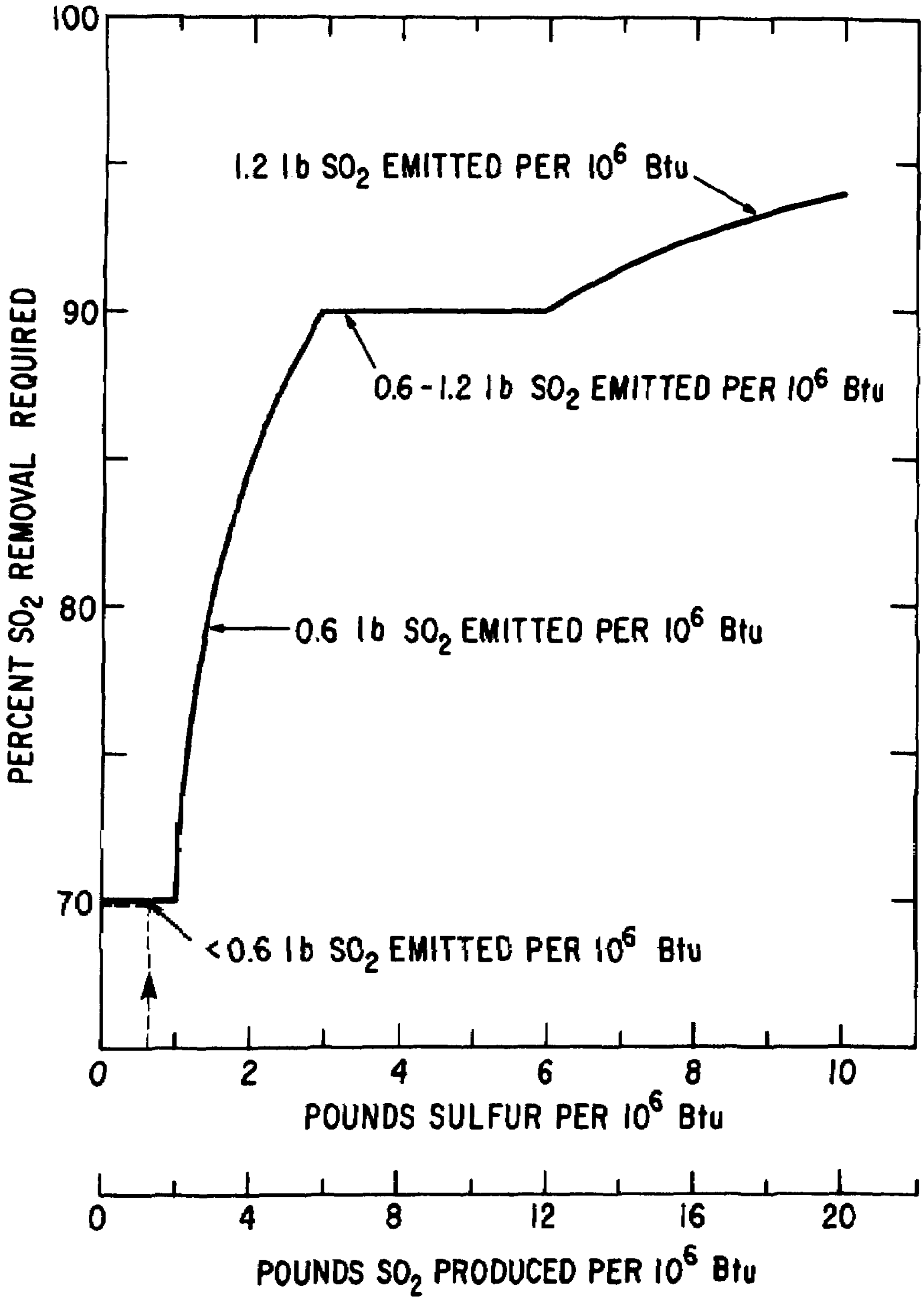


Figure 19. Percentage SO_2 Removal Required to Meet USEPA Emissions Standards. The dashed line illustrates the example in Box 2.

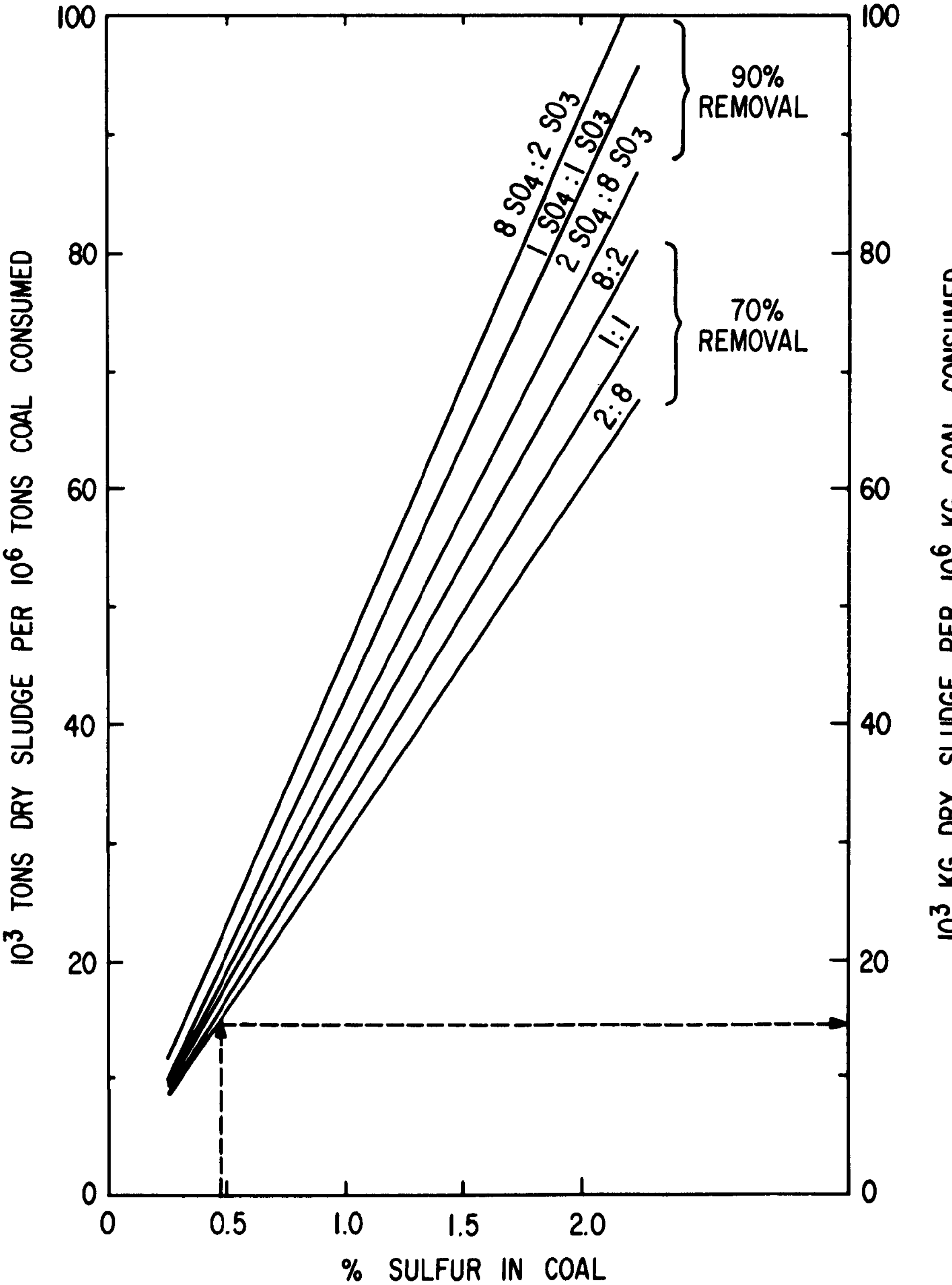


Figure 20. Amount of FGD Sludge Solids Produced When the Sulfur Content of Coal is < 2% as a Function of Coal Sulfur Content and Percent Removal of SO_2 from the Flue Gas. The dashed line illustrates the example in Box 3.

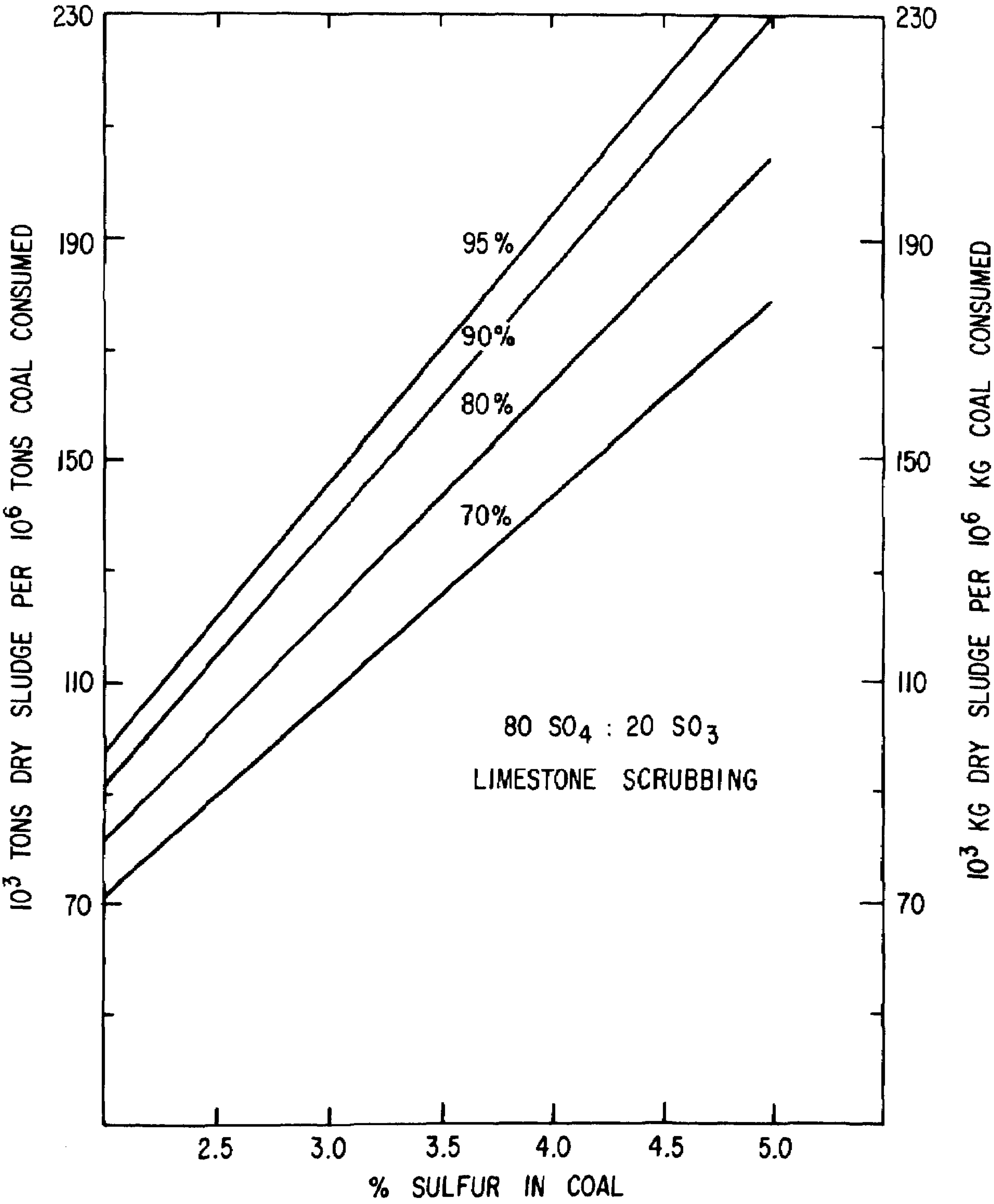


Figure 21. Amount of FGD Sludge Solids Produced for Limestone Scrubbing and Coal Sulfur Contents > 2% as a Function of Sulfur Content of the Coal and Percent Removal of SO_2 from the Flue Gas.

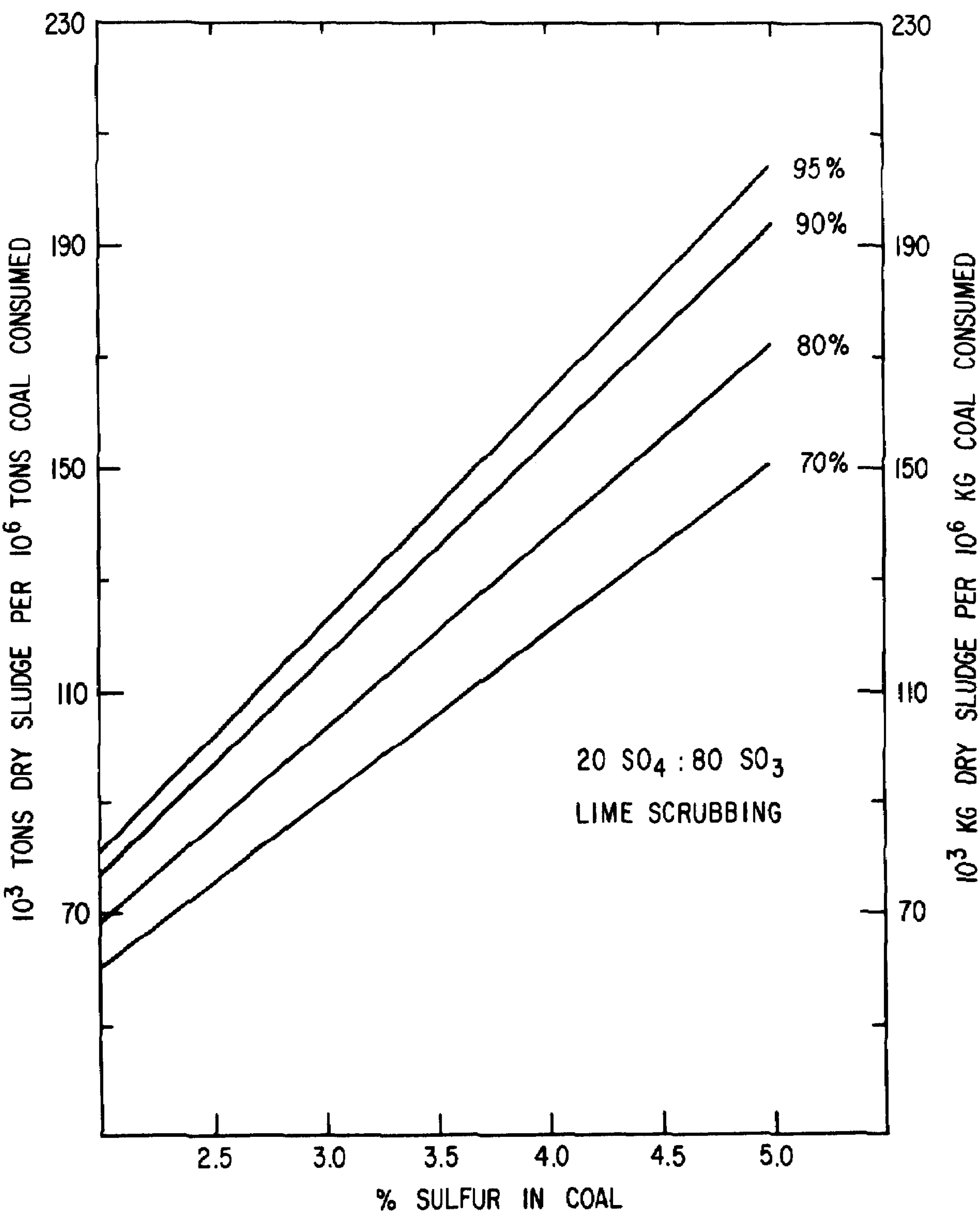


Figure 22. Amount of FGD Sludge Solids Produced for Lime Scrubbing and Coal Sulfur Contents > 2% as a Function of Coal Sulfur Content and Percent Removal of SO_2 from the Flue Gas.

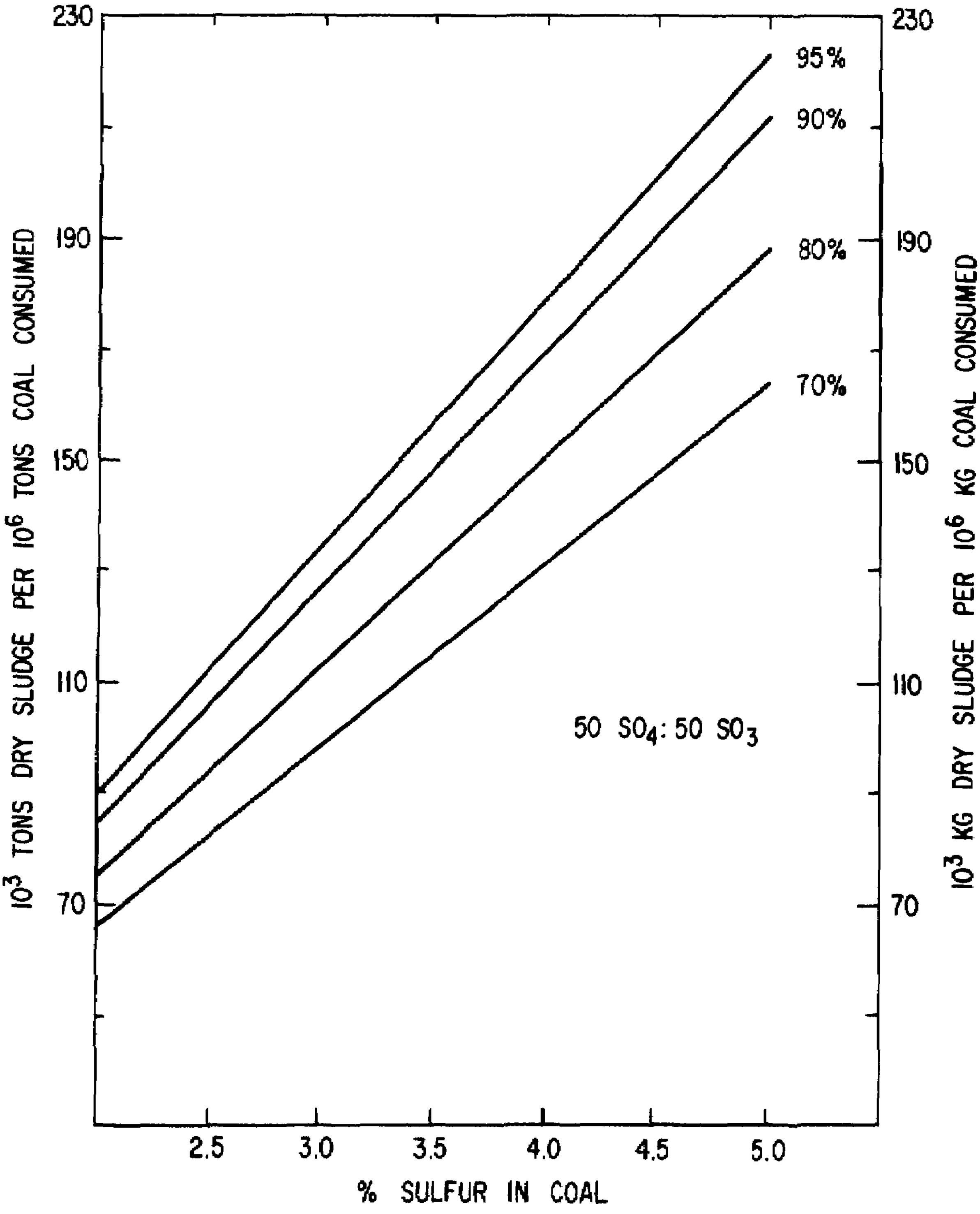


Figure 23. Amount of FGD Sludge Solids Produced from Combined Lime/ Limestone Scrubbing and Coal Sulfur Contents > 2% as a Function of Sulfur Content and Percent Removal of SO_2 from the Flue Gas.

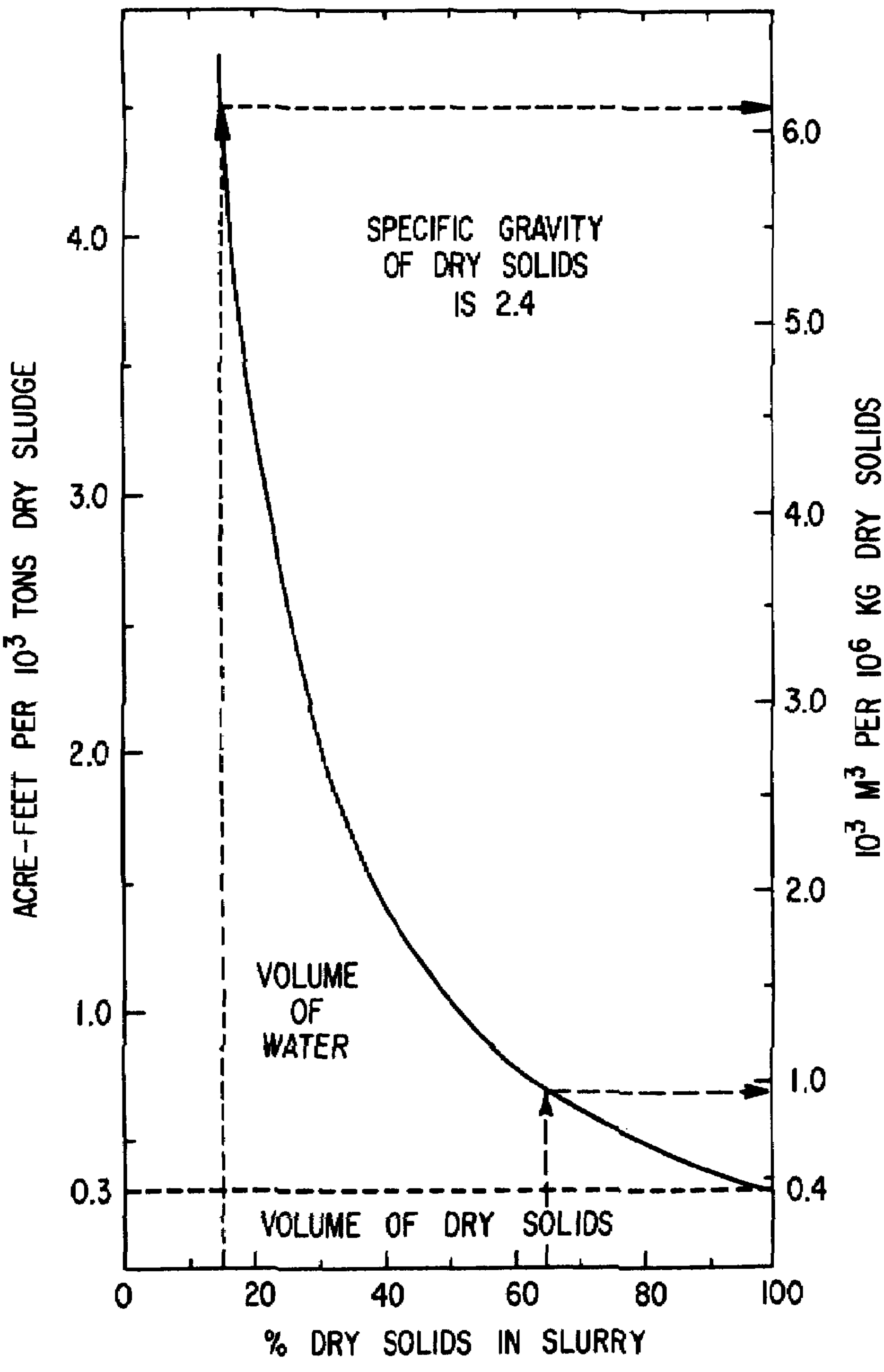


Figure 24. Volume of FGD Sludge as a Function of the Percentage of Dry Solids. The dashed lines with arrows illustrate the examples in Boxes 3 and 4.

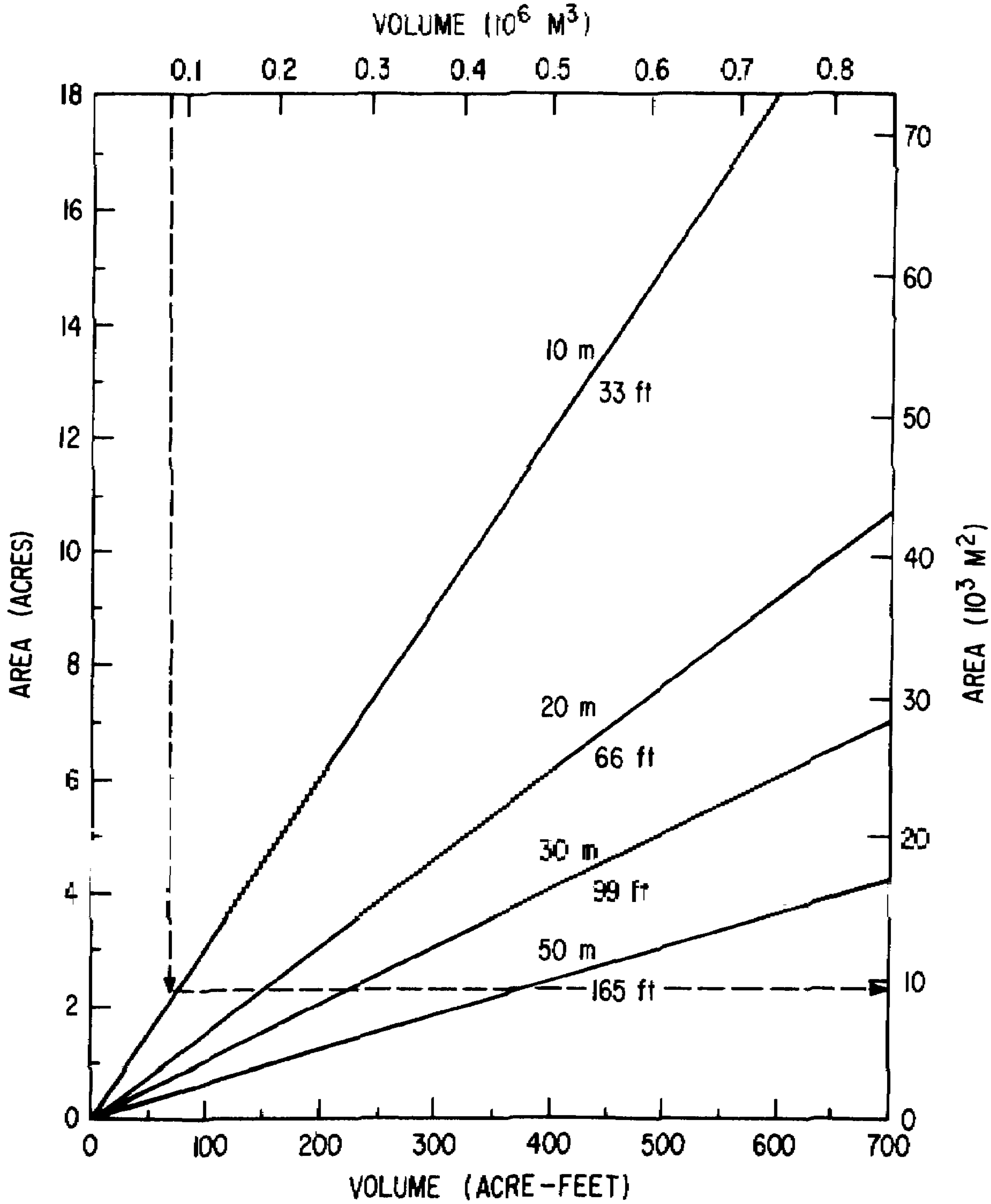


Figure 25. Acreage Required to Hold Waste as a Function of Volume of Waste and Depth of Storage. The dashed line illustrates the example in Box 3.

Impounded wastes require an additional preemption of land by the berm or dike surrounding the storage area. If more accurate information is not available, one may use an approach for estimating area under the dike as illustrated in Figure 26. This figure presents a schematic of the distance beyond the waste covered by a dike with a 5:1 external slope and 3:1 internal slope, i.e., 3 horizontal meters for each vertical meter. For this estimate, it was assumed that waste depth was 9.1 m, freeboard (height from waste surface to top of dike) was 1.5 m, and a 5-m wide roadway ran along the top of the dike. Under these assumptions, simple geometric calculations yield a dike basal width of 65.5 m. In adding the dike width to area preempted by waste alone, a correction for displacement by the internal slope can be estimated as half the horizontal distance from the contact points of the dike and the substrate to that of the dike and the waste surface (15 m in our example). The total area preempted by the berm can then be approximated as width of dike times length of dike required. In the example, 50.5 m is the width of the dike (65.5 m) minus the correction for displacement of waste by the dike (15 m). In some areas (particularly urban areas), a 30-m buffer area may also be required around the site (Duvel et al. 1979). Thus, for the Western model site, the <u>minimum</u> amount of land for the storage impoundment would be about 36 ha for <u>sludge</u> and 14 ha for berm, or 50 ha in order to hold the FGD waste from 40 years of plant operation.

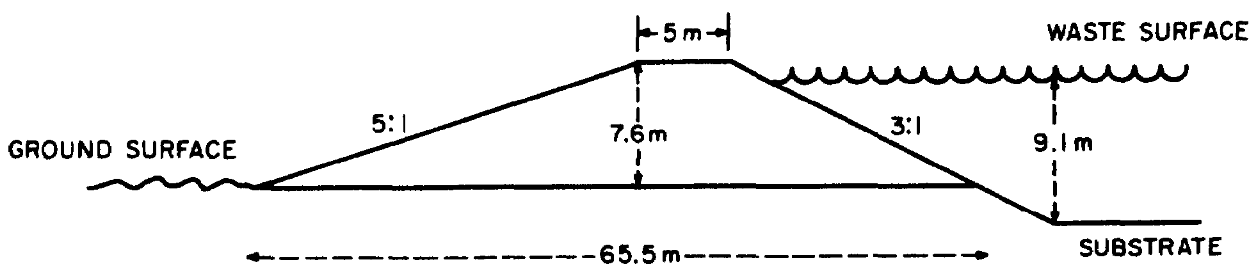


Figure 26. Schematic of a Generalized Impoundment Dike for the Western Plant.

The area set aside for storage of 40-years' production of waste at each of the model plants is as follows:

Model plant	Area for storage of 40-years' waste production	
	hectares	acres
Western	53	130
Ohio River valley	670	1,650
Texas	730	1,800
Southeastern coastal	730	1,800

IMPACT ANALYSIS [43]

Over the past several years, the U.S. Fish and Wildlife Service has been developing a methodology for evaluating the value of land as wildlife habitat, i.e., "The Habitat Evaluation Procedure" (U.S. Fish Wildl. Serv. 1980). These procedures provide the wildlife biologist with a means for comparing the value of different habitats that may be affected by development of a waste-storage facility. Galvin (1979) provides a collection of information on wildlife and their habitat requirements that can be useful in estimating habitat value. Additionally, it is necessary to know the availability of that habitat for use by wildlife populations. If a habitat is rare and of high wildlife value, it is less desirable as a waste-storage site than is a more common habitat of moderate value. The Soil Conservation Service, Bureau of Land Management, and state wildlife officials may serve as sources of information on habitat distribution in the region of concern. In the end, the wildlife biologists must rely greatly upon their own experience and knowledge to evaluate the potential for adverse impacts from developing a waste-storage facility at a given site.

Preemption of land at the four model facilities will result in an incremental loss of potential wildlife habitat. Therefore, there will be potential for decrease in those species utilizing this habitat. Even after reclamation, the site will not be as valuable for wildlife habitat for at least several decades. At the Western site, the habitat to be lost is of relatively high value to wildlife, but is only a small fraction of the habitat available in the region. At the Ohio River site, more area will be lost and, because the area is already highly industrialized, this could be of importance to several populations of wildlife. However, bald eagles and Virginia big-eared bats would not be directly impacted by these habitat losses. There will be a reduction in red wolf habitat (open woodlands) at the Texas site, which could be detrimental to local populations. The Southeastern coastal facility will use as much land as the Texas facility, but the habitat to be preempted does not support populations of wildlife that are as sensitive as the red wolf. Of all the sites, the Texas facility is most likely to threaten the survival of a wildlife population.

INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of wildlife habitat loss as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Power plant operating characteristics and coal type	Facility operator
Design of storage facility	Facility operator
Location and area of proposed site	Facility operator Site visit Estimated from quantities of waste to be produced
Habitat type	Facility operator Literature Site visit U.S. Fish and Wildlife Service Other federal agencies Local university biologist
Important wildlife resources	Facility operator Literature Site visit U.S. Fish and Wildlife Service Other federal agencies Local university biologist

MITIGATIVE MEASURES

The loss of potential wildlife habitat is unavoidable for any waste-storage facility. However, some mitigation of impacts is possible. The four methods most likely to be used at a waste-storage site are:

- Maximizing the density of the waste so that less land is required per unit volume of waste.
- Increasing the depth of stored waste so that less area is used.
- Revegetating the site as it is filled.
- Protecting from development an area of equivalent or higher wildlife value in compensation for preempting land for waste storage.
- Upgrading of nearby habitat to enhance value to wildlife.

Chapter 6
Water Consumption

POTENTIAL IMPACTS [73-75]

Numerous water bodies (lakes, ponds, reservoirs, and rivers) have competing water users; the addition of a coal-fired power plant or a change in the processing of combustion waste products could place an additional demand on water resources managed for fish and wildlife. Changes that occur in ecosystems from which water is drawn are directly related to water loss. The severity of these effects is modified by season of the year and rate and frequency of drawdown associated with consumptive water use. Changes in both terrestrial and aquatic ecosystems will be greater where the percentage change from baseline characteristics is greatest; this is more likely in small watersheds or in more arid areas where the amount of available water is low.

A reduction in total volume of water in aquatic systems can stress aquatic biota by causing changes in production, loss of habitat, and changes in species composition. Organisms can become concentrated, thereby increasing both competition for resources and interactions with other species. These effects can be important if the littoral zone is reduced or eliminated, because it is this zone in which forage grows and becomes available to support the many interrelated organisms within the ecosystem.

Potential impacts from impingement or entrainment are generally small to immeasurable due to the low flows (<10 cfs) required to support waste-handling operations.

QUANTIFICATION

Estimating Consumptive Use of Water

The volume of water required for solid-waste disposal will depend on the specific waste-handling procedure employed. Using Figure 24, the amount of water required in waste handling can be estimated from the amount of solids and the percentage of water in the waste stream. There will be evaporative loss of water in the scrubbers; however, no attempt has been made to quantify this loss.

Consumptive Use of Water by Model Plants

Western plant. The lime scrubbing process generates a slurry of 85% water by weight and requires 52 ha-m (420 acre-ft) of water per year supplied from the Powder River. The slurry is thickened to 65% water by weight, and water from the thickening process is recycled to the scrubbing system. Thus, 32 ha-m (280 acre-ft) of water are recycled per year, and 20 ha-m (140 acre-ft) of water are required per year. However, based on leachate seepage estimates (p. 80), 9 ha-m/yr (70 acre-ft/yr) of the 20 ha-m/yr (140 acre-ft/yr) are reintroduced to the Powder River water system and the loss from the system is 9 ha-m/yr (70 acre-ft/yr). The average precipitation falling on the pond surface inside the berm area--which is not reintroduced to the hydrological system--is 38 cm/yr on 36 ha (98 acres) or 14 ha-m/yr (130 acre-ft/yr). Adding 11 ha-m/yr loss from evaporation, the total water loss is 25 ha-m/yr (200 acre-ft). A sample calculation is presented in Box 4.

Ohio River valley plant. The lime scrubbing process generates a slurry of 85% water by weight and requires 360 ha-m (2880 acre-ft) of water per year. Excess water from the storage pond is not recycled to the scrubbing system. However, based on leachate seepage estimates (p. 80), 80 ha-m/yr (650 acre-ft/yr) of the 360 ha-m/yr are reintroduced to the Ohio River system and 750 ha-m/yr (6100 acre-ft/yr) minus 540 ha-m/yr (4360 acre-ft/yr) of precipitation are reintroduced by surface discharges. Therefore, net consumptive water use is 360 ha-m/yr minus (80 ha-m/yr plus 210 ha-m/yr) or 70 ha-m/yr (570 acre-ft/yr).

Texas plant. The limestone scrubbing process generates a slurry of 85% water by weight and requires 120 ha-m/yr (950 acre-ft/yr) of water. Water from mechanically thickened sludge (98 ha-m/yr or 790 acre-ft/yr) is not recycled to the limestone scrubbing system but is discharged to a nearby stream. The average net consumptive water requirement for the scrubbing system is 20 ha-m/yr (160 acre-ft/yr).

Southeastern coastal plant. The limestone scrubbing process generates a slurry of 85% water by weight and requires 160 ha-m (1260 acre-ft) of water per year. Water from the storage pond underdrain system is recycled to the limestone scrubbing system. Assuming that seepage discharge from the pond is limited by the hydraulic conductivity of the ash-sludge mixture, which is assumed to be 1×10^{-6} cm/s, through approximately 570 surface hectares (1400 acres), the equivalent of all leachate seepage from the initial 85% water by weight and the final 35% water by weight is recycled (150 ha-m or 1200 acre-ft of water per year) to the limestone scrubbing system. The total water withdrawn from the hydrological system is 43 ha-m (350 acre-ft) per year. This water is obtained from an onsite well because of the low flow (950 ha-m/yr) within the nearby stream.

BOX 4

SAMPLE CALCULATION OF WATER USE AT THE WESTERN PLANT

STEP 1: Scrubber solids produced (from Step 3, Box 3) = $\underline{9.0 \times 10^7 \text{ kg/yr}}$.

STEP 2: % Solids in initial slurry (from p. 29) = $\underline{15\%}$.

STEP 3: Volume of water in initial slurry (using Step 2 in Figure 24) $\cong \underline{5.8 \times 10^3 \text{ m}^3 \text{ per } 10^6 \text{ kg dry solids}}$.

STEP 4: Volume of water per year in initial slurry = Step 1 × Step 3 $= (9.0 \times 10^7) \times (5.8 \times 10^3) \div 10^6 = 5.2 \times 10^5 \text{ m}^3/\text{yr}$ $= \underline{52 \text{ ha-m/yr}}$.

STEP 5: % Solids in dewatered sludge (from Table 11) = $\underline{35\%}$.

STEP 6: Volume of water in dewatered sludge (using Step 5 in Figure 24) $\cong \underline{2.2 \times 10^3 \text{ m}^2 \text{ per } 10^6 \text{ kg dry solids}}$.

STEP 7: Volume of water per year in dewatered sludge = Step 1 × Step 6 $= (9.0 \times 10^7) \times (2.2 \times 10^3) \div 10^6 = 2.0 \times 10^5 \text{ m}^3/\text{yr}$ $= \underline{20 \text{ ha-m/yr}}$.

STEP 8: Volume of water recycled from dewatering = Step 4 - Step 7 $= 52 - 20 = \underline{32 \text{ ha-m/yr}}$.

STEP 9: Volume of water in seepage (from p. 80) = $\underline{9 \text{ ha-m/yr}}$.

STEP 10: Volume of water lost from hydrologic system = Step 7 - Step 9 $= 20 - 9 = \underline{11 \text{ ha-m/yr}}$.

STEP 11: Minimum area for rainfall caught in pond (from p. 51) = $\underline{36 \text{ ha}}$.

STEP 12: Average annual precipitation = $\underline{0.38 \text{ m/yr}}$.

STEP 13: Volume precipitation caught in pond = Step 12 × Step 11 $= 0.38 \times 36 = \underline{14 \text{ ha-m/yr}}$.

STEP 14: Total water loss to hydrologic system = Step 10 + Step 13 $= 11 + 14 = \underline{25 \text{ ha-m/yr}}$.

Evaluating Consumptive Use of Water

Impact analysis is based on direct removal of water from an aquatic ecosystem for handling of combustion and emission-abatement wastes. If cumulative demands of industrial, utility, municipal, and agricultural consumptive water are substantial, regional analysis of consumptive use is necessary. Piecemeal consideration may be misleading, and on a case-by-case basis one may dismiss impacts as negligible although the cumulative effect to aquatic resources may be marked.

In assessing the significance of water withdrawal from an aquatic habitat, the biologist must rely heavily upon his own knowledge of the habitat requirements of populations inhabiting the source of makeup waters. Impacts can be evaluated by determining the habitat alterations that will occur due to the continuous withdrawal of water. The Western Energy and Land Use Team of the U.S. Fish and Wildlife Service is developing instream flow strategies for many states. As part of this effort, weighted criteria are used to assess the impacts of altered stream-flow regimes on a stream habitat (Bovee and Cochnauer 1977). This information base can be used to evaluate the impacts of withdrawing water from stream ecosystems. For lake or pond systems, the habitat alteration due to lowering the water level can be estimated from knowledge of the system's morphometry. The significance of habitat attenuation to the affected fishery resources can be evaluated by determining if the habitat requirements of the fish populations are compatible with the expected habitat changes.

Impact of Consumptive Use of Water by Model Plants

Consumptive use of water for waste handling at the model plants is as follows:

	Consumptive use of water	
Model plant location	ha-m/yr	acre-ft/yr
Wyoming	25	200
Ohio	70	570
Texas	20	160
North Carolina	43	350

Consumptive use at the Wyoming storage site, along with other consumptive uses of the power plant, puts increased pressure on already scarce water resources of the area. Removal of water from the Powder River during periods of low flow may result in adverse impacts to fish and wildlife. However, consumptive use of water at the storage site should not substantially alter the flow regime of the Powder River (ca. 2.5×10^4 ha-m/yr) or the available aquatic habitat. Thus, there should be little impact to fish and wildlife resources.

Stream flows at the Ohio and Texas plants are ca. 9.5×10^6 ha-m/yr and 9500 ha-m/yr, respectively. Consumptive water use for waste-handling procedures at these plants puts little pressure on water resources of the areas. Although dilution rates for downstream discharges could be lessened, this is not likely to be of major concern because both plants withdraw less than 0.2% of the stream flow. Fish and wildlife should not be impacted adversely.

The North Carolina plant obtains water from a well, and fisheries resources will not be impacted.

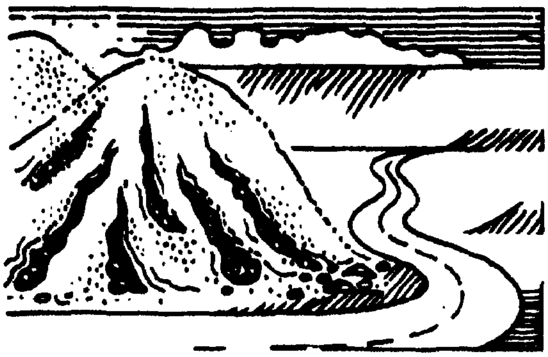
INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of water consumption as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Procedures for handling wastes	Facility operator
Storage site operation and design	Facility operator
Site-specific aquatic habitat data, including water quality and quantity and biological assemblages	Site visit Facility operator U.S. Army Corps of Engineers U.S. Fish and Wildlife Service Local Public Health Service

MITIGATIVE MEASURES

The volume of water required for solid-waste disposal will depend on the specific waste-handling procedure employed. Thickening and dewatering (by means of settling ponds, thickeners, vacuum filters, and centrifuges) are used on the scrubber bleed stream to reduce the water content. Increasing the sulfate content of the sludge (e.g., by forced oxidation) improves the dewatering potential of the wastes. Pipeline transport of wastes to basins will require large volumes of water if no recycling is practiced. After the solids have settled, the supernatant water may be discharged to surface waters, evaporated, or recycled. Consumptive use is greatest if dewatering is by evaporation, least if the supernatant liquid is discharged to surface waters, and intermediate if the water is recycled. Recycling can reduce the amount of water consumed by an order of magnitude over dewatering by evaporation. These options for reducing consumptive water use are particularly important where water resources are scarce, e.g., the arid West. Additionally, if impacts to aquatic ecosystems due to consumptive water use during low flow periods are projected to be substantial, water probably can be removed during high flow periods and stored in a reservoir. This would result in less impact to the aquatic ecosystem, although more water would be required to take into account evaporation from the reservoir.



Chapter 7
Runoff and Erosion

POTENTIAL IMPACTS [44-50]

Constituents of ash and FGD sludge wastes can be dispersed from the storage site into terrestrial and aquatic environments through runoff. Raindrop impact and the overland flow of water (i.e., runoff) are processes that result in water erosion of both suspended and dissolved solids. Although raindrop impact contributes to displacement of erodible materials, runoff is the principal transport mechanism of the erosion-sedimentation processes induced by water.

There are two aspects of waste storage that may be affected by erosion: the waste material itself and cover or containment materials used to confine the wastes. The cover and containment materials are usually composed of disturbed and perhaps compacted soils and subsoils. The principles of erosion that have been elucidated over the past several decades are derived from the behavior of undisturbed soils. In the discussion of erosion presented here, these principles are applied to the erosion of wastes and cover on containment materials. These materials do not behave exactly like true soils, but the general principles of erosion are still valid.

The potential for transport of coal combustion wastes into the environment through runoff is a function of (1) the method of ash and FGD sludge storage, (2) local climatic conditions, (3) topography, and (4) waste or cover material characteristics. Brief intense rainfalls, sparse vegetative cover, low infiltration capacity, and location of a storage facility in hilly topography will promote erosion.

QUANTIFICATION [44-50]

At sites where water erosion is a critical issue, the investigator may elect to use the Universal Soil Loss Equation (USLE) for predicting erosion potential. The equation is usually adequate for characterizing the water-erosion potential for small areas such as waste-storage sites (Wischmeier and Smith 1978) because it can be used to estimate the sediment generated and displaced from a given area by sheet and rill erosion during a future period of time. As presented here, the USLE should not be interpreted as a precise prediction of erosion loss. Many of the factors influencing erosion have been generalized to obtain a tool that can be readily used without a background in soil science. The USLE is expressed as:

$$\text{Erosion Loss} = R \times K \times LS \times C \times P \tag{4}$$

The soil model from which the USLE was derived can be extrapolated to other materials such as berm spoils, coal ash, and FGD sludge. Thus, we have used this equation as a means of estimating erodibility of coal combustion waste-storage areas. However, the properties of combustion wastes and soils are different due to differing origins of the materials, and, although the factors that influence soil erosion can generally be said to affect the erosion of other materials, the magnitude of the effects may not be precisely the same.

Rainfall Factors (R)

Rainfall factors or R values, which represent the integration of raindrop effect and the amount of runoff, have been calculated for numerous areas throughout the contiguous United States. They are the basis for the isoerodent (lines of equal R values) delineations shown in Figure 27. The R value for a given site can be established by interpolation between two adjacent isoerodents. For example, R values for the southern third of Illinois range between 200 and 250; the value for a site equidistant between the isoerodents is 225. The isoerodents are based on rainfall characteristics, and empirical evidence shows that R values for areas where significant runoff results from ice and snowmelt must be adjusted by adding 1.5 times the rainfall equivalent of the annual snowfall. For example, given an R value of 20 in western Colorado and precipitation from 1 December through 31 March equivalent to 12 inches of water: $R = 1.5\ (12) + 20$, or 38.

Erodibility Factors (K)

Tables of experimentally determined erodibility factors or K values are available from state SCS offices for many specific soils. However, such values may or may not be appropriate for subsurface and other materials exposed during site development and management operations. Given the textural composition, organic matter content, structural characteristics, and permeability of the materials to be exposed, the K values can be approximated by use of the nomograph presented as Figure 28. Much of the necessary information should be obtainable from the utility. Other information can usually be extracted or approximated from published soil surveys or other literature, but analysis of materials will probably be necessary in some instances. For dry coal ash, K is approximately 0.85--assuming particle size distribution of a clay, no organic matter, very fine granular structure, and very slow permeability.

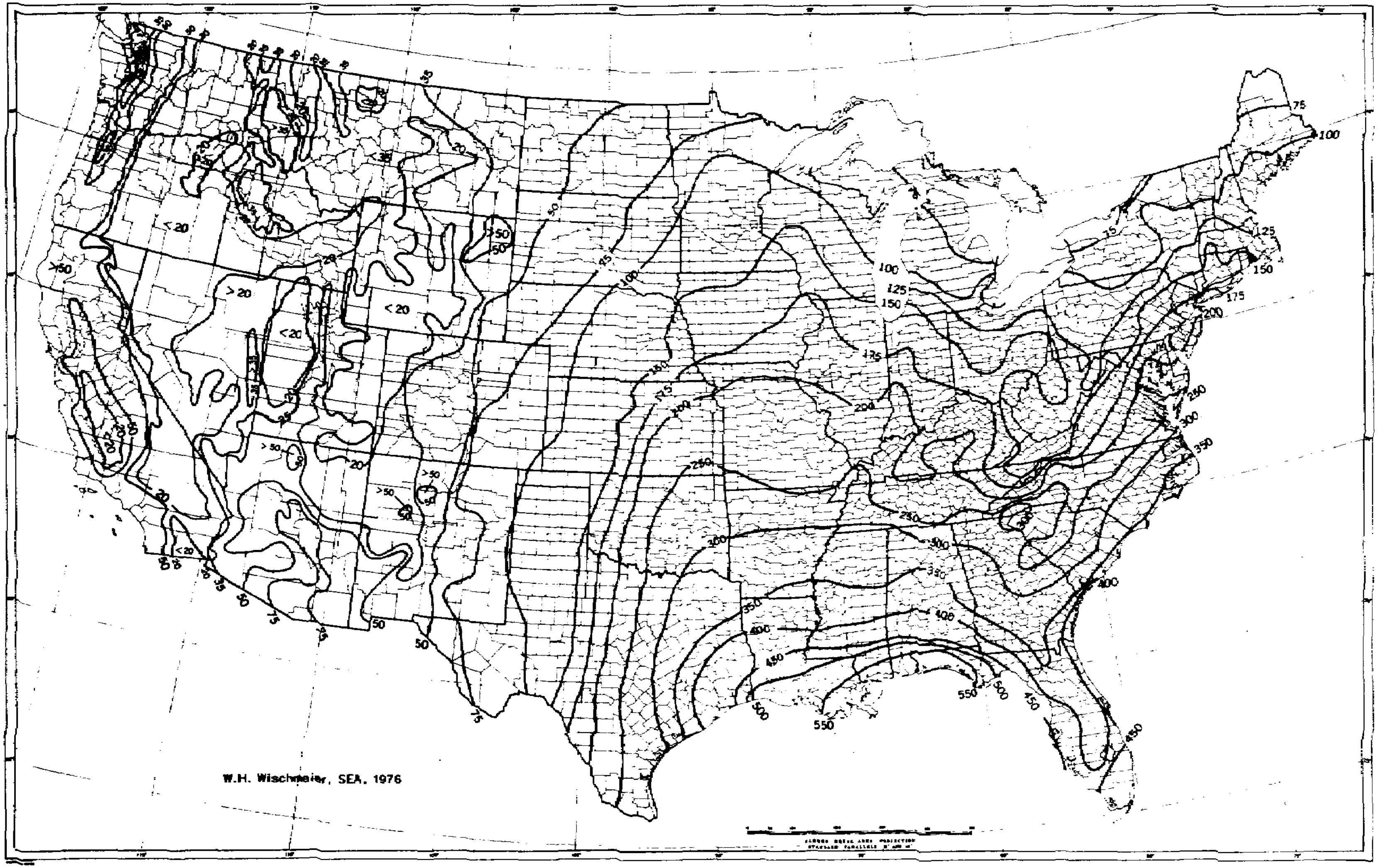


Figure 27. Average Annual Values of the Rainfall Erosion Index. From Wischmeier and Smith (1978).

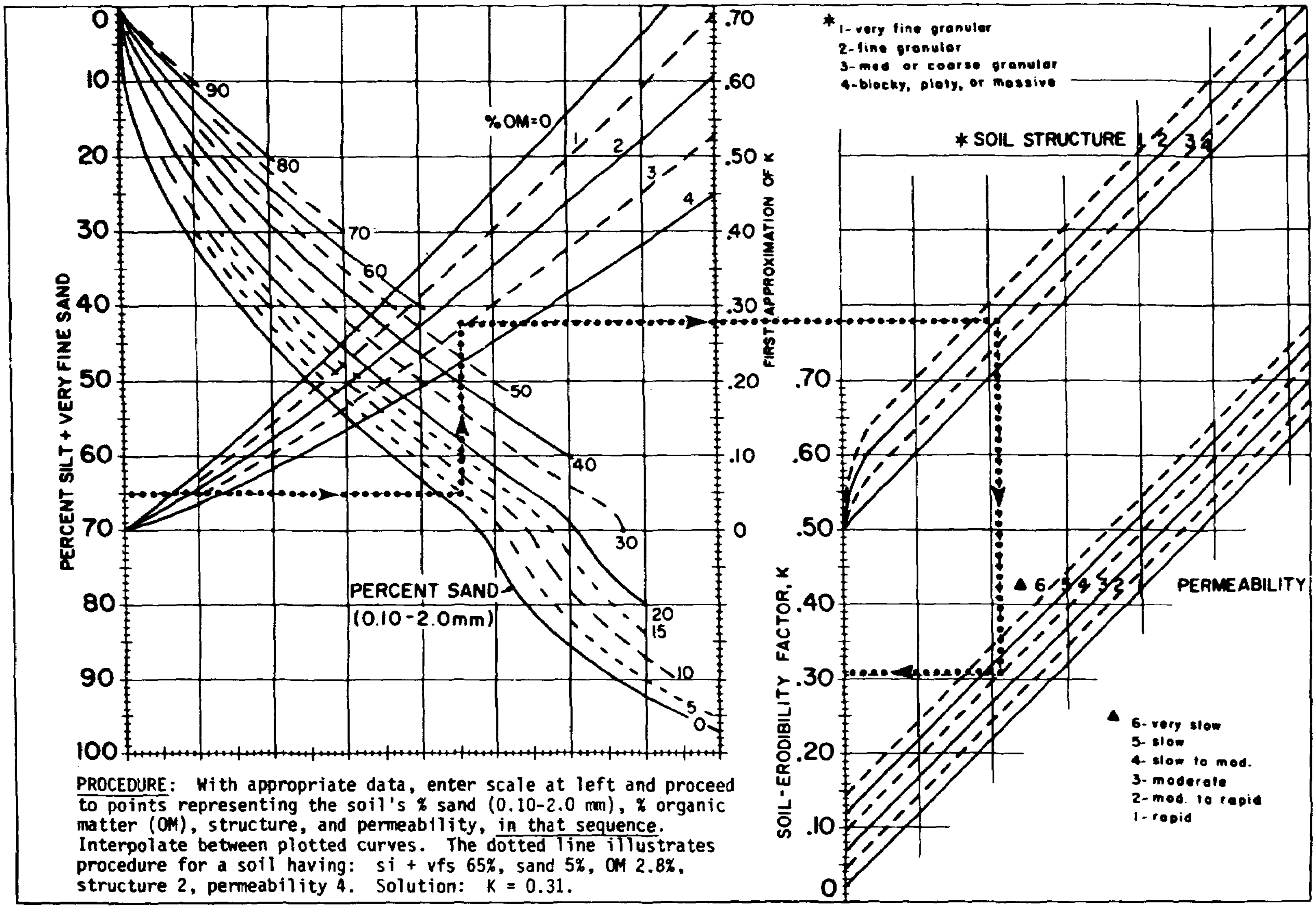


Figure 28. The Soil-Erodibility Nomograph. From Wischmeier and Smith (1978).

Topographic Factors (LS)

Topographic factors (LS) are a combination of slope length (L) and slope gradient (S) factors. The L factor is the ratio of soil loss from the field slope length of the area in question to that from a 72.6-ft slope length under identical conditions. The S factor is the ratio of the soil loss from a field slope gradient to that from a 9% slope under otherwise identical conditions. Topographic factors are presented in Figure 29. To use the figure, identify a field-measured length of slope on the horizontal axis; move vertically to intercept the appropriate percent slope measured in the field; then read the LS value on scale at the left. For example, the LS value for a 200-ft slope with a 14% gradient is about three. The LS values derived in this manner are appropriate only for uniform slopes.

Cover Factors (C)

Cover factors (C) represent the effects of vegetative cover and land-management variables (including effects associated with agricultural practices). In the event that all aboveground vegetation and plant roots are removed, as in the case of an unrevegetated waste-storage pile, C for the denuded area will be equal to one. Numerous measures can be initiated to reduce the C value, including applications of various types of mulch. Some examples of the effects of mulching are illustrated in Table 12.

Support Practice Factors (P)

The support practice factor (P) is the ratio of soil loss with a support practice (contouring, strip cropping, or terraining) to that with straight-row farming up and down the slope. P factors for open waste dumps will usually be equal to one, and thus will not affect estimates based on other USLE factors. P factors for managed waste dumps can be less. Terracing could be used to reduce LS, but the erosion-reducing effects due to terracing would be accounted for in the determinations of LS values.

IMPACT ANALYSIS [44-50]

Evaluating Erosion Potential

Evaluating erosion potential is a prerequisite to assessing the potential for dispersal of waste constituents from a given waste-storage site. Although it is unlikely that information will be available describing the physical characteristics of the coal ash or scrubber sludge to be produced by a proposed coal-burning powerplant, data from the literature (e.g., Duvel et al. 1979; GAI Consultants, Inc. 1979; and Page et al. 1979) can be used to adequately describe the waste materials. When these data are coupled with design details of the proposed waste-storage facility (e.g., method of waste deposition, length and steepness of slopes) and information describing local topography and climatic conditions, the USLE can then be used to estimate the potential for erosion of berms and wastes from the proposed facility.

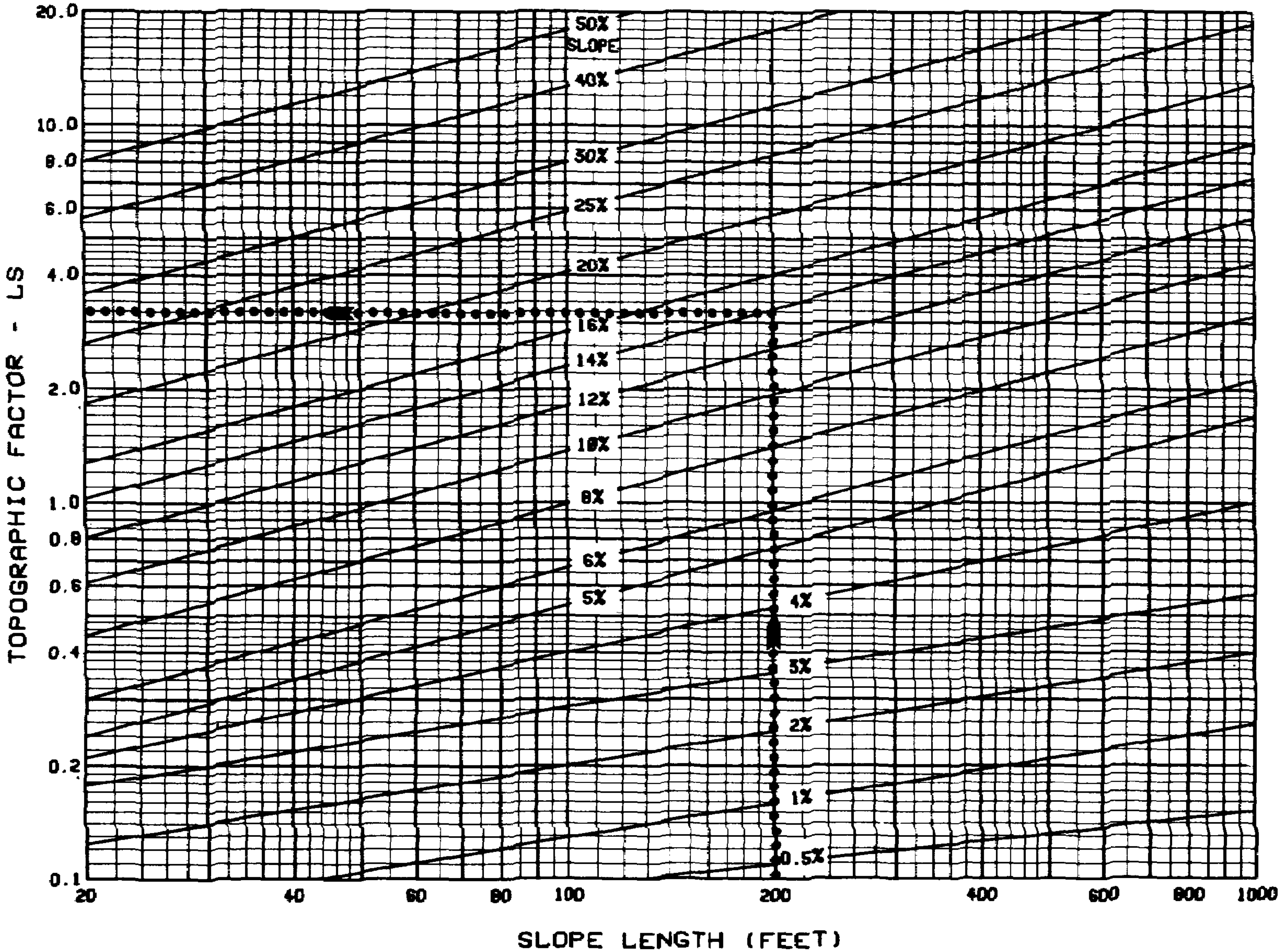


Figure 29. Slope Effect Chart. The dotted line illustrates the example on page 65. From Wischmeier and Smith (1978).

Table 12. Mulch Factors and Length Limits for Construction Slopes[a]

Type of mulch	Mulch rate (103 kg/ha)	Land slope (%)	Cover factor (C)	Length limit[b] (m)
None	0	all	1.0	-
Straw or hay	2.2	1-5	0.20	60
(tied down by anchoring and	2.2	6-10	0.20	30
tacking equipment)[c]	3.3	1-5	0.12	90
	3.3	6-10	0.12	45
	4.4	1-5	0.06	120
	4.4	6-10	0.06	60
	4.4	11-15	0.07	45
	4.4	16-20	0.11	30
	4.4	21-25	0.14	22
	4.4	26-33	0.17	15
	4.4	34-50	0.20	10
Crushed stone	297.	<16	0.05	60
(¼ to 1½ inches)	297.	16-20	0.05	45
	297.	21-33	0.05	30
	297.	34-50	0.05	22
	528.	<21	0.02	90
	528.	21-33	0.02	60
	528.	34-50	0.02	45
Wood chips	15.	<16	0.08	22
	15.	16-20	0.08	15
	26.	<16	0.05	45
	26.	16-20	0.05	30
	26.	21-33	0.05	22
	55.	<16	0.02	60
	55.	16-20	0.02	45
	55.	21-33	0.02	30
	55.	34-50	0.02	22

[a]Adapted from Meyer and Parts (1976). Originally developed by an interagency workshop group on the basis of field experience and limited research data.

[b]Maximum slope length for which the specified mulch rate is considered effective. When this limit is exceeded, either a higher application rate or mechanical shortening of the effective slope length is required.

[c]When the straw or hay mulch is not anchored to the soil, C values on moderate or steep slopes of soils having K values greater than 0.30 should be taken at double the values given in this table.

Careful consideration should also be given to how local soils used in the construction of dikes or runoff channels could be affected by water erosion. Soils containing a high proportion of clay will have low infiltration capacities, which will enhance runoff. Soil survey maps with suitable interpretations will provide information for specific sites, including erosion potential. These surveys may identify plants suitable for establishing vegetation cover with a minimum of soil treatment. Many such surveys are available from local Soil Conservation Service offices. In addition, onsite soil investigations before and during operations are generally needed to supplement the soil survey.

The USLE can be used to estimate the amounts of water erosion expected from a waste-storage facility. However, the biologist must determine whether a given level of erosion will be hazardous to the biota of adjacent areas or eventually undermine the integrity of the storage facility.

Impact of Runoff Dispersal from the Model Storage Sites

In the Wyoming, Ohio, and North Carolina model storage sites, scrubber sludge or the combination of scrubber sludge and coal ash are disposed of in diked storage ponds. For each of these storage facilities, the length-slope factor of the USLE is zero for the storage area; therefore, erosion loss per unit area per unit time is zero. Potential for soil loss from the storage pond dikes can be minimized by proper design to preserve dike integrity.

At the Texas model plant, runoff dispersal of the wastes could occur without proper management of the heaped-landfill. The rainfall and runoff factor (R) of the USLE is high (Figure 27). The soil erodibility factor (K) is approximately 0.85 for ash and 0.68 for Tuckerman loam soil cover (Figure 28)--assuming that the soil has blocky structure, is very slowly permeable, and is composed of 0% organic matter, 80% fine sand and silt, and 5% sand. The vegetation cover (C) and support practice (P) factors can be assumed to be one. As can be seen from the calculation of USLE in Box 5, anticipated erosion loss from the landfill embankments is high. The landfill will have to be properly revegetated to reduce C, and terraced or otherwise contoured to reduce P. Design of the embankment slope could be modified to reduce LS but this would require increasing the areal extent of the landfill.

BOX 5

SAMPLE CALCULATION OF RUNOFF DISPERSAL AT THE TEXAS PLANT

STEP 1: Rainfall and runoff factor (R): Using Figure 27, R = 400.

STEP 2: Soil erodibility index (K): Using Figure 28 for Tuckerman loam (a soil with blocky structure, very slow permeability, and 0% organic matter, 80% fine sand and silt, and 5% sand), K = 0.68.

STEP 3: Topographic factor (LS): Using length of slope (76.9 ft) and percent slope (5:1 or 20%) in Figure 29, LS = 3.6.

STEP 4: Cover factor (C): For an unrevegetated slope, C = 1.

STEP 5: Support factor (P): Assumed for this example, P = 1.

STEP 6: Erosion loss (A): Using Equation 4, $A = R \times K \times LS \times C \times P$ $= 400 \times 0.68 \times 3.6 \times 1 \times 1 =$ 979.2 tons/acre/yr.

INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of runoff and erosion as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Characteristics of soils: Soil maps Detailed soil descriptions Land-use capabilities and limitations Soil management guidelines Descriptions of local climate, geology, and topography	Field offices of Soil Conservation Service Local universities
Precipitation and evaporation potential	Local weather reporter Natl. Weather Service Facility operator
Design of the storage site	Facility operator
Properties of the waste	Facility operator

MITIGATIVE MEASURES [111]

In general, mitigation of erosion involves manipulating the parameters of the Universal Soil Loss Equation in order to reduce the rate of soil loss.

Storage-Site Design

Various structures can be designed to control surface runoff from waste -storage sites, including:

- Contour terraces, at intervals normal for sloping surfaces, to increase surface storage capacity

- Storage or siltation ponds to increase surface storage capacity

- Ditches, earthern dikes, piping, hay bales to temporarily divert and spread runoff

- Permanent structures to collect and channelize runoff

- Permanent check dams, at intervals within the runoff-collection channel, to control gully or channel erosion and depositions of sediment downslope

The kinds and extent of structures used for surface runoff control will be dependent on site-specific considerations. Control measures will also vary according to the storage method.

Physical Methods

Surface runoff from waste-storage sites can be reduced through the use of the following techniques:

- Tillage of waste surfaces to increase roughness and cloddiness of exposed materials, thereby increasing rainfall infiltration.

- Emplacement of organic mulches crimped into surface materials by discing.

- Applications of thin layers of coarse gravel, country rock, or crushed stone.

Chemical Methods

The promotion of surface crusting by chemical stabilizers is effective for controlling water erosion. Surface crusts absorb the energy of raindrop impact, preventing the detachment of surface particles. However, these crusts also decrease rainfall infiltration and enhance surface runoff. Because of the binding effect of the stabilizers, the runoff would have a lower particulate load. Several available chemicals have been shown to be cost effective in stabilizing mill tailings under laboratory conditions (Dean et al. 1974).

Vegetative Methods

The establishment of a self-perpetuating vegetative cover on a waste-storage site is one of the more cost-effective and aesthetically desirable methods for controlling water erosion. Vegetation obstructs the flow and tends to reduce the velocity of surface runoff, thus reducing the erosive force of the runoff. However, opportunities for establishing vegetation prior to final reclamation of a given waste-storage area will be dependent on site-specific conditions as well as the storage method.

Chapter 8
Seepage of Leachate

POTENTIAL IMPACTS [50-54]

Vertical and lateral seepage of leachate can occur from ash and sludge waste-storage sites, particularly where the waste material is deposited as a slurry. The major impact of seepage is addition of potentially toxic leachate waste constituents to groundwater and soil. Contamination of groundwater can result in eventual contamination of fish and wildlife water sources.

Seepage and transport of potentially toxic elements and ions from storage sites are influenced by a number of factors (Dvorak et al. 1978; Duvel et al. 1979). The most important are: physicochemical properties of ash and/or sludge waste and surrounding substrate (including permeability, pH, cation exchange capacity, and trace element composition) and rainfall zone.

Physicochemical Properties of Waste Materials and Surrounding Substrate

Permeability. Permeability of ash and sludge wastes and storage-site substrates is one of the most important parameters influencing leachate seepage from storage sites (Duvel et al. 1979). Hydraulic conductivities for different soil types and waste materials are presented in Figure 30. Hydraulic conductivity (k) is a constant property of a material and is one of the parameters determining permeability of that material. Permeability is a direct function of k. Hydraulic conductivity is expressed in units of length per time (e.g., cm/s).

Stratification of soils and wastes can also markedly affect permeability by creating layers of differing compaction. Other factors affecting permeability are density, trapped air pockets, and dissolved salt content of the leachate--all of which are inversely correlated with bulk water movement (Duvel et al. 1979). Contamination of groundwater is related to the permeability of the impoundment material; in general, the permeability of such material increases in the order: granite < shale < sandstone < soil < sand.

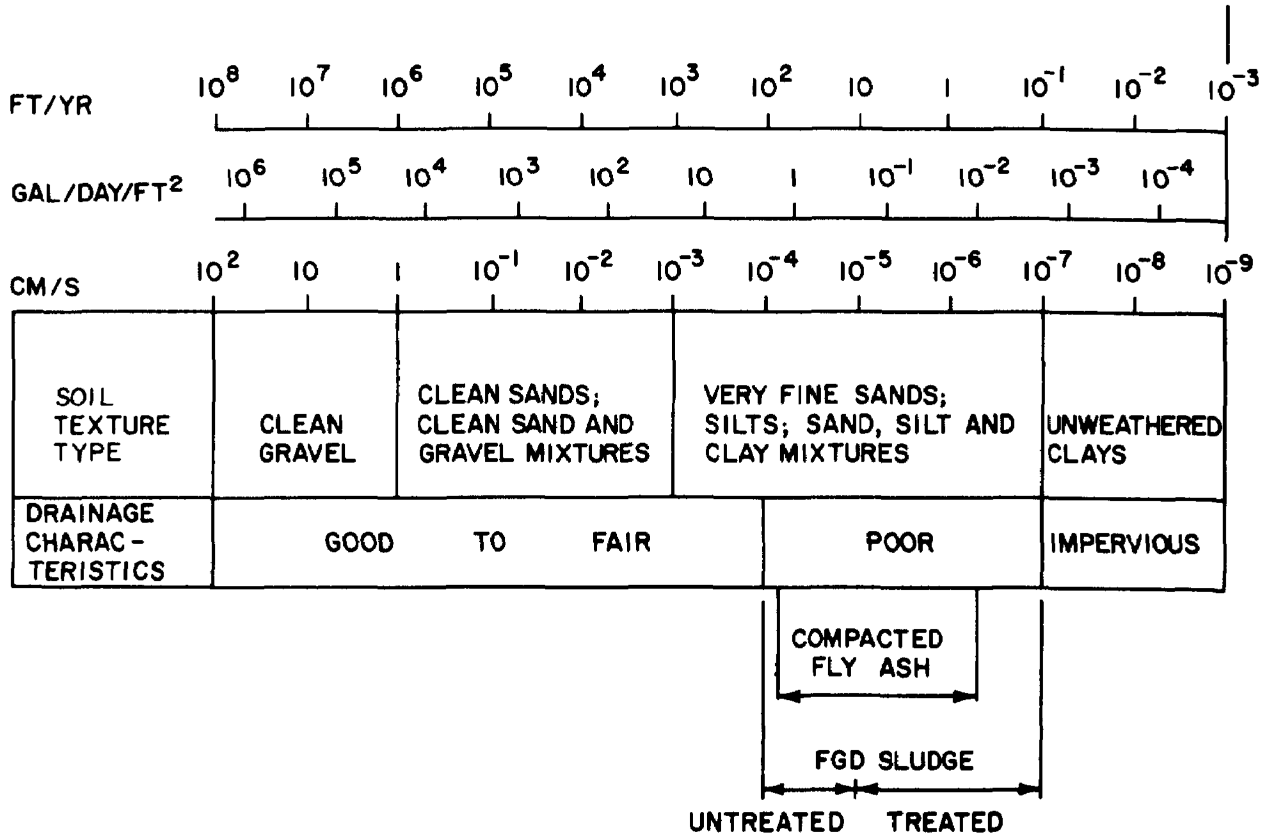


Figure 30. Saturated Hydraulic Conductivities for Different Soil Types at Unit Gradients. Modified from Duvel et al. (1979); compacted fly ash data based on Frascino and Vail (1976).

pH. Soil pH influences movement of leachate seepage. The solubilities of most trace elements in water tend to decrease as pH is increased (Frascino and Vail 1976). The pH of most ash- and sludge-pond leachates will be neutral or alkaline. In general, trace-element-toxicity effects should be of more concern when the absorbing medium (soil) and transporting medium (pond leachates) are acidic rather than neutral to alkaline. However, elements forming anions (e.g., boron and arsenic) may be as mobile under alkaline as under acidic conditions.

Cation exchange capacity. Cation exchange capacity of a soil influences transport of solutes. In general, the higher the clay content and organic matter of a soil, the greater is its cation exchange capacity (Table 13). A high clay content in a soil tends to bind cations in seepage and to reduce the percentage of cations entering groundwater. Such retention in the soil allows a greater concentration source for eventual uptake by vegetation. If the soils are sandy, there is a tendency for rainfall to leach away the cations from the root zone, but this increases the chances for groundwater contamination.

Table 13. Factors Affecting Soil Cation Exchange Capacity (CEC)[a]

Soil factor	Relative CEC
Texture	
Sand	Low
Loam	Moderate
Clay	High
Organic content	
Low	Low
High	High
Clay type	
Hydrous oxides	Low (4 meq/100 g)
Kaolinite	Low (8 meq/100 g)
Chlorite	Low (30 meq/100 g)
Hydrous micas	Low (30 meq/100 g)
Montmorillonite	High (100 meq/100 g)
Vermiculite	High (150 meq/100 g)

[a]Based on data in Brady (1974).

Trace-element composition. The background levels of trace elements in soils are important in influencing the potential for toxic effects from waste leachate. There are regions of the country where high concentrations of certain elements such as selenium and molybdenum occur locally (see Dvorak et al. 1978). In these regions, addition to the soil of these elements from waste seepage over the long term may aggravate the potential for adverse effects to wildlife. Also, incoming seepage may displace potentially toxic ions (e.g., aluminum) from soil and transport them to groundwater.

Rainfall Zone

The amount of rainfall entering a waste-storage site and its environs markedly affects the potential for adverse effects from the waste at sites where the waste-storage impoundments are not lined. If the average annual rainfall is low, seepage from the waste-storage site will tend to remain in the upper layers of the soil, thus increasing the chances for uptake by vegetation; however, seepage to groundwater will be low, depending on the depth at which the water table occurs. In zones of high rainfall, ionic constituents of waste will tend to be leached rapidly to groundwater, particularly where the substrate is sandy or otherwise relatively permeable. High rainfall will also tend to move dissolved material laterally into the soil.

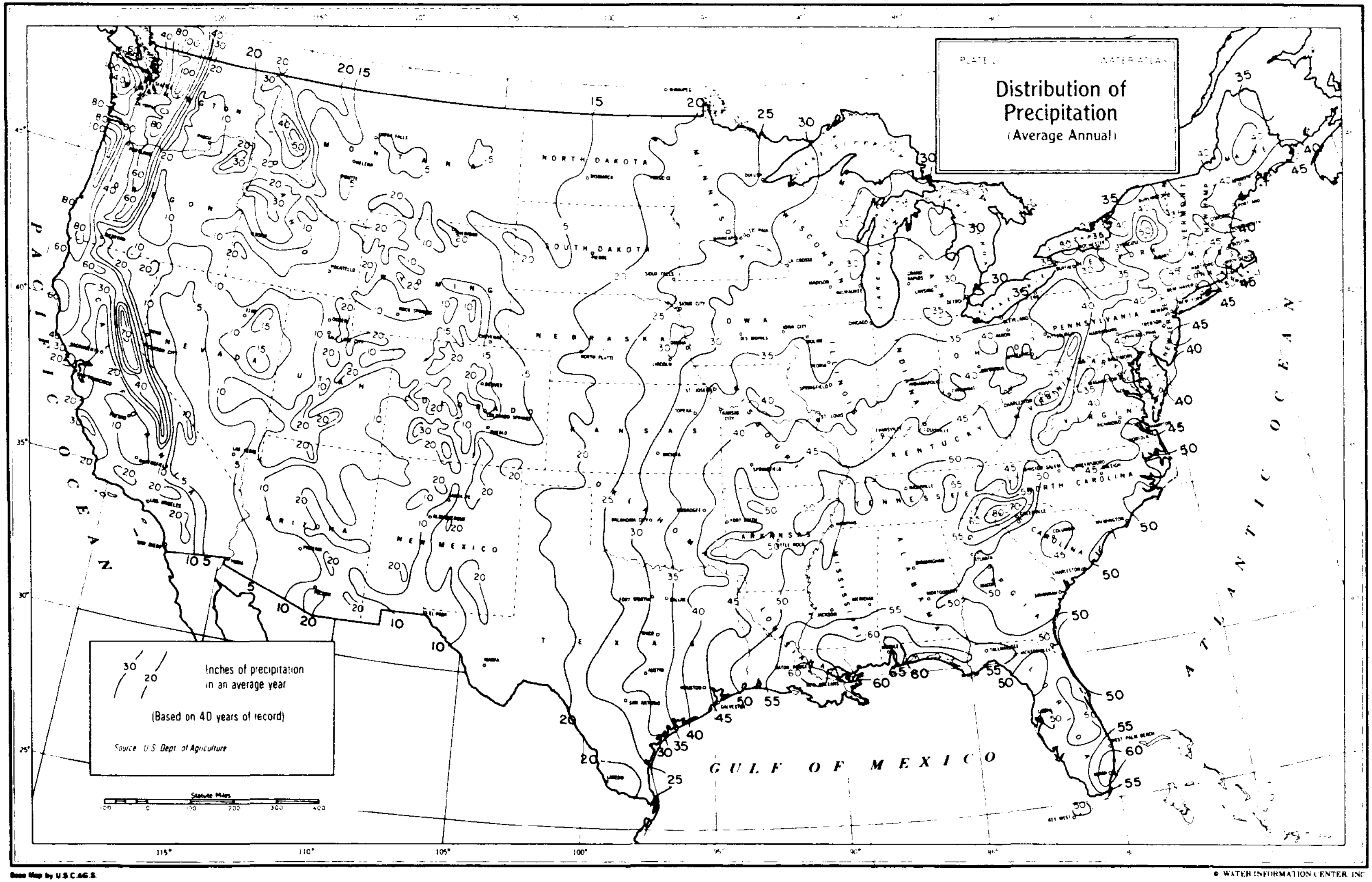


Figure 31. Average Annual Precipitation in the United States. From Geraghty et al. (1973) (reprinted with permission from Water Information Center, Inc., Syosset, NY, Copyright 1973).

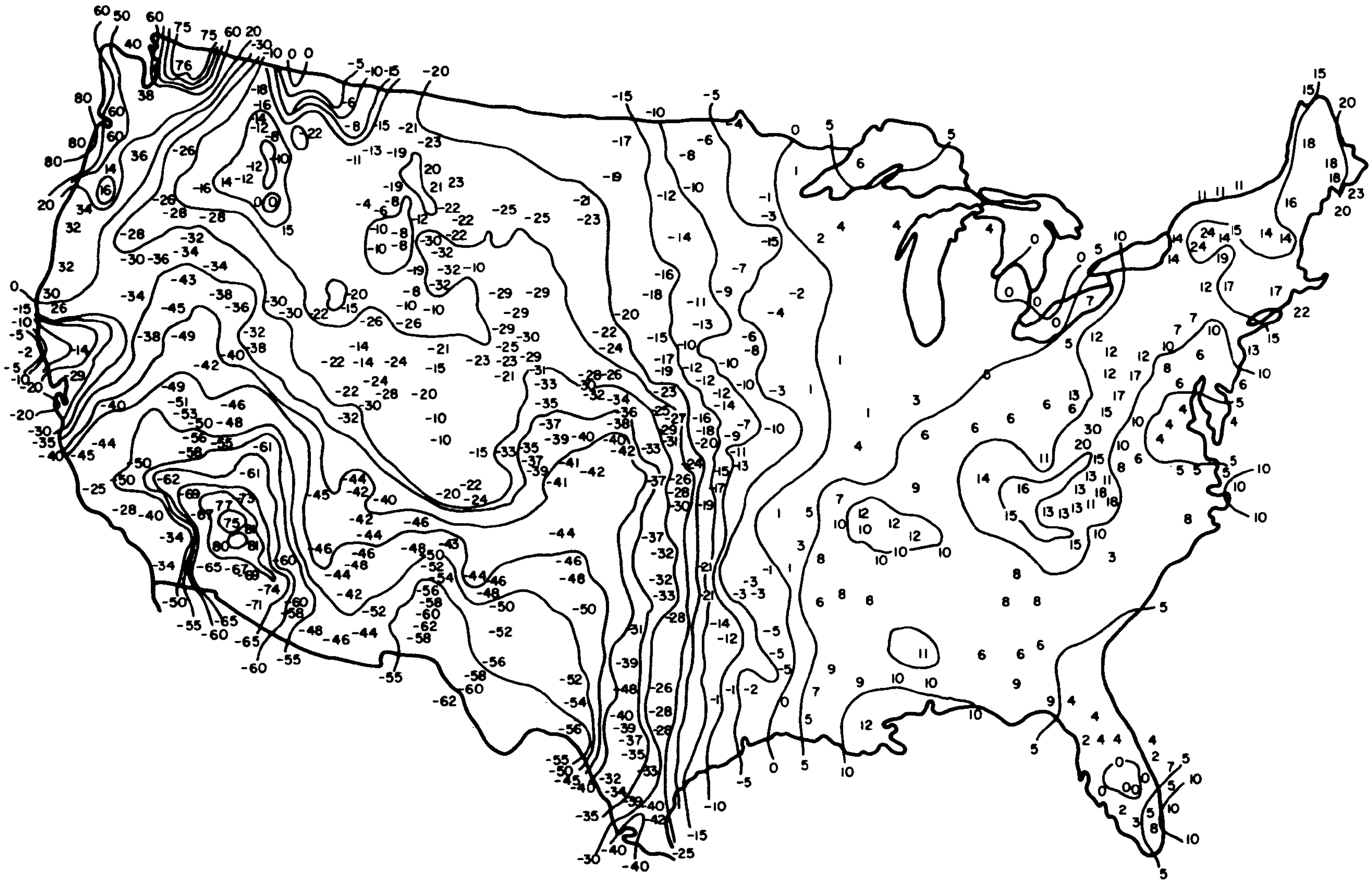


Figure 32. Average Net Precipitation in the United States. Figures represent difference in inches between precipitation and evaporation. From Duvel et al. (1979).

Average annual and net precipitation (difference in inches between precipitation and evaporation) tend to increase west to east across the United States, excluding coastal areas (Figures 31 and 32). Average net precipitation values in the eastern United States are positive, whereas in most of the western United States values are negative. In general, leachate quantities are likely to be greater in the eastern part of the country. However, in the arid West where net precipitation is negative, seepage of ions could lead to soil salinization as the ions are carried up into the plant rooting zone.

QUANTIFICATION AND IMPACT ANALYSIS [54-59]

Quantity, composition, and movement (seepage) of leachate are influenced by the physicochemical properties of the wastes and surrounding substrates, climatic conditions, and storage-site design and management practices that are site-specific (Duvel et al. 1979). The accuracy of estimating quantities of leachate seepage depends on the accuracy of permeability estimates, which requires extensive field and laboratory testing of ash and sludge wastes and storage-site substrates. However, given some general information about a particular site and assuming that the storage area is unlined, some indication of the potential for impact from seepage can be derived from the data in Table 14. Additionally, one can obtain estimates of leachate production using the following procedures.

Landfill Leachate Production

Order-of-magnitude estimates of leachate quantities from landfill storage sites are obtained by assuming a given percent infiltration, with overall hydraulic conductivity (k) of the waste or substrate being a limiting condition (Figure 33) (Duvel et al. 1979); either the overall percent infiltration or the hydraulic conductivity of the materials can limit the leachate quantity in each situation. A net infiltration rate of 20% of the precipitation is a reasonable estimate for many situations. However, when site-specific measurements are available, 30%, 40%, or 50% net infiltration may be more appropriate. Using Figure 33, if the average rainfall is 50 cm/yr (20 in./yr), with 20% infiltration and $k = 7.5 \times 10^{-7}$ cm/s, the leachate seepage rate from the storage site--which is limited by the infiltration rate in this case--would be about 4.2 m^3/ha/day (450 gal/acre/day). If $k = 2.5 \times 10^{-7}$ cm/s, the leachate seepage from the storage site--which is limited by hydraulic conductivity of the materials in this case--would be about 2.1 m^3/ha/day (225 gal/acre/day). By selecting the appropriate lining materials and proper compaction of the fill, hydraulic conductivity can be adjusted at a landfill site to minimize the leachate seepage rate.

Pond Leachate Production

The quantity of seepage from a pond storage system is influenced by permeability of the wastes and substrate, dimensions and configuration of the pond, and boundary conditions of the entire system. Unlike landfill sites, supernatant liquid is present as a recharge source for leachate generation. Figure 34 can be used to obtain an approximate estimate of seepage quantities

Table 14. Potential for Adverse Effects to Groundwater from Seepage from Unlined Ash and Sludge Waste-Storage Sites[a]

Factor	Relative probability of groundwater contamination
Nature of waste	
Dry	Low to moderate
Slurry	High
Acid	High
Alkaline	Low to moderate
Nature of substrata[b]	
Granite	Extremely low
Shale	Low
Sandstone	Moderate
Soil	
Clays	Low
Loams	High
Sands, sandy loams	Very high
Rainfall zone[c]	
$<$ 25 cm ($<$ 10 inches)	Low
25-76 cm (10-30 inches)	Low to high
$>$ 76 cm ($>$ 30 inches)	High

[a]Derived from Dvorak et al. (1978).
[b]Defined as the layer or layers of natural material beneath the waste, or between the waste impoundment and the groundwater aquifer, and may include the soil.
[c]Annual average precipitation.

if (1) the substrate beneath the pond is more permeable than the wastes, (2) the depth to any impervious stratum is much greater than pond depth, (3) the depth of supernatant is small compared to sludge depth, and (4) there are no complex subsurface conditions. For example, if the hydraulic conductivity of the sludge is 10^{-5} cm/s, the volume of leachate generated is about 84 m^3/ha/day (9000 gal/acre/day) (Figure 34). If substrate permeability is less than waste permeability or if depth to an impervious layer beneath the pond is not much greater than pond depth, the seepage quantities will be less than predicted by using Figure 34. If the depth of pond supernatant is large, seepage quantities will be increased; depth of pond supernatant is dependent on net precipitation (Figure 32) and storage practices. A method for estimating seepage quantities in cases with more complex boundary conditions than those assumed in Figure 34 has been developed by Witherspoon and Narasimhan (1973).

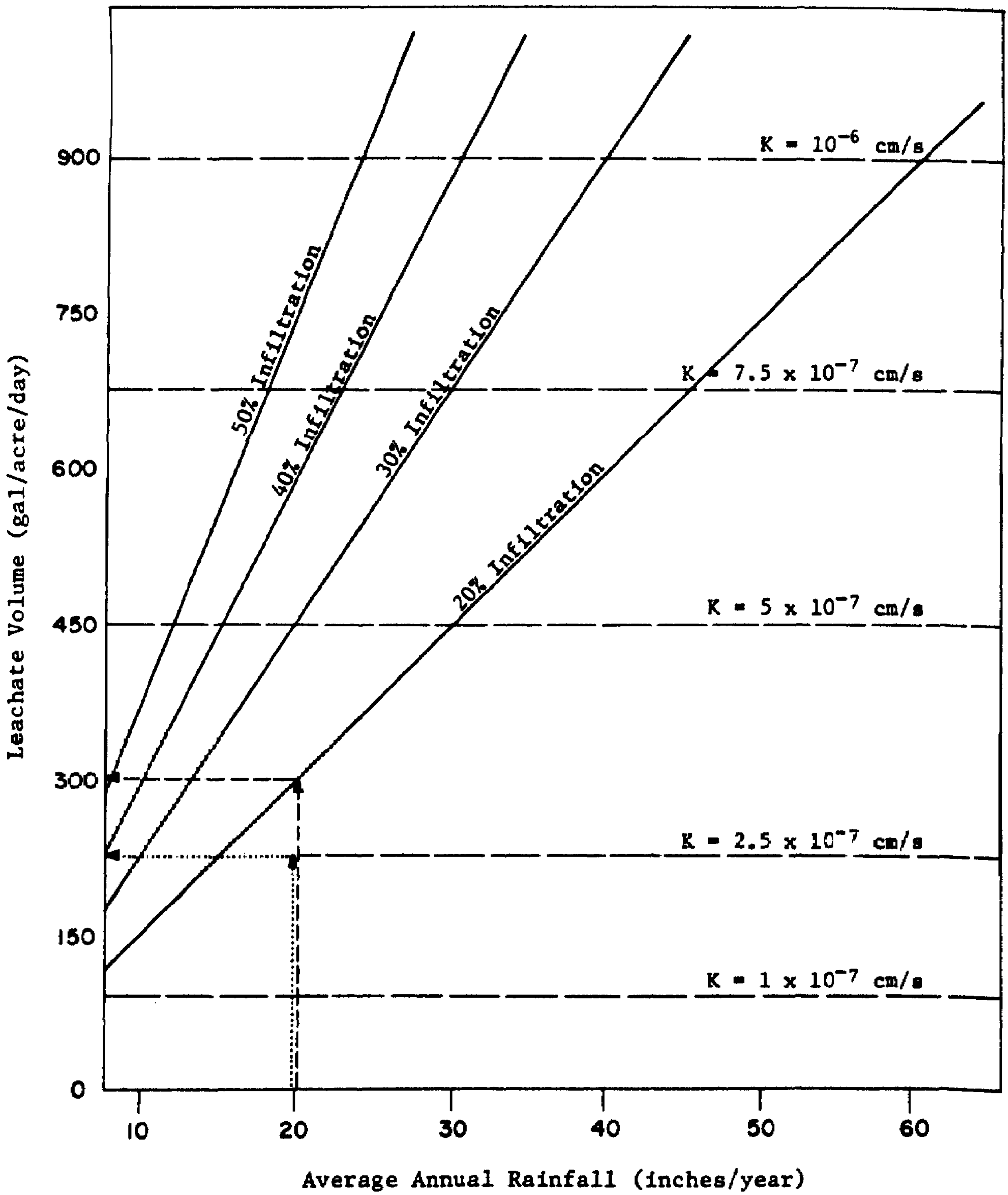


Figure 33. Quantity of Leachate from a Landfill. The dashed line illustrates the infiltration-limited example and the dotted line the conductivity-limited example on page 77. From Duvel et al. (1979).

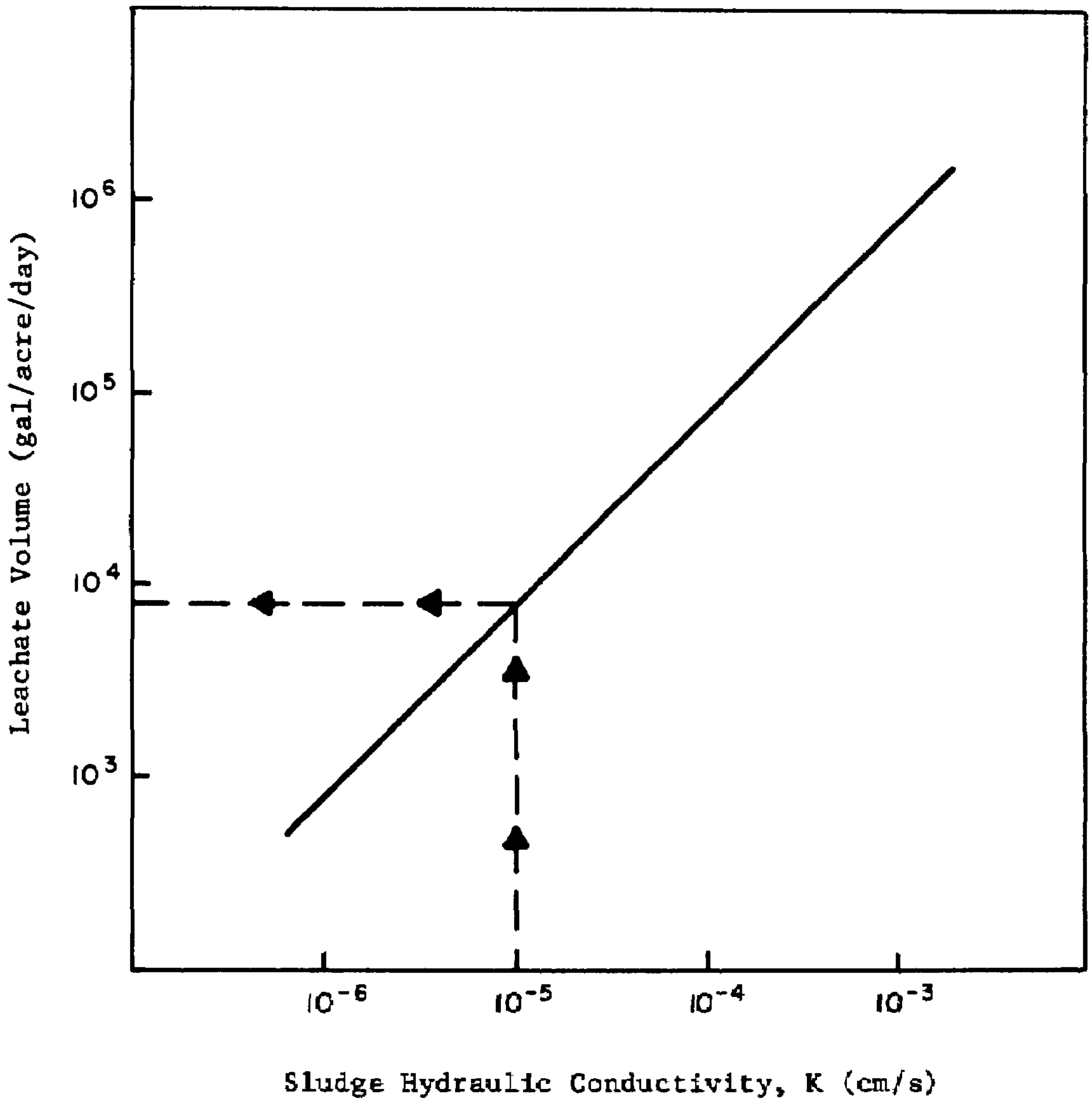


Figure 34. Effect of Sludge Hydraulic Conductivity on the Volume of Leachate from a Pond. The dashed line illustrates the pond leachate example on page 77. From Duvel et al. (1979).

Leachate Seepage Discharge from the Model Plant Storage Sites

The sandy loam soils and somewhat higher rainfall at the North Carolina site means that there is a large potential for impacts from leachate seepage from an unlined pond at this site (Table 14). The Ohio site has a slightly higher potential for leachate dispersal than the Wyoming site because of the higher rainfall. Dry storage at the Texas site results in the least potential for leachate dispersal.

A permanent head of water will not be allowed to develop at the Wyoming and Ohio waste-storage sites. Therefore, leachate discharges from the storage areas may be estimated using Figure 33. However, rainfall will pool up in the ponds, allowing for nearly 100% infiltration of the water; in both cases, the seepage rate is limited by hydraulic conductivity.

Seepage discharge from the Wyoming pond is limited by hydraulic conductivity of the clay liner (hydraulic conductivity = 7.5×10^{-7} cm/s). Therefore, the discharge rate is approximately 6.3 m^3/ha/day (680 gal/acre/day) through an average of 40 ha (98 acres) of 250 m^3/day (9 ha-m/yr) seepage from the storage site. Leachate from the ash wastes may alter the quantity or quality of leachate associated with coal mining activities, but this cannot be quantified without more detailed knowledge of the local subsurface hydrology.

Seepage discharge from the Ohio pond is limited by the clay liner (hydraulic conductivity = 5×10^{-7} cm/s). Therefore, the discharge rate is approximately 4.2 m^3/ha/day (450 gal/acre/day) through an average of 510 ha (1260 acres), or 80 ha-m/yr (650 acre-ft/yr) seepage from the storage site.

Seepage discharge from the Texas landfill is not limited by the hydraulic conductivity of the ash-sludge mixture. With an average annual rainfall of 114 cm with 20% infiltration, the discharge rate is approximately 6.3 m^3/ha/day (680 gal/acre/day) through 0 to 730 ha (0 to 1800 acres) as the landfill increases in size.

Leachate seepage at the North Carolina site is collected by the underdrain system and recycled to the scrubber system and not discharged to the environment.

INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of seepage of leachate as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Design and operation of the storage site	Facility operator
Climatology and meteorology	Facility operator Natl. Weather Service
Characteristics of soils	Facility operator Field offices of Soil Conservation Service
Depth to water table	Facility operator U.S. Geological Survey Field offices of Soil Conservation Service

MITIGATIVE MEASURES [104-106]

Steps should be taken to minimize leachate seepage to groundwater if a problem is indicated. This is particularly important where an underlying aquifer is either currently or potentially useful as a water supply. Contamination is less likely where the difference between water table elevation and bottom of the landfill or pond is large. Additionally, movement of leachate seepage away from a storage site can be reduced by using liners, stabilizing the wastes and reducing permeability, or using underdrains. However, liners have a finite lifetime, and the seepage rate will increase as a liner deteriorates.

A wide variety of natural or synthetic materials may be placed on the inside surface of an impoundment basin to reduce seepage from the basin., The necessity for a liner is dependent upon the properties of the ponded effluents, the quantity and chemical quality of potential leachate, the impacts of seepage, the geology and geography of the site, the availability of process water, and the regulations governing seepage. Liners may be grouped into five major categories: (1) flexible synthetic liners, (2) admixed materials, (3) soil sealants, (4) natural soil systems, and (5) stabilized wastes.

Flexible Synthetic Liners

Flexible synthetic liners (e.g., polyvinyl chloride or polyethylene) are the only "impermeable" liners. They are manufactured as long continuous sheets that can be sealed at the edges so that each liner exactly fits the pond. Flexible liners rely upon the earthen structure for support. They may be vulnerable to puncture (especially during installation), aging with exposure to sun or temperature extremes, reaction with ponded wastes, and stresses from trapped gases or groundwater.

Admixed Liners

Admixed liners (such as concrete or gunites) provide some structural support rigidity as well as reducing pond seepage, but they are not impermeable. The major disadvantage of rigid liners is their susceptibility to fracture under seismic, hydrostatic, thermal, and weathering stresses.

Soil Sealants

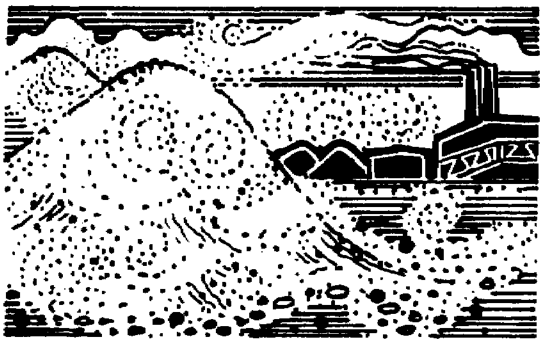
Chemical sealants and soil additives seal the impoundment basin by filling soil interstices or by causing reactions that reduce permeability. Chemical sealants such as sodium carbonate or polyphosphates may be applied by spraying, mixing with soil, or as additions to the waste stream inflow. Chemical sealants are not always effective, due in part to soil nonhomogeneities and in part to the sealant itself. Additionally, the chemicals themselves could pose toxic hazards.

Natural Soil Systems

Liners constructed of natural soil materials will generally be flexible to some degree. They can thus withstand seismic activity and normal subgrade settlement and are usually stable in both wet and dry conditions. In comparison to compacted clay and bentonite liners, liners of coarser textured soils are relatively permeable.

Stabilized Wastes

Stabilized coal combustion and emission-abatement wastes may have value as liners, and waste-storage capacity would be increased by incorporating the wastes into pond embankments. However, the use of compacted wastes for liners is not widespread.



Chapter 9
Wind Erosion and Fugitive Dusting

POTENTIAL IMPACTS [62-65]

Deposited waste materials that have low moisture content and are exposed to strong winds are readily erodible. If proper control measures are taken, wind erosion of ash or sludge waste-storage sites is generally expected to result in minimal fugitive dust impacts to biota of adjacent areas.

Wind erosion moves particulate matter through three transport modes (Figure 35):

- Saltation
- Surface creep
- Suspension

Saltation is the skipping or leap-frogging of windblown particles over a surface. The particles become airborne by wind gusts or by impact of other particles, but they are too large or heavy to remain airborne for long (Donovan et al. 1976). Surface creep is particle motion along a surface without the particles becoming airborne. Suspension is the process whereby particles become airborne and are transported long distances downwind; this process is the most significant source of fugitive dust emissions (Donovan et al. 1976). The range of particle sizes most likely to be affected by each of the three wind erosion processes is shown in Figure 36. The majority of fly ash particles fall into the size range erodible by suspension (Figure 37); thus, the potential exists for these particles to be transported far from the storage site. Because of the inverse relationship between fly ash particle size and the concentration of trace elements adsorbed to the particles, the particles most likely to become airborne also have the greatest potential for carrying toxic trace elements.

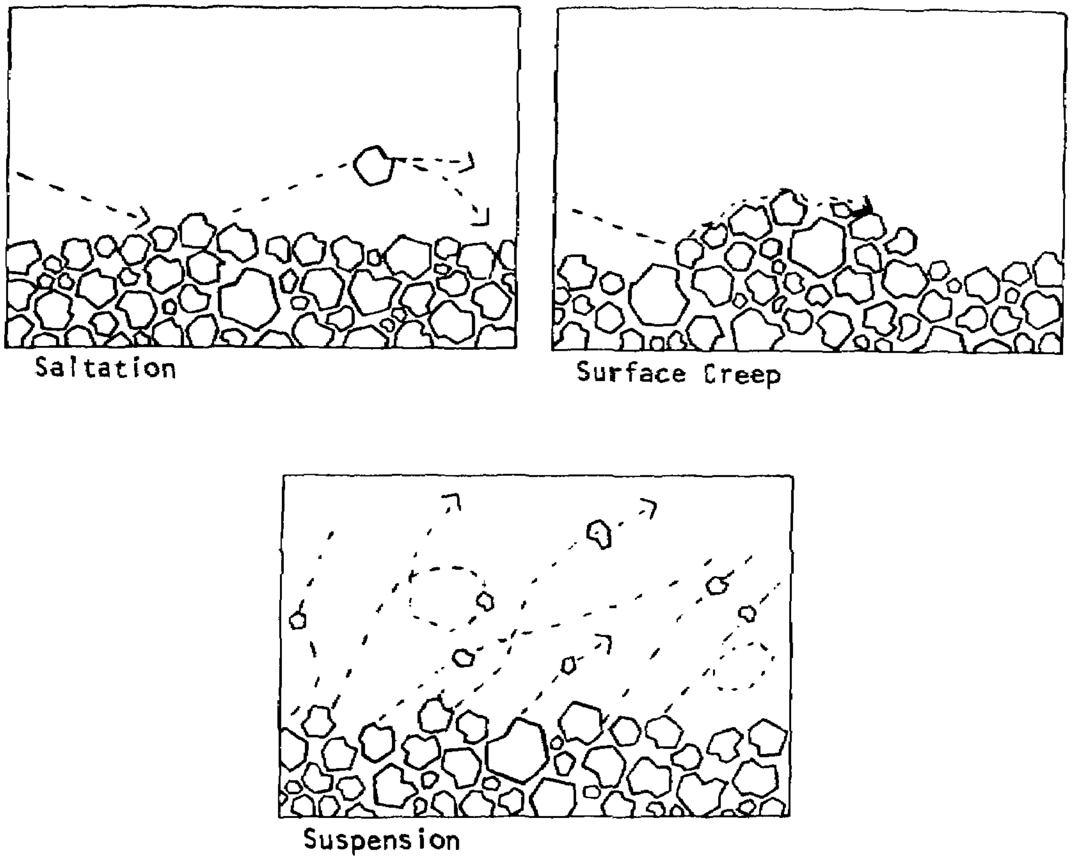


Figure 35. Transport Modes Through Which Particulate Matter is Moved by Wind Erosion. From Donovan et al. (1976) (originally from Witco Chemical Co. 1970).

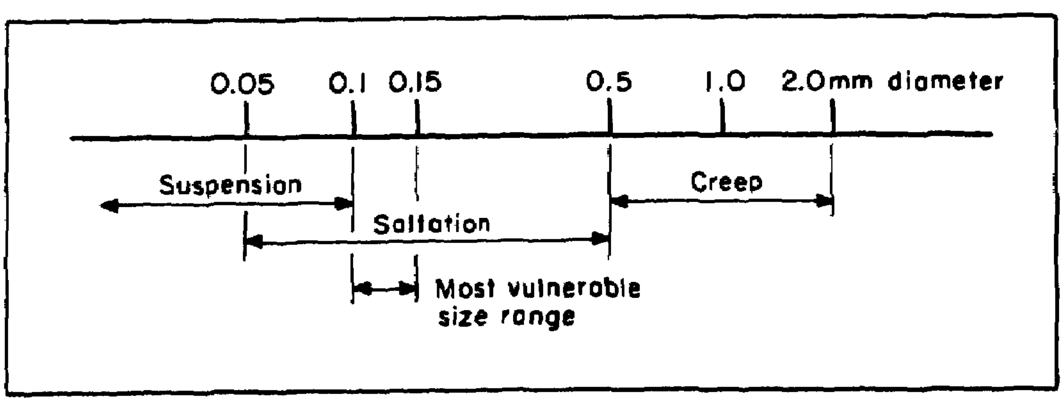


Figure 36. Dominant Mode of Windblown Soil Transport as a Function of Particle Size. Adapted from Donovan et al. (1976) (originally from Hudson 1971).

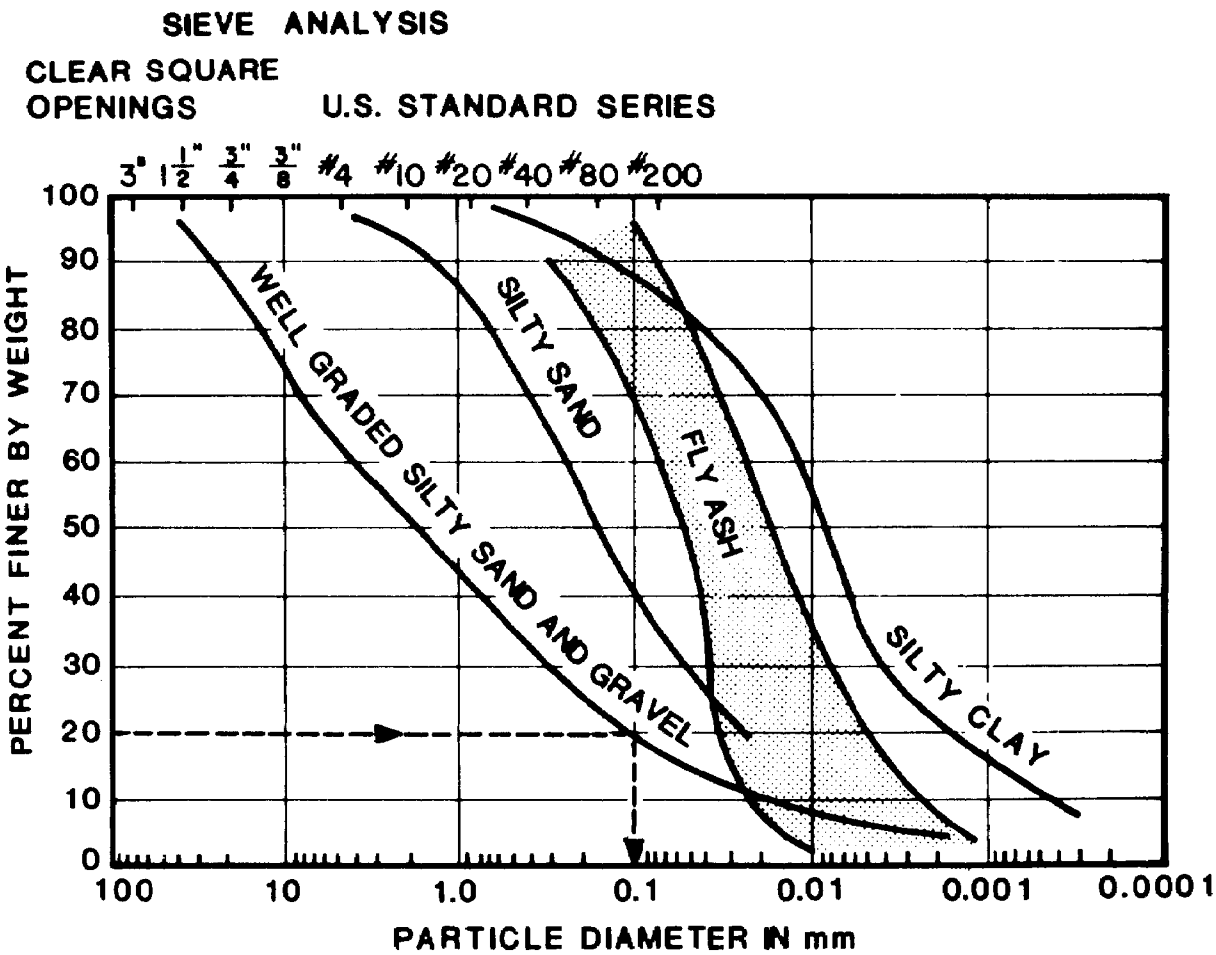


Figure 37. Cumulative Grain Size Distributions for Bituminous Fly Ash. The dashed line illustrates an example where 20% of well-graded silty sand and gravel has a particle size of 0.1 mm or less. Adapted from GAI Consultants (1979) (originally from Faber and DiGioia 1976).

QUANTIFICATION [63-65]

In some instances, it may be worthwhile for the investigator to attempt to quantify wind erosion potential using the Wind Erosion Equation (Skidmore and Woodruff 1968). The equation is used by the U.S. Soil Conservation Service (SCS) for designing erosion control practices and for advising farmers on soil conservation programs (Woodruff et al. 1977). Thus, the investigator is advised to consult with SCS personnel regarding appropriate applications of the equation under considerations specific to a given storage site. The Wind Erosion Equation is expressed as:

Soil Loss = Function of (Erodibility, Surface Roughness, Climate, Open Field Length, and Vegetation Cover) (5)

Equation 5 is a useful tool in determining: (1) potential for wind erosion on a site under existing conditions, and (2) conditions of surface roughness, soil cloddiness, vegetative cover, sheltering, width, and orientation of a site necessary to reduce wind erosion to a tolerable level (Woodruff et al. 1977). To give the reader a basic understanding of the Wind Erosion Equation, the variables involved in the calculation of erosion loss are discussed in general below. For a detailed explanation of the equation and its use, see Woodruff and Siddoway (1965) or Skidmore and Woodruff (1968). In most cases, the Wind Erosion Equation will be useful as a qualitative tool for evaluating relative potential for wind erosion and fugitive dusting.

Erodibility

The structural stability of surface materials greatly influences erosion potential. Alternate freeze-thaw and wet-dry cycles as well as raindrop impact tend to cause disintegration of surface aggregates, resulting in increased erosion potential. On the other hand, rainfall or wetting may consolidate certain fine-grained materials, such as ash and subsequent drying results in formation of a crust that is relatively resistant to wind erosion. Aside from structural relationships, the density and particle size (Figure 36) of surface materials also influence erosion and dusting. For a given fraction, the lighter particles are more readily displaced. Materials comprised of a high proportion of fine particles are strongly cohesive and highly resistant to wind erosion unless the surface layers are disturbed.

Surface Roughness

Small ridges and depressions, clods, and surface aggregates collectively contribute to the roughness of an erodible surface. These surface irregularities alter wind speed by absorbing and deflecting some of the wind energy. Microrelief of 5 to 12 cm (2 to 5 inches) is considered the most effective in limiting wind erosion losses (Woodruff et al. 1977). Greater microrelief causes increased wind turbulence and therefore increased erosion.

Vegetative Cover

The presence of living vegetation and/or vegetative residues reduces the erosion potential of a given area. When determining the wind erosion potential of a waste-storage site before final revegetation, vegetative cover will likely be zero.

Open-Field Length

For a single erosion event, the erosion loss from an unprotected open area is strongly dependent on the length of eroding surface in parallel with the direction of the erosive wind. If the eroding area is of sufficient length, the sediment load increases to the maximum that the wind can sustain, and the rate of erosion remains constant regardless of additional length of eroding surface.

Climate

Characteristics of the climate that affect wind erosion include wind, precipitation, temperature, and humidity. Wind is the energy source for the erosion process, and the effects of the process vary with the velocity, turbulence, direction, and duration of wind flow. Erosion is initiated when wind action is sufficient to dislodge and transport surface particles. Given initial particle transport, the rate of erosion increases with incremental increases in wind speed; i.e., under otherwise comparable conditions, the rate or erosion for a 48-km/h (30-mph) wind is more than three times that for a 32-km/h (20-mph) wind (Woodruff et al. 1977).

IMPACT ANALYSIS [62-65]

Evaluating the Potential for Wind Erosion and Fugitive Dusting

Analyses and integration of information obtained by literature review and field reconnaissance will usually provide an adequate basis for evaluating wind-erosion potential at a proposed waste-storage site. In many instances, accurate prediction of the potential intensity of wind erosion from a given waste-storage site is difficult; however, because most wind erosion/dust suppression methods are highly effective, the impacts associated with wind erosion and fugitive dusting will often be minimal when these methods are employed.

For a given ash and sludge storage method, the potential for wind erosion and fugitive dust production will vary as a function of climatic factors including precipitation, evaporation, and wind speed. Wind erosion is more of a problem in areas of low, variable precipitation where drought is frequent and in areas where temperature, evaporation, and wind speeds are high (Woodruff et al. 1977). Coal combustion waste-storage facilities in these areas will lose moisture quickly and be subject to high wind energy.

Given these considerations and information on regional mean annual precipitation, evaporation, and wind speed [see U.S. Department of the Interior (1970)], it is possible to indicate the potential for wind erosion in various regions of the country. Brady (1974) indicates that there are two areas within the western Midwest and lower near West regions that have the highest potential for wind erosion in the United States: (1) the central portions of North Dakota, South Dakota, and Nebraska; and (2) the western portions of Kansas, Oklahoma, and Texas; and southeastern Colorado and eastern New Mexico.

Local topographic features also modify wind erosion by reducing exposure to wind erosion. Ash and sludge wastes stored in flat, exposed areas will be more subject to wind erosion than those stored in hilly, forested areas. In this regard, ash and sludge wastes in the Northeast and Southeast will be least subject to wind erosion because of generally hilly terrain and large forested areas. The Prairie and Great Plains regions have large flat areas with no forests, and ash and sludge wastes stored in these areas will be subject to high wind erosion. Wind energy effects on ash and sludge wastes in the eastern Midwest will be more moderate because of an interspersion of hilly and flat areas with prairie and forested areas.

Impact of Wind Erosion and Fugitive Dust at the Model Storage Sites

In the model sites where combustion wastes will be stored in diked ponds (Western, Ohio, and North Carolina plants), fugitive dusting from the stored wastes will be low. In ponds containing wet materials, fugitive dust emissions may occur if the basin surfaces dry. Storage pond dikes will be designed such that wind erosion is minimized to protect dike integrity. Measures will have to be taken to control fugitive dust during the interim between basin surface drying and the final reclamation of the storage pond. The choice of mitigative measures will be limited because the surface of the ponded wastes will probably not be able to withstand the weight of tillage equipment or heavy-duty vehicles.

Trucking ash to the surface mine adjacent to the Wyoming plant poses the potential for fugitive dust problems along haul roads. The site is located in an area of high winds, low rainfall and negative net precipitation. Fly ash particles are susceptible to wind entrainment (Figures 36 and 37), and application of water or chemical stabilizers will be necessary to reduce fugitive dusting during transport.

Fugitive dusting is also likely to occur from the ash landfill storage site of the Texas plant. These emissions will occur as the result of heavy equipment operations during waste deposition and compaction, as well as from exposed surfaces of deposited ash. Water application to haul roads and in conjunction with surface compaction activities will reduce fugitive dust emissions associated with the operation of the landfill. Emissions from exposed surfaces can be reduced by the timely application of the clay cap and topsoil layer. The establishment of vegetation on the topsoil will reduce dust emissions from this material.

INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of fugitive dusting as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Methods used to suppress dust and prevent wind erosion	Site visit Facility operator Field offices of Soil Conservation Service
Data required to apply Wind Erosion Equation; determination if Wind Erosion Equation is applicable to a given site	Field offices of Soil Conservation Service
Precipitation, evaporation potential, and wind velocity and direction	Natl. Weather Service Facility operator
Local topography	Site visit U.S. Geological Survey
Habitat of areas adjacent to waste-storage site	Site visit Facility operator Field offices of Soil Conservation Service

MITIGATIVE MEASURES [107-111]

Many of the mitigative measures used in controlling water erosion are also effective in reducing wind erosion and fugitive dusting. Although these methods can be categorized as involving physical, chemical, and vegetative processes, the basic purpose of all control methods is to modify one or more of the parameters of the Wind Erosion Equation (Equation 5). The usefulness of a given procedure varies according to site-specific conditions and the method of waste deposition. In most cases, a combination of procedures will be required to adequately control wind erosion.

Physical Methods

Procedures included in this category involve efforts to reduce the local wind velocity across the surface of the wastes or physically stabilize the erodible surfaces of deposited waste material. Wind barriers oriented at right angles to the prevailing wind direction can effectively protect a leeward area for a distance of approximately 15 times the height of the barrier (Woodruff et al. 1977). Typical wind barriers are solid wood fences or snow fences, although it may be feasible to establish tree and/or shrub shelterbelts on areas directly adjacent to waste-storage sites.

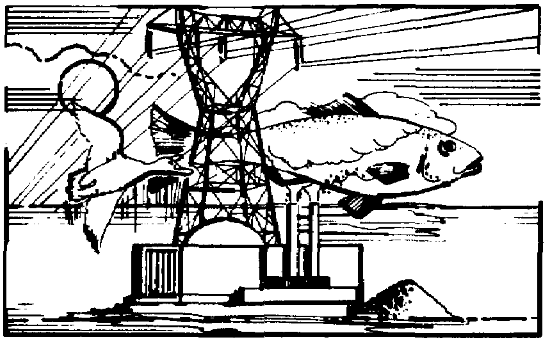
Tillage equipment can be used to roughen or ridge the surface of deposited wastes to reduce wind velocity and trap windborne particles. However, the operation of tillage equipment on waste surfaces may not always be practical, especially in the case of ponded scrubber sludge. The most widespread technique for stabilizing the surfaces of deposited waste materials is through water application in conjunction with surface compaction. This technique is particularly effective for fine-grained materials such as fly ash. Other physical methods of surface stabilization include the crimping of organic or inorganic mulches into the waste surface and the application of thin layers of coarse gravel, country rock, or crushed stone. The latter materials have proven to be useful in arid areas where wind velocities are consistently high.

Chemical Methods

The application of chemicals to waste surfaces causing the formation of a surface crust can significantly reduce the wind erodibility of fine-grained particles. A list of chemicals shown to be effective in the formation of surface crusts (e.g., potassium and sodium silicates) can be found in Dean et al. (1974).

Vegetative Methods

The vegetation of a site absorbs some wind energy, thereby reducing local wind velocity; it also intercepts or entraps windborne particles, reducing the amount of material removed from the eroding surface. Additionally, root systems help to bind soil or waste particles together. Although the opportunity to establish vegetation directly upon waste surfaces prior to the final reclamation of the disposal site will be dependent on site-specific conditions, it seems unlikely that vegetative methods will be used to temporarily stabilize coal-combustion waste surfaces.



Chapter 10
Consequences to Biota

POTENTIAL IMPACT [65-71, 75-81]

Runoff, seepage, and dusting are means by which potentially toxic constituents of ash and FGD sludge are mobilized and dispersed from storage sites into terrestrial and aquatic environments. Organisms can also serve as agents for dispersal by absorbing these constituents from their physical environment and diluting, concentrating, transforming, and immobilizing them--thus affecting their ultimate toxicity (Van Hook 1978).

Biological pathways of dispersal in terrestrial ecosystems include:

- Microbial interactions in soil
- Plant uptake from the soil-soil water continuum
- Translocation in plant tissues
- Food-chain transmissions to primary and secondary consumers

Biological pathways of dispersal in aquatic ecosystems include:

- Microbial-sediment interactions
- Absorption and adsorption from water by phytoplankton
- Food-chain transmission to consumers
- Direct uptake from water by consumers

Direct uptake from air through inhalation by animals can occur in terrestrial systems, but probably does not represent a major food web pathway for coal ash and FGD sludge constituents.

Concentration and toxicity of trace elements in plants are element- and species-specific, as well as site-specific. A number of environmental and physiological factors can affect uptake, accumulation, and toxicity of trace elements. Moreover, trace elements have a variety of effects on plants including changes in physiology, productivity, reproductive success, community composition, and species abundance.

Differential accumulation of toxic elements in terrestrial and aquatic plant tissues may determine which elements are ingested by fish and wildlife foraging on different plant tissues. Most terrestrial plant species tend not to readily translocate As, Be, Cr, Pb, Ni, and V from the root; whereas B, Cd, Cu, Se, and Zn, among others, are more readily translocated to the shoot. Based on the literature and their own experiments, Wallace and Romney (1977) have tentatively placed a number of trace elements into three groupings regarding element distribution between roots and shoots:

1. Reasonably uniformly distributed: Zn, Mn, Ni, Li, B.

2. Usually more in roots than in shoots, but often moderate with sometimes large quantities in shoots: Fe, Cu, Al, Cd, Co, Mo.

3. Mostly in roots with very little in shoots: Pb, Sn, Ti, Ag, Cr, V, Zr, Ga.

These generalizations are not always true for all species under all conditions, particularly when very high levels of an element are present in the soil.

One pathway by which potentially toxic substances could come in contact with wildlife is ingestion of impoundment liquors. Particularly in arid areas, waste ponds could be attractive watering sites for local or migrating wildlife, resulting in potential toxic impacts to the wildlife or disruption of their migratory patterns.

Little is known about the potential for toxic effects of ash and sludge waste constituents to animals. The effects that have been demonstrated required direct ingestion of ash in acute dosages. The best indicator of potential impacts to herbivores is probably obtained from looking at plant tissue concentrations of trace elements known to be toxic to animals. Less is known about the toxicity and mutagenicity of organic constituents of coal combustion wastes.

Biological effects of exposure to a single trace contaminant can be modified by addition of one or more different trace contaminants. Interaction effects with biota can be:

- Additive - Same as the sum of exposure to the individual components

- Antagonistic - Less than the effects of each component taken additively

• Synergistic - Greater than additive effects

Emissions from combustion waste-storage sites are likely to contain complex mixtures of potentially toxic materials, making it imperative that the complex mixtures, themselves, and not just the individual constituents be studied for potential toxicity on a site-specific basis.

There are a number of studies that present data on toxicity of various contaminants for fish, wildlife, and plants. Recent studies include Cleland and Kingsbury (1977), Gough et al. (1979), and Johnson and Finley (1980).

QUANTIFICATION AND IMPACT ANALYSIS [71-72]

The actual magnitude of impacts to fish and wildlife from ash and sludge wastes is extremely site- and species-specific. Only after extensive studies of a given situation can one make site-specific predictions of impacts to biota contacting constituents of these wastes. In most cases, such studies will not have been carried out on projects which the fish and wildlife biologist reviews. Additionally, it will be difficult to predict accident scenarios and associated impacts to fish and wildlife.

One method of estimating impacts to fish and wildlife (Lewis et al. 1978) is to assume that at equilibrium the concentration of a given trace element in the soil as a result of seepage will be the same as the concentration in the leachate and will be in a form available for biotic uptake (losses through leaching and soil binding being ignored). Plant concentrations are then calculated using plant:soil concentration ratios (e.g., Table 15), which are multiplied by 10 to provide a safety margin. These values are compared with normal concentration ranges and suggested maximum tolerable concentrations in plant leaves and with trace-element concentrations known to be toxic to animals (cf. Gough et al. 1979).

Lewis et al. (1978) recognized a number of limitations in their method. In addition to the imprecision inherent in predicting concentrations in vegetation (particularly cumulative concentrations in perennials), there are uncertainties in estimating toxic levels in different animal species due to differences in excretion rates, quantity of the vegetation species consumed, quantity of other food in the diet, physiological response to a given concentration in the diet, and effects of long-term consumption of supposedly nontoxic concentrations.

Due to the lack of species- and site-specific data, a set of impact criteria have been adopted in this manual for quantification purposes. Generalized criteria for determining the potential harm to human health and the environment have been developed by Cleland and Kingsbury (1977) under the sponsorship of the USEPA. These criteria, termed "estimated permissible ambient concentrations" (EPC), represent indicator thresholds above which deleterious effects may occur to biota (including wildlife resources) during chronic long-term exposure. If the estimated amount of a given constituent of coal combustion waste exceeds an EPC, it does not necessarily mean an adverse impact will occur but indicates there is a potential for deleterious effects that requires further scrutiny.

Table 15. Generalized Biological Concentration Factors for Elements in Aquatic and Terrestrial Ecosystems[a]

	Concentration factor ([biota]/[growth medium])[b]							
	Terrestrial		Freshwater			Marine		
Element	Plant	Animal	Macrophyte	Invertebrate	Fish	Plant	Invertebrate	Fish
Aluminum	0.007	0.001	-[c]	-	-	6,000	-	-
Antimony	0.03	0.003	-	10	1	-	5	40
Arsenic	~0.03	0.03	1,000	300	300	10,000	300	300
Barium	0.03	0.002	-	-	-	1,000	-	-
Beryllium	0.02	0.0003	-	10	2	2,000	200	200
Boron	5	0.02	-	-	-	30	-	-
Cadmium	10	8	4,000	2,000	200	4,000	200,000	3,000
Chromium	0.002	0.0008	2,000	-	-	20,000	-	-
Cobalt	~0.06	0.004	4,000	-	-	2,000	-	-
Copper	~0.7	0.1	200	1,000	200	4,000	2,000	1,000
Fluorine	~0.2	3	-	-	-	3	-	-
Lead	~0.3	0.2	500	100	300	300,000	1,000	200
Manganese	~0.7	0.0002	200	-	-	30,000	-	-
Mercury	0.5	2	200,000	100,000	1,000	1,000	30,000	2,000
Molybdenum	~0.4	0.1	1,000	-	-	40	-	-
Nickel	~0.08	0.02	3,000	100	100	600	200	100
Selenium	1	10	-	200	200	10,000	1,000	4,000
Vanadium	0.016	0.002	-	-	-	1,000	-	-
Zinc	~2	3	5,000	10,000	1,000	20,000	100,000	2,000

[a]Data from Bowen (1966), Braunstein (1978), and Hutchinson (1975).
[b]Growth medium: soil for terrestrial biota, water for aquatic biota.
[c]A hyphen indicates data not available.

Permissible concentrations for the protection of health (EPC_H) were derived by Cleland and Kingsbury (1977) from laboratory animal toxicological studies using acute exposures. These values can be used as indicators of the potential for adverse direct impacts to wildlife. The EPC_H for soils represent threshold limits for wildlife via their food, whereas the EPC_H for water represent threshold limits for ingestion of water. Permissible concentrations in soils for the protection of the environment (EPC_E) were derived from studies of plant toxicology. These values may be used as indicators of the potential for adverse indirect impacts to wildlife, i.e., impacts to wildlife habitat.

EPC values in Table 16 are less than threshold values for acute toxicity. Dilution factors were applied to toxicity threshold values in order to reflect the lower concentrations required to elicit responses during chronic exposure, which is the type of exposure most likely for wildlife in waste-handling areas.

The elemental concentrations presented in Table 16 are for constituents in solution; thus, in general, the values represent amounts potentially available for biological uptake. For soils, this amount can be considerably less than the total amount of the element in a unit of soil.

The approach presented here does have limitations. The complex interactions of trace elements and other factors in the environment cannot be easily quantified and incorporated into the evaluation of impacts to biota. The criteria in Table 16 are only for trace elements, and we have not considered potential impacts from other constituents of the coal combustion wastes, e.g., organic compounds and sulfites. Moreover, the criteria are generalized from data on different organisms and do not precisely apply to site-specific situations. Therefore, predictions of impacts from coal and FGD sludge contain a degree of uncertainty. As more research data are accumulated, more sophisticated approaches can be devised.

<u>Terrestrial Wildlife</u>

Where data on ambient concentrations of constituents dispersed from wastes are unavailable, a worst-case scenario may be developed for analysis. As illustrated in Table 17, maximum soil concentrations of waste constituents can be estimated from estimated concentrations in the leachate from a coal combustion waste-storage site. Soil bulk density was assumed to be 1.5 g/cm^3 and soil water content 33%. If leachate replaces all soil water, concentrations of the elements in the soils are given by:

$$C_s = \frac{C_1 \times 0.33}{1.5\ \text{g/cm}^3 \times 1000\ \text{cm}^3/\text{L}} \qquad (6)$$

where C_s is the soil concentration (μg/g) and C_1 is the leachate concentration (μg/L). Maximum water concentrations of the elements can be taken as the

Table 16. Estimated Permissible Ambient Concentrations (EPC) of Ash and Sludge Waste Constituents[a]

Constituent	EPC_H		EPC_E	
	Water (μg/L)	Soil or sediment (μg/g)	Water (μg/L)	Soil or sediment (μg/g)
Aluminum	73	0.15	200	0.4
Antimony	7	0.014	40	0.08
Arsenic	50	0.1	10	0.02
Barium	1,000[b]	2[b]	-	-
Beryllium	-	-	11[b]	0.022[b]
Boron	43	0.09	5,000	10
Cadmium	10	0.02	0.4	0.0004
Chromium	50	0.1	50	0.1
Cobalt	0.7	0.001	50	0.1
Copper	1,000	2	10	0.02
Lead	50	0.1	10	0.02
Manganese	50	0.1	20	0.04
Mercury	2	0.004	0.05[b]	0.0001[b]
Molybdenum	70	0.14	1,400	0.02
Nickel	1.4	0.003	2	0.004
Selenium	10	0.02	5	0.01
Strontium	27	0.05	-	-
Vanadium	7	0.014	75	0.15
Zinc	5,000	10	20	0.04

[a]Data from Cleland and Kingsbury (1977), except as indicated. EPC_H are permissible concentrations for health effects; EPC_E are permissible concentrations for environmental effects. EPC in soil or sediment represent amounts available for biological uptake, i.e., that dissolved in soil solution.
[b]Data from U.S. Environmental Protection Agency (1976).

concentrations in the leachate. In this example (Table 17), the elements most likely to cause problems for wildlife are boron, nickel, and vanadium--values for which all markedly exceed EPC.

Table 17. Factors by Which Maximum Ambient Concentrations Exceed Estimated Permissible Ambient Concentrations (EPC) for a Waste-Storage Site[a]

Element	Concentration (μg/L) in leachate[b]	Factors based on health effects		Factors based on environmental effects
		Water	Soil or sediment	Soil or sediment
Antimony	16	2	<1	<1
Arsenic	19	<1	<1	<1
Barium	640	1	<1	-
Beryllium	2	-	-	<1
Boron	1840	43	4	<1
Cadmium	1	<1	<1	1
Chromium	171	3	<1	<1
Copper	19	<1	<1	<1
Lead	5.4	<1	<1	<1
Manganese	2	<1	<1	<1
Mercury	0.6	3	<1	1
Molybdenum	158	2	<1	2
Nickel	50	36	4	<1
Selenium	92	9	1	2
Vanadium	100	14	2	<1
Zinc	20	<1	<1	<1

[a]The factors were calculated by dividing the values for concentration (μg/L) in leachate by the EPC values from Table 16.
[b]Derived from Holland et al. (1975).

The many complex interactions that may occur among constituents of ash and sludge wastes have not been taken into account for the values listed in Table 16. For general assessment purposes, it can be assumed that the interactions are additive and that the potential for adverse effects exists if any waste constituent present in the environment occurs at a concentration higher than the EPC value for that constituent as given in Table 16.

Sophisticated levels of assessment cannot be accomplished without more detailed site-specific information, including more complex models of (1) the interactions of the abiotic and biotic components of the affected ecosystem and (2) the dispersal and interactions of waste constituents. In most instances, however, these detailed data and analyses will not be available.

Generalized criteria for determining the potential for harm to aquatic biota have also been developed by Cleland and Kingsbury (1977). These criteria are the EPC_E for water listed in Table 16 and are equivalent to the USEPA's "quality criteria for water." Expected concentrations of trace elements in the waste liquors can generally be obtained from the operator of the proposed facility. With this information, one can calculate a dilution factor (D_f) or factor by which leachate concentration exceeds EPC:

$$D_f = \frac{C_e}{EPC} \tag{7}$$

C_e is the concentration of a constituent in the waste leachate or discharge effluent and EPC is the estimated permissible concentration of that constituent (from Table 16). The dilution factors can be used as indicators of which waste constituents discharged or leached into surface waters could pose potential hazards to aquatic biota. For example, for the waste-handling facility in Table 18, the elements mercury, selenium, and nickel will require the greatest amount of dilution before they can be brought to levels that will ensure protection of aquatic life. When the concentrations of elements in waste discharge are known, the same approach can be used to indicate potential problem areas for other situations.

If effluents, including leachate seepage, from ash and sludge waste-storage sites are discharged into flowing surface waters, the following relationship can be used to conservatively predict receiving-stream flows that are required to achieve acceptable EPC_E values for potentially toxic discharge constituents, with no losses after complete mixing:

$$D_r = \frac{D_e(C_e - EPC)}{EPC - C_r} \tag{8}$$

D_r is the receiving-stream flow; D_e is the effluent flow; C_e is the effluent concentration of a given constituent; C_r is the ambient receiving-stream concentration of a given constituent before effluent addition (generally considered to be zero for nonpolluted streams); and EPC is the permissible concentration of a given constituent in the receiving water after complete mixing (Table 16).

The complex interactions that occur between discharge constituents and receiving-stream biota can be conservatively modeled by an additive relationship. Information on receiving-stream and discharge flows and chemistry may be available from the operators of the proposed facility. If receiving-stream flows are above the calculated D_r for a given constituent or combination of constituents, one can generally conclude that aquatic biota in the receiving stream will be unaffected by the operation. Where the measured flow of the receiving stream is less than D_r, the likelihood for impact is indicated. The actual degree of environmental impact caused in aquatic ecosystems by ash and sludge waste storage will be dependent on the quantity and quality of storage-site discharges, receiving-stream flows, and other site-specific variables.

Table 18. Dilution Factors Required to Achieve Estimated Permissible Ambient Concentrations (EPC) for Water of Coal Combustion Waste Constituents from a Waste-Handling Facility[a]

Element	Concentration (µg/L) in discharge or seepage[b]	Dilution factors
Antimony	16	<1
Arsenic	19	2
Barium	640	-
Beryllium	2	<1
Boron	1840	<1
Cadmium	1	2
Chromium	171	3
Copper	19	2
Lead	5.4	1
Manganese	2	<1
Mercury	0.6	12
Molybdenum	158	<1
Nickel	50	25
Selenium	92	18
Vanadium	100	1
Zinc	20	1

[a]The factors were calculated by dividing the values for concentration (µg/L) in discharge or seepage by the EPC values from Table 16.
[b]Derived from Holland et al. (1975).

Impact of Effluent Discharges, Runoff Dispersal, Leachate Seepage, and Wind Dispersal at the Model Plants

Effluent discharges. Surface discharges from waste-handling procedures at the Wyoming, Ohio, Texas, and North Carolina model plants are assumed to have the constituent concentrations and discharge volumes outlined in Tables 19-22, respectively.

Receiving-stream flows at the Wyoming, Ohio, and Texas sites are, respectively: 8.0 m^3/s (280 cfs); 3.0×10^3 m^3/s (1.0×10^5 cfs); and 3.0 m^3/s (100 cfs). These rates should be sufficient to dilute potentially toxic constituents to acceptable EPC. There should be little biological concentration and magnification of potentially toxic constituents to toxic levels at the storage site areas based on concentration factors presented in Table 15. There is no effluent discharge at the Wyoming facility; thus, only in the immediate vicinity of the Ohio and Texas discharge sites is there potential for gradual accumulation of potentially toxic constituents.

Surface discharges from the North Carolina storage pond [1.9×10^{-1} m^3/s (7 cfs)] enter a small stream (average annual flow = 3×10^{-1} m^3/s or 10 cfs) which flows into a large estuary. The stream does not provide sufficient flow to dilute some constituent concentrations to EPC in the water (Tables 16 and 22). However, the estuary provides sufficient volume and flow to dilute total constituent concentrations to acceptable EPC in water, with the possible exception of nickel. There will be a potential for biological concentration and magnification of potentially toxic constituents to toxic levels in the stream (500 m in length) before it enters the estuary based on the bioconcentration factors presented in Table 15. Although the discharge will be rapidly diluted in the estuary, biological concentration occurring in the stream could impact estuarine organisms. There could also be high background concentrations of potentially toxic constituents (particularly nickel) and, with addition of the discharge, critical levels required for protection of fish and wildlife could be exceeded. The discharge will be a long-term addition to the stream and estuarine system, and there could be biomagnification of potentially toxic trace elements in food webs leading to the bald eagle, American alligator, and important fishery species.

Runoff dispersal. If proper erosion-control techniques are used, runoff dispersal from the model storage sites should result in little, if any, movement of potentially toxic combustion wastes and should have little impact on fish and wildlife.

Wind dispersal. If proper erosion-control techniques are used, wind dispersal from the model storage sites should result in minor movement of potentially toxic combustion wastes and should have little impact on fish and wildlife.

Table 19. Factors by Which Elemental Concentrations in Leachate Exceed Estimated Permissible Ambient Concentrations at the Western Model Power Plant[a]

Element	Concentration in leachate[b] (µg/L)	Water	Soil or Sediment
Antimony	14	<1	<1
Arsenic	2	<1	<1
Beryllium	2	<1	<1
Boron	2600	1	<1
Cadmium	0.5	1	<1
Chromium	1	<1	<1
Copper	31	3	<1
Lead	5.6	1	<1
Manganese	2	<1	<1
Mercury	0.5	10	1
Molybdenum	63	<1	1
Nickel	50	25	3
Selenium	45	9	1
Vanadium	100	1	<1
Zinc	5	<1	<1

[a]No surface discharge.
[b]From Holland et al. (1975).

Table 20. Factors by Which Elemental Concentrations in Leachate Exceed Estimated Permissible Ambient Concentrations at the Ohio River Valley Model Power Plant[a]

Element	Concentration in leachate[b] (μg/L)	Water	Soil or Sediment
Antimony	22	1	<1
Arsenic	72	7	<1
Beryllium	1	<1	<1
Boron	1100	<1	<1
Cadmium	1	2	1
Chromium	1000	20	2
Copper	13	1	<1
Lead	4.3	<1	<1
Manganese	2	<1	<1
Mercury	0.3	6	1
Molybdenum	690	<1	8
Nickel	50	<1	3
Selenium	470	94	10
Vanadium	200	3	<1
Zinc	5	<1	<1

[a]Surface discharge = 750 ha-m/yr (6100 acre-ft/yr) or 2.4×10^{-1} m^3/s (8.4 cfs).
[b]From Holland et al. (1975).

Table 21. Factors by Which Elemental Concentrations in Leachate Exceed Estimated Permissible Ambient Concentrations at the Texas Model Power Plant[a]

Element	Concentration in leachate[b] (µg/L)	Water	Soil or Sediment
Antimony	18	<1	<1
Arsenic	84	8	1
Beryllium	0.6	<1	<1
Boron	16,900	3	<1
Cadmium	2.5	6	1
Chromium	210	4	<1
Copper	31	3	<1
Lead	2.7	<1	<1
Manganese	2	<1	<1
Mercury	0.5	10	1
Molybdenum	52	<1	1
Nickel	15	8	1
Selenium	0.5	10	<1
Vanadium	100	1	<1
Zinc	25	1	<1

[a]Surface discharge = 95 ha-m/yr (750 acre-ft/yr) or 3×10^{-2} m^3/s (1 cfs).
[b]From Holland et al. (1975).

Table 22. Factors by Which Elemental Concentrations in Leachate Exceed Estimated Permissible Ambient Concentrations at the Southeastern Coastal Model Power Plant[a]

Element	Concentration in leachate[b] (μg/L)	Water	Soil or Sediment
Antimony	8.7	<1	<1
Arsenic	6	1	<1
Beryllium	0.3	<1	<1
Boron	48	<1	<1
Cadmium	1.1	3	1
Chromium	14	<1	<1
Copper	15	2	<1
Lead	6.3	1	<1
Manganese	2	<1	<1
Mercury	0.3	6	1
Molybdenum	10	<1	<1
Nickel	46	23	2
Selenium	0.5	<1	<1
Vanadium	100	1	<1
Zinc	17.5	1	<1

[a]Surface discharge = 620 ha-m/yr (5050 acre-ft/yr) or 1.9×10^{-1} m^3/s (7 cfs).
[b]From Holland et al. (1975).

Leachate seepage. Concentrations of leachate seepage constituents from waste-handling procedures at the Wyoming, Ohio, Texas, and North Carolina plants are presented in Tables 19-22. Maximum hydraulic conductivities through the wastes and underlying substrates at three sites are as follows:

Model site	Maximum hydraulic conductivities (cm/s)	
	Wastes	Substrates
Wyoming	7.5×10^{-7}	1×10^{-4}
Ohio	5×10^{-7}	1×10^{-4}
Texas	1×10^{-6}	2×10^{-4}

Movement through the substrate is substantially faster. Leachate seepage at the North Carolina site is collected by the underdrain system and recycled to the scrubber system.

Assuming that the substrate is 33% water by volume, leachate movement away from the Wyoming, Ohio, Texas, and North Carolina sites should be sufficient to dilute the total constituent concentrations to EPC in the soil (Tables 16 and 19-22). There should be little biological concentration and magnification of potentially toxic constituents to toxic levels at the storage-site areas based on concentration factors presented in Table 15. Therefore, little short-term impact to biota is expected due to leachate seepage. However, in the immediate vicinity of the Wyoming, Ohio, and Texas sites, there is potential for accumulation of constituents from leachate seepage in soil. As a result of physical and chemical processes, including soil reaction pH, concentrations of several constituents could exceed EPC values, including nickel at the Wyoming site and molybdenum and selenium at the Ohio site. Additionally, if there are high background concentrations of potentially toxic constituents at the sites, critical levels required for protection of fish and wildlife resources could be exceeded with the addition of leachate seepage constituents.

INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of consequences to biota as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Runoff and effluent discharges from the storage site	See RUNOFF
Seepage from the storage site	See SEEPAGE
Dusting from the storage site	See WIND EROSION AND FUGITIVE DUSTING
Habitat data including soils, water, and biological assemblages	Site visit Facility operator Field offices of Soil Conservation Service U.S. Fish and Wildlife Service
Toxicity data	Facility operator
Reclamation plans	Facility operator

MITIGATIVE MEASURES

Impacts to biota can be mitigated by minimizing runoff, seepage, and dusting dispersal of potentially toxic ash and FGD sludge waste constituents from storage sites (see Mitigative Measures for RUNOFF, SEEPAGE and WIND EROSION AND FUGITIVE DUSTING). Additionally, wildlife can be discouraged from using impoundments by means of fences, netting, scarecrows, or noisemakers. Plans can be developed to protect fish and wildlife resources in the event of catastrophic release of wastes.

Chapter 11
Reclamation of Waste-Storage Sites

INTRODUCTION [115-129]

Currently, there is no federal regulatory program addressing requirements for acceptable reclamation of coal combustion waste-storage sites. However, regulations recently implemented or newly promulgated through federal and state laws, outlining standards for waste storage and the protection of water resources, have provided the impetus for careful planning of waste-storage-site retirement (GAI Consultants 1979). This will most likely result in the development of a reclamation program for a proposed waste-storage facility. The reclamation plan should describe, in some detail, practices useful for erosion and sediment control, vegetation establishment, postreclamation monitoring, and future land uses.

In the section that follows, the components of a comprehensive reclamation program will be discussed to give the reader an introduction to the types of information needed to develop such a plan. Although it is difficult to accurately predict whether a proposed reclamation plan will result in the successful rehabilitation of a given storage site, it is possible to judge the adequacy of the planning effort for closure of a facility.

PREDISTURBANCE SITE DESCRIPTION

During the process of selecting a waste-storage site, a great deal of baseline data concerning the existing environmental conditions of candidate sites are gathered. Climatological data are helpful in selecting appropriate plant species for use in revegetation, in determining the schedule of planting, and in designing erosion and sediment control structures. A vegetation survey of the proposed site and adjacent habitats identifies the plant species and plant community types adapted to local climatic and edaphic conditions. Soil surveys of the proposed storage site aid in determining the potential available volumes of topsoil, friable subsoil, and low permeability subsoil. The quality, thickness, spatial distribution, and quantity of the soil resource at a given site dictates the type of artificial soil profile constructed over the deposited waste materials, which in turn will determine the success of revegetation and erosion control practices. Analyses of the texture, fertility, and pH of the soil aid in determining application rates of fertilizer, lime, and other soil amendments.

WASTE-STORAGE SITE DESIGN [129]

Certain design characteristics (e.g., length and gradient of slopes) will influence the types of reclamation practices employed and the subsequent revegetation of the storage site. Therefore, one should become familiar with the proposed engineering design of a given storage facility before evaluating the reclamation program for that facility.

Storage-site design characteristics that influence reclamation will, in turn, be greatly influenced by regulations promulgated under the Resource Conservation and Recovery Act of 1976 (RCRA). Although the regulatory program for RCRA is currently incomplete, proposed guidelines for regulations could have a significant impact on erosion control practices, revegetation, and closure of ash and FGD sludge storage sites (GAI Consultants 1979). These guidelines include:

- Construction of runoff diversion structures.
- Inclusion of terraces at 6-m (20-ft) vertical intervals.
- Seeding the final soil cover.
- Making landfill grades no greater than 33%.
- Routing offsite runoff and uncontaminated onsite runoff to a sedimentation basin prior to discharge.
- Preparing a final landfill cover with 15 cm (6 in.) of clay followed by 45 cm (18 in.) of soil capable of supporting vegetation, the upper 15 cm (16 in.) of which must be topsoil or soil-covering material with plant production capacity greater than or equal to the original soil.
- Maintaining the landfill in an aesthetic manner.

WASTE-STORAGE SITE REVEGETATION [127-129]

When preparing a waste-storage disposal site for closure, one of the principal concerns is development of measures to prevent the dispersal of deposited wastes into the surrounding environment. Good vegetation cover and proper design of a water-disposal system are needed in controlling erosion and stabilizing waste surfaces (Donovan et al. 1976). It is difficult to establish vegetation directly upon coal ash or FGD sludge because plant growth is inhibited by a variety of toxic constituents of these materials (e.g., high boron and soluble salt content) and the lack of essential plant nutrients (nitrogen and phosphorus). Although vegetation has been established directly upon fly ash following the addition of organic materials or fertilizer (Rippon and Wood 1975; Townsend and Gillham 1975) or following the weathering and leaching of the deposited ash (Townsend and Gillham 1975), little effort has been made to directly revegetate FGD sludge. In either case, the development of self-perpetuating plant communities as a result of direct seeding of waste surfaces has not been demonstrated. Currently, one can conclude that the direct revegetation of waste surfaces is not a viable reclamation practice.

Since coal combustion wastes appear to be, at best, marginal plant growth materials, successful reclamation of storage sites will require the placement of a soil mantle over the waste materials to help ensure the establishment of vegetation and reduce erosion. The depth of the soil mantle will play an important role in determining revegetation success. A primary factor affecting soil mantle thickness is the moisture regime of the storage site. In arid regions of the country, a thick soil mantle may be required to sustain plant growth, whereas a thinner mantle may be acceptable in more mesic regions.

A review of several experiments suggests that 30 cm of soil cover should provide for adequate rooting and minimal susceptibility to drought in most instances (GAI Consultants 1979). However, the study also indicated that increased soil cover thickness 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.

In contrast to the review by GAI Consultants (1979), Hodgson et al. (1963) indicated that 60 cm of soil fertilized at normal rates was required to obtain satisfactory plant growth. Furthermore, Dvorak et al. (1979) reported that vegetation growing on a 60-cm mantle of subsoil placed over acidic coal refuse was able to survive a five-week drought better than vegetation growing on 15- or 30-cm deep subsoil mantles.

On the basis of this limited research, it appears that at least 60 cm of soil is required to sustain plant growth; this soil depth is often mentioned in reclamation plans. Many states (for example, Arizona, Florida, Illinois, Kentucky, Missouri, Montana, Pennsylvania, Oklahoma) have solid waste-handling regulations that require a minimum of 60 cm of soil cover. If borrow pits are necessary to obtain cover materials, larger areas could be impacted.

Once the optimal soil mantle thickness for a given storage site has been determined, the plant species adapted to the climatic and predicted edaphic conditions of the site should be identified and candidate species for revegetation selected. The practices appropriate for the preparation and seeding of the soil-covered storage site can then be determined. Plants should be selected that provide short- and long-term cover. The ultimate long-term cover should provide the percent cover required to control erosion. This can be determined by use of the USLE (Equation 4).

Plant Species Selection

The species selection process should begin with an examination of native species occurring at the proposed storage site. These native species and plant community types are adapted to the site's existing environmental condition and can probably survive the environmental conditions of the developed storage facility. Each plant species has its own growth characteristics that determine its value in stabilizing soil for reclamation (Mills and Char 1976). Information should then be gathered describing the characterisitics (e.g., environmental requirements, agronomic uses, performance in field tests) that may be used to determine the capability of that species to grow in the new "habitat" of the soil-covered storage facility. The habitat created on the storage site will be a function of local climatic conditions, soil types used in the soil mantle, and storage-site design.

There will often be cases when seeds, cuttings, or containerized plantings of native vegetation will not be available, or prohibitively expensive, and other plant species will have to be selected (GAI Consultants 1979). Plant species useful in the revegetation of buried coal combustion wastes are listed in Appendix C.

In reviewing the species selected for revegetating a waste-storage site, the reader may wish to determine whether the species chosen meet the following criteria (Mills and Char 1976; GAI Consultants 1979):

- Able to withstand the erosive and traffic stresses presented at the storage site.
- Adaptable to storage-site soil conditions (i.e., pH, moisture, texture, and fertility).
- Adaptable to climatic conditions (i.e., sunlight exposure, temperature, wind exposure, and precipitation) at the site.
- Resistant to insect damage and disease.
- Compatible with other plants selected for use.
- Compatible with post-closure land use.

- Able to propagate themselves (either vegetatively or by seed).

- Able to provide good surface coverage.

- Somewhat tolerant of the constituents of the buried wastes (e.g., tolerant of saline or alkaline conditions; resistant to the effects of boron)

Cover Soil Placement

After the deposited waste materials have been graded to final contour, the soil mantle should then be placed. Most blade-type machinery may be used to spread the soil cover. The major concern in this stage of reclamation is to monitor the degree of compaction that occurs within the soil mantle during placement (GAI Consultants 1979). For successful plant establishment, a dry bulk density of the soil mantle in the range of 1.2 to 1.6 g/cm^3 is recommended.

Seedbed Preparation

Following application of the soil mantle over the surface of the deposited waste materials, the soil should be prepared for planting as quickly as possible. The nutrient status, pH, and bulk density of the soil should be determined (GAI Consultants 1979), and appropriate amounts of fertilizer and lime applied to the soil cover. If the soil cover has been severely compacted during placement, the soil can be loosened by scarification or tillage. Disc harrowing to a depth of 15 to 25 cm mixes amendments into the cover soil and will prepare the soil surface for planting.

Seeding

Once the seedbed has been prepared, one or more methods of planting vegetation should be identified. Currently used methods of establishing vegetation and their specific suitability include (Mills and Char 1976):

Broadcasting, in which seed is dispersed by a fly wheel mechanism as the seed falls from a container. Uniform distribution is difficult on sloping areas or areas difficult to traverse with planting equipment.

Seed drilling, in which seed placement (distribution and planting depth) is ensured. This is the preferred method for establishing herbaceous vegetation, but use is limited to rolling or level terrain that is relatively free of stones; it cannot be used on slopes greater than 3:1.

Hydro-seeding, which is commonly used for seeding disturbed areas. Application of seed and possibly fertilizers and mulch is made by spraying a slurried mixture over the surface. It is useful in seeding steep outslopes and other areas where equipment accessibility is limited.

Hand planting, which is used when trees or, more likely, shrubs are planted as bare-root stock or tublings.

Mulching

Mulching is required to protect the newly seeded area from erosion during and immediately following germination. In addition, mulching provides a better environment for germination and plant development by increasing soil moisture, moderating soil temperature, and increasing soil organic matter content. The mulch should be "crimped" into the soil surface soon after application to prevent the loss of mulch by wind and water. County agricultural extension agents can aid in determining appropriate mulch application rates.

POSTRECLAMATION LAND USE AND MANAGEMENT [129]

It will be difficult to identify the land use appropriate for a given reclaimed storage site prior to its construction and ultimate closure. However, a statement describing the potential land-use categories (Table 23) for which a storage site is being considered should be included in the reclamation plan because the proposed end use of a storage site will influence both the reclamation methods and the vegetation species employed.

Postreclamation site management includes all efforts to perpetuate vegetation established on the site and maintain the physical integrity of the site, thus preventing exposure and subsequent dispersal of waste materials. The major emphasis of reclaimed waste-site management can be classified as:

- Monitoring environmental and site conditions
- Site maintenance

The degree of postreclamation maintenance required at a storage site will largely depend upon the proposed land use of the reclaimed site, method of waste placement, and federal and state regulations (GAI Consultants 1979).

Immediately following revegetation, data should be gathered describing germination and early growth of vegetation. Decisions can then be made as to the need for additional fertilization, reseeding, or irrigation. Periodic measurement of plant density and/or plant cover over several growing seasons will indicate the success of revegetation. Additional observations should be made to estimate the suitability of the revegetated area for wildlife.

Table 23. Potential Land-Use Categories for Coal Combustion Waste-Storage Sites[a]

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: Cropland Athletic fields Golf courses	Possible increase in soil cover depth; management and maintenance of vegetation; stable underlying waste; possible increased erosion control to prevent exposure of waste.
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.

[a]Source: GAI Consultants (1979).

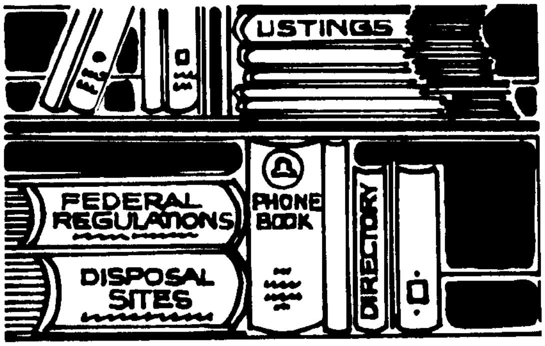
Site maintenance includes required upkeep and other work identified as necessary by the monitoring program. Operations necessary to maintain the integrity of the storage site include:

- Repair of fences surrounding the site
- Maintenance and clearing of water drainage pathways and erosion control structures
- Upkeep of access roads and earth embankments

INFORMATION REQUIREMENTS AND SOURCES

The following is a list of information required to carry out an analysis of reclamation of waste-storage sites as discussed in this chapter. The most likely sources of this information are also identified.

Information required	Sources
Local climatological data: Range of temperature Amount of precipitation Intensity of precipitation	Facility operator Natl. Weather Service
Vegetation survey: Plant species of site Plant community types adapted to local climatic and edaphic conditions	Facility operator Site visit Field offices of Soil Conservation Service State Department of Natural Resources
Soil survey: Soil types Spatial distribution across site	Facility operator Field offices of Soil Conservation Service Agricultural Extension Service
Soil analyses: Soil texture Soil fertility Soil pH	Facility operator Field offices of Soil Conservation Service Soil survey reports Agricultural Extension Service



Chapter 12
Sources of Current Information

This chapter presents sources of current information on combustion waste production, waste handling, applicable regulations, reclamation, and fish and wildlife resources. Approaches to environmental assessment are being developed by a number of the agencies listed below, and these may prove useful to the reader as supplements or more sophisticated substitutes for the approach outlined in this manual. Researchers are expanding the data base for toxicological effects of combustion waste materials. Several of the agencies listed here are sponsoring such research and can serve as sources of ongoing research. To maintain a current knowledge of toxicological effects, one must keep up with the current literature. Journals that are likely to carry pertinent articles include:

Archives of Environmental Health
Bulletin of Environmental Contamination and Toxicology
Environmental Health Perspectives
Environmental Pollution
Environmental Science and Technology
Journal of Environmental Quality
Minerals and the Environment
Soil Science
Water, Air, and Soil Pollution
Water Research
Water Resources Bulletin
Water Resources Research

This list of sources is not exhaustive but is provided to serve as a starting point for acquiring information. Appropriate state and local agencies can be identified by consulting the appropriate regional offices listed below or the Conservation Directory.

PUBLICATIONS

Conservation Directory, published annually by the National Wildlife Foundation, 1412 16th St. NW, Washington, DC 20036. Telephone: (202) 797-6800.

Energy Users Report, published weekly by the Bureau of National Affairs, Washington, DC 20037. Telephone: (202) 452-4200.

Environment Reporter, published weekly by the Bureau of National Affairs, Washington, DC 20037. Telephone: (202) 452-4200.

EPRI Journal, published monthly by Electric Power Research Institute, P.O. Box 10412, Palo Alto, California 94303. Telephone: (415) 855-2000.

Federal Register, published daily during the working week by the Office of the Federal Register, National Archives and Records Service, General Services Administration, Washington, DC 20408. Telephone: (202) 523-5227.

Inside EPA Weekly Report, published weekly by Inside Washington Publishers, P.O. Box 7167, Ben Franklin Station, Washington, DC 20044. Telephone: (202) 347-3976.

FEDERAL AGENCIES

Regional Offices of the U.S. Environmental Protection Agency

Region I
John F. Kennedy Federal Building
Boston, Massachusetts 02203

Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont

Region II
26 Federal Plaza
New York, New York 10007

New Jersey, New York, Puerto Rico, Virgin Islands

Region III
6th and Walnut Streets
Philadelphia, Pennsylvania 19106

Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia

Region IV
345 Courtland Street, N.E.
Atlanta, Georgia 30308

Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee

Region V
230 S. Dearborn Street
Chicago, Illinois 60604

Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

Region VI
1201 Elm Street
Dallas, Texas 75270

Arkansas, Louisiana, New Mexico, Oklahoma, Texas

Region VII
1735 Baltimore Street
Kansas City, Missouri 64108

Iowa, Kansas, Missouri, Nebraska

Region VIII
1860 Lincoln Street
Denver, Colorado 80203

Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming

Region IX
100 California Street
San Francisco, California 94111

Arizona, California, Hawaii, Nevada, Pacific Trust Territories

Region X
1200 6th Avenue
Seattle, Washington 98101

Alaska, Idaho, Oregon, Washington.

State Offices of the U.S. Soil Conservation Service

Alabama
Soil Conservation Building
P.O. Box 311
Auburn, Alabama 36830

Alaska
Severns Building
P.O. Box F
Palmer, Alaska 99645

Arizona
230 N. 1st Avenue
6029 Federal Building
Phoenix, Arizona 85025

Arkansas
Federal Office Building
Room 5401
Little Rock, Arkansas

California
Tioga Building
2020 Milvia Street
Berkeley, California 94704

Colorado
12417 Federal Building
Denver, Colorado 80202

Connecticut
Mansfield Professional Building
Storrs, Connecticut 06268

Delaware
501 Academy Street
P.O. Box 418
Newark, Delaware 19711

Florida
Federal Building
P.O. Box 1208
Gainesville, Florida 32601

Georgia
Old Post Office Building
P.O. Box 832
Athens, Georgia 30601

Hawaii
440 Alexander Young Building
Honolulu, Hawaii 96813

Idaho
5263 Emerald Street
P.O. Box 38
Boise, Idaho 83707

Illinois
Federal Building
200 W. Church Street
P.O. Box 678
Champaign, Illinois 61820

Indiana
311 West Washington Street
Indianapolis, Indiana 46204

Iowa
693 Federal Building
Des Moines, Iowa 50209

Kansas
760 South Broadway
P.O. Box 600
Salina, Kansas 67401

Kentucky
1409 Forbes Road
Lexington, Kentucky 40505

Louisiana
3737 Government Street
P.O. Box 1630
Alexandria, Louisiana 71301

Maine
USDA Building
University of Maine
Orono, Maine 04473

Maryland
4321 Hartwick Road
College Park, Maryland 20740

Massachusetts
27-29 Cottage Street
Amherst, Massachusetts 01002

Michigan
1405 South Harrison Road
East Lansing, Michigan 48823

Minnesota
200 Federal Building
316 North Robert Street
St. Paul, Minnesota 55101

Mississippi
Milner Building, Room 490
P.O. Box 610
Jackson, Mississippi 39205

Missouri
601 West Business Loop 70
P.O. Box 459
Columbia, Missouri 65201

Montana
Federal Building
P.O. Box 970
Bozeman, Montana 59715

Nebraska
134 South 12th Street
Lincoln, Nebraska 68508

Nevada
Room 234
U.S. Post Office Building
P.O. Box 4850
Reno, Nevada 89505

New Hampshire
Federal Building
Durham, New Hampshire 03824

New Jersey
1370 Hamilton Street
P.O. Box 219
Somerset, New Jersey 08873

New Mexico
517 Gold Avenue, S.W.
P.O. Box 2007
Albuquerque, New Mexico 87103

New York
Midtown Plaza, Room 400
700 East Water Street
Syracuse, New York 13210

North Carolina
1330 Saint Marys Street
P.O. Box 12045
Raleigh, North Carolina 27605

North Dakota
Federal Building
P.O. Box 1458
Bismarck, North Dakota 58501

Ohio
200 N. High Street
Room 526
Columbus, Ohio 43215

Oklahoma
Agriculture Center Building
Farm Road and Brumley Street
Stillwater, Oklahoma 74074

Oregon
Washington Building
1218 S.W. Washington Street
Portland, Oregon 97205

Pennsylvania
Federal Bldg. and Court House
Box 985
Harrisburg, Pennsylvania 17101

Puerto Rico
G.P.O. Box 4868
Santurce Station
San Juan, Puerto Rico 00936

Rhode Island
Soil Conservation Service
East Greenwich,
Rhode Island 02818

South Carolina
Federal Building
901 Sumter Street
Columbia, South Carolina 29201

South Dakota
239 Wisconsin Avenue, S.W.
P.O. Box 1357
Huron, South Dakota 57350

Tennessee
561 U.S. Court House
Nashville, Tennessee 37203

Texas
16-20 South Main Street
P.O. Box 648
Temple, Texas 76501

Utah
4012 Federal Building
125 South State Street
Salt Lake City, Utah 84111

Vermont
19 Church Street
Burlington, Vermont 05401

Virginia
Federal Building, Room 7408
400 N. 8th Street
P.O. Box 10026
Richmond, Virginia 23240

Washington
360 U.S. Courthouse
W. 920 Riverside Avenue
Spokane, Washington 99201

West Virginia
209 Prairie Avenue
P.O. Box 865
Morgantown, West Virginia 26505

Wisconsin
4601 Hammersley Road
P.O. Box 4248
Madison, Wisconsin 53711

Wyoming
Tip Top Building
345 East 2nd Street
P.O. Box 340
Casper, Wyoming 82602

State Offices of the Bureau of Land Management

Alaska
Bureau of Land Management
701 C Street
Box 13
Anchorage, Alaska 99513

Arizona
Bureau of Land Management
2400 Valley Bank Center
Phoenix, Arizona 85073

California
Bureau of Land Management
Federal Building
Sacramento, California 95825

Colorado
Bureau of Land Management
Colorado State Bank Building
Denver, Colorado 80202

Eastern States
Bureau of Land Management
7981 Eastern Avenue
Silver Spring, Maryland 20910

Idaho
Bureau of Land Management
Federal Building
Boise, Idaho 83724

Montana
Bureau of Land Management
Granite Tower Building
222 N. 32nd Street
Billings, Montana 59101

Nevada
Bureau of Land Management
Federal Building
Reno, Nevada 89509

New Mexico
Bureau of Land Management
Federal Building
Santa Fe, New Mexico 87501

Oregon
Bureau of Land Management
729 NE Oregon Street
Portland, Oregon 97208

Utah
Bureau of Land Management
University Club Building
136 E. South Temple Street
Salt Lake City, Utah 84111

Wyoming
Bureau of Land Management
Federal Building
Cheyenne, Wyoming 82001

Regional Offices of the Office of Surface Mining Reclamation and Enforcement

Region I
1st Floor, Thomas Hill Bldg.
950 Kanawha Blvd. East
Charleston, West Virginia 25301

Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, New York, Connecticut, New Jersey, Maryland, Pennsylvania, Delaware, West Virginia, Virginia

Region II
530 Gay St. SW
Suite 500
Knoxville, Tennessee 37902

Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi

Region III
Federal Bldg., U.S. Courthouse
Room 510
46 E. Ohio St.
Indianapolis, Indiana 46204

Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota

Region IV
Scarritt Bldg.
818 Grand Ave.
Kansas City, Missouri 64106

Iowa, Missouri, Nebraska, Kansas, Oklahoma, Arkansas, Texas, Louisiana

Region V
Brook Towers
1020 15th St.
Denver, Colorado 80205

North Dakota, South Dakota, Montana, Wyoming, Colorado, Utah, Arizona, Nevada, California, Idaho, Oregon, Washington, Alaska, Hawaii, New Mexico

Offices of the U.S. Fish and Wildlife Service

Region I
U.S. Fish and Wildlife Service
Lloyd 500 Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

Region II
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

Region III
U.S. Fish and Wildlife Service
Federal Building
Fort Snelling
Twin Cities, Minnesota 55111

Region IV
U.S. Fish and Wildlife Service
17 Executive Park Drive, N.E.
P.O. Box 95067
Atlanta, Georgia 30347

Region V
U.S. Fish and Wildlife Service
One Gateway Center, Suite 700
Newton Corner, Massachusetts 02158

Region VI
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

Eastern Energy and Land Use Team
Office of Biological Services
U.S. Fish and Wildlife Service
Route 3, Box 44
Kearneysville, West Virginia 25430

Western Energy and Land Use Team
Office of Biological Services
U.S. Fish and Wildlife Service
2625 Redwing Road
Fort Collins, Colorado 80526

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Appendix A

English/Metric Equivalents

Multiply	By	To obtain
Acres	0.4047	Hectares (ha)
Acre-feet	1.2335×10^3	Cubic meters (m^3)
British thermal units [(Btu) thermochemical]	1.0544×10^3	Joules (J)
British thermal units/pound (Btu/lb)	2.324×10^3	Joules/kilogram (J/kg)
Calories (cal)	4.18	Joules (J)
Cubic feet (ft^3)	0.0283	Cubic meters (m^3)
Degrees Fahrenheit (°F) - 32	5/9	Degrees Celsius (°C)
Feet (ft)	0.3048	Meters (m)
Gallons (gal)	3.7854	Liters (L)
Gallons (gal)	0.0038	Cubic meters (m^3)
Gallons/minute (gal/min)	0.0631	Liters/second (L/s)
Gallons/minute (gal/min)	6.309×10^{-5}	Cubic meters/second (m^3/s)
Inches (in.)	2.540	Centimeters (cm)
Kilowatt-hours (kWh)	3.60×10^6	Joules (J)
Miles (mi)	1.6093	Kilometers (km)
Pounds (lb)	0.4536	Kilograms (kg)
Square feet (ft^2)	0.0929	Square meters (m^2)
Square miles (mi^2)	2.590	Square kilometers (km^2)
Tons, short (t)	9.0718×10^2	Kilograms (kg)
Tons, short (t)	0.9072	Tons, metric (MT)

Appendix B

Glossary

The technical terms selected for the Glossary are mainly terms that may not ordinarily be familiar to biologists. The definitions provided are those applicable to the subject matter of this report.

ACID MINE DRAINAGE - Acidic seepage from mines in which the spoil is high in pyrite (FeS); when oxidized in the presence of water, pyrite yields sulfuric acid.

AGGREGATE (BOILER) - That part of residual combustion solids that has fused into particles heavy enough to drop out of the furnace gas stream.

AQUIFER - A permeable unit of rock or sediment from which groundwater can be extracted. Confined aquifers are bounded on top and bottom by impermeable materials. Unconfined aquifers are bounded on top by a water table.

ASH (COAL) - The solid material remaining after coal is burned. Contains most of the mineral and inorganic material originally present in the coal.

AVAILABLE ELEMENTS (SOIL) - Chemical elements in a soil that are in a form capable of assimilation by plants. May comprise only a portion of the total amount of the element present in that soil.

BAG HOUSE - A series of filters to remove particles from the flue gases.

BERM - A bench of soil or rock built on an earthen structure. It may serve various purposes such as a dike, an encasement for a drainage system, a weight for structural stabilization of an embankment, or an erosion-control structure.

BOTTOM ASH - Dry ash from coal combustion that does not melt but is too heavy to be entrained in the flue gas. Also called cinders.

BUFFERING CAPACITY - A measure of the tendency of a soil or water to resist large changes in pH.

BULK DENSITY (SOIL) - The weight per unit volume of soil. Agricultural soils have bulk densities usually between 1.2 and 1.7 g/cm^3. A compacted clay may have a bulk density of 2 g/cm^3.

CATION EXCHANGE CAPACITY (CEC) - The relative adsorptive power of a soil for cations. Expressed as the number of milliequivalents of cations per 100 grams of dry soil.

CLARIFLOCCULATOR - A device for handling dilute suspensions to produce a relatively clear supernatant liquid (overflow) and an agglomeration of settleable or filterable solids that are withdrawn at the bottom of the device (underflow). It consists of a tank, a means for introducing the feed suspension, a drive-actuated rake mechanism for moving settled solids to a discharge point, a means for removing the thickened solids, and a means for removing the clarified liquor. Chemicals may be added to the feed to enhance the physical separation.

CLAY LINER (WASTE DISPOSAL) - A liner consisting of a compacted layer of a clay with a low hydraulic conductivity.

CODE OF FEDERAL REGULATIONS (CFR) - A codification of all executive and administrative rules and regulations having general applicability and legal effect issued by the administrative agencies of the federal government.

CONSUMPTIVE USE (WATER) - That portion of water taken into a power plant that is not directly returned to the surface water body. The water is lost through evaporation and seepage.

DEWATERING (SLURRY) - The process of removing water from a slurry. Processes include natural evaporation, centrifugation, decantation, and filtration.

ELECTROSTATIC PRECIPITATOR - A device used to remove particles from flue gases, by charging the particles electrically and collecting them on appropriate electrodes.

FIXATIVE (FOR FGD SLUDGE) - A chemical additive that is mixed with FGD sludge to give it more desirable properties for disposal. Commonly, a fixative is used to lessen the thixotropic characteristics of the sludge.

FLOODPLAIN - The portion of a river or stream valley that is periodically inundated during episodes of excessive runoff. The solid waste-disposal regulations (40 CFR, Part 257) use the term "floodplain" to refer to the 100-year floodplain. The 100-year floodplain is the area that is likely to be inundated once in one hundred years.

FLOW, AVERAGE ANNUAL - The average volume of water to pass a given cross section of a stream during a given year. Usually expressed in units such as cubic feet per second (cfs).

FLOW, 7-DAY/10-YEAR LOW FLOW - The lowest volume of flow statistically expected to pass through a given cross section of a stream during a 7-day timespan in any 10-year period.

FLUE-GAS DESULFURIZATION (FGD) - Any process used to remove sulfur (largely sulfur oxides) from flue gases.

FLUSHING TIME (IMPOUNDMENT) - The period of time required to completely replace the volume of water in an impoundment through natural processes.

FLY ASH - That portion of the coal ash carried up the flue.

FUGITIVE DUST - Particles of dust removed from a surface by the wind.

GROUNDWATER - The water contained within the pore spaces of rock or soil.

HEAT RATE - Efficiency of conversion of boiler heat energy to electrical energy--e.g., if X amount of boiler heat is needed to produce Y amount of electricity, heat rate is X Btu/Y kWh.

HEATING VALUE - Amount of heat released per weight of coal during combustion.

HIGH-SULFUR COAL - In general, coal that contains over 1% sulfur. In some instances, however, it is defined as coal containing over 3% sulfur.

HYDRAULIC CONDUCTIVITY - The velocity at which water can flow through a permeable material.

HYDRAULIC GRADIENT - The change in hydraulic head over distance. Nearly horizontal flow has a very small gradient.

HYDRAULIC HEAD - The energy that allows water to flow. It consists of a pressure and a height component. Water flows from areas of higher to lower head.

IMPERMEABLE LINER (WASTE DISPOSAL) - Material placed on the bottom and sides of a waste impoundment to contain the waste material. No liner is completely impermeable, but many of the synthetic materials are relatively impermeable compared to natural earth liners.

INFILTRATION RATE (SOIL) - The rate at which water enters the surface layer of soil.

ISOERODENTS - Lines of equal values of R (rainfall and runoff factor) in the Universal Soil Loss Equation.

LEACHATE - Water and dissolved constituents draining out of a given column of saturated porous material such as soil.

LEACHING - The process of moving dissolved constituents (usually by water) downward through a column of porous material such as soil.

MINE-MOUTH - Operations such as coal washing and power generation carried out adjacent to the coal mine.

ORGANIC MATTER (SOIL) - The amount of plant and animal residues in a soil. Soils typically contain about 1 to 6% organic matter.

PERMEABILITY (SOIL) - The quality of a soil that enables it to transmit water or air. It is not equivalent to infiltration rate (see INFILTRATION RATE).

PERMEABILITY CLASSES (SOIL) -

	Hydraulic conductivities		
	(inches/hour)	(centimeters/second)	(meters/day)
Very slow	< 0.05	$< 3.5 \times 10^5$	< 0.006
Slow	0.05 - 0.20	$3.5 \times 10^5 - 14 \times 10^5$	0.006 - 0.023
Moderately slow	0.20 - 0.80	$14 \times 10^5 - 56 \times 10^5$	0.023 - 0.046
Moderate	0.80 - 2.50	$56 \times 10^5 - 176 \times 10^5$	0.046 - 0.289
Moderately rapid	2.50 - 5.00	$176 \times 10^5 - 352 \times 10^5$	0.289 - 0.578
Rapid	5.00 - 10.00	$352 \times 10^5 - 704 \times 10^5$	0.578 - 1.156
Very rapid	> 10.00	$> 704 \times 10^5$	> 1.156

PIPING - A progressive failure of a dike or embankment that occurs when a seepage velocity is great enough to cause internal erosion.

PLANT CAPACITY (RATED CAPACITY) - Nominal capacity for the power output by a electric generating unit, usually expressed in kilowatts or megawatts.

PLANT FACTOR - Ratio of electricity generated during a year to the electricity that could have been generated if the plant operated at nominal capacity for the entire year.

PLUME (WATER) - A stream of water that enters an existing body of water and is still distinguishable because of differences between the influent water and the receiving water in such factors as velocity, chemistry, or temperature. A plume dissipates with dilution and dispersion.

POINT SOURCE (WATER) - A single source of pollutant discharge to surface waters.

POZZOLANIC - Pertaining to a material that becomes cementlike after exposure to water.

RECLAMATION - Usually implies the restoration of disturbed land to primary production.

RUNOFF (RAINFALL) - All rainfall (and snowmelt) that does not soak into the ground, does not evaporate immediately, or is not used by vegetation. This flows down slopes and forms streams.

SCRUBBER SLUDGE (FGD) - Semisolid waste material, usually $CaSO_3$ and $CaSO_4$, resulting from the removal of sulfur oxides from flue gases using lime, limestone, or double-alkali techniques.

SEEPAGE - Any water or liquid effluent that flows through a porous medium. This term is often used to refer to the liquid lost through the bottom of a waste pond.

SLAG - That portion of the coal ash that melts to a viscous fluid at boiler operating temperatures, and cools to a glassy, angular material.

SLURRY - Any mixture of water and finely divided solids. Can refer to mixtures of coal and water (coal slurry), ash and water (ash slurry), desulfurization sludge and water (scrubber slurry), or coal refuse and water (refuse slurry).

SPLIT FACTOR - Percentage of ash that becomes entrained in flue gas as fly ash.

STEAM-ELECTRIC POWER PLANT - A power plant that generates electric power through steam-driven turbines. In commercial power plants, the fuel used to produce steam from water can be coal, oil, natural gas, or enriched uranium.

TEXTURE (SOIL) - The proportion of sand, silt, and clay in a soil. Soil texture is expressed in terms such as "sandy loam", "clay", "silty clay loam", etc.

THIXOTROPIC - Having the property of liquefying when disturbed and returning to the solid phase upon standing undisturbed.

THROW-AWAY SYSTEM (FGD) - A system in which the waste product from flue-gas desulfurization is not recycled or reclaimed, but instead is disposed of as waste.

TRACE ELEMENTS - Chemical elements that normally are present in minute (trace) quantities. Includes metals such as chromium, zinc, cadmium, and copper, and nonmetals such as selenium, boron, and arsenic.

UNDERFLOW (CLARIFIER) - The stream of coarse particles that are separated by a clarifier or cyclone (see also CLARIFLOCCULATOR).

UNSATURATED FLOW - Flow of a liquid through a porous medium in which some of the pore space is occupied by air. Unsaturated flow is usually slower than saturated flow under the same conditions.

VACUUM DISK FILTER - A continuous rotary vacuum filter made up of filter disks mounted at regular intervals around a hollow center shaft covered with a cloth filter. The device is used for dewatering sludge or solids by application of a vacuum inside the disks. A layer of caked solids (filter cake) is formed on the outer filter surface, and is subsequently removed.

WATER-HOLDING CAPACITY (SOIL) - The total amount of water capable of being held in a soil by capillary forces. Usually expressed as percent by weight of dry soil.

WATERSHED - An area, usually a valley or collection of valleys, surrounded by surface-water divides. All precipitation falling into a watershed supplies runoff to the same stream.

WATER TABLE - The surface that separates the groundwater in an unconfined aquifer (an aquifer not bounded on top by an impermeable layer) from the unsaturated zone above it (see AQUIFER).

Appendix C

Species of Vegetation Appropriate for Revegetating Waste-Storage Sites

The selection of plant species for use in the revegetation of buried coal combustion wastes is extremely difficult, because little effort has been made to identify species appropriate for this purpose. To date, no large-scale reclamation of these wastes has been attempted in the United States. This section can therefore only identify plant species that may be suitable for the revegetation of these wastes, based upon the performance of these species in the reclamation of other types of covered or buried anthropogenic waste. Specifically, those species used to successfully revegetate coal mining wastes and mineral tailings were considered. Table C.1 is a list of plant species adaptable to a wide range of soil pH, fertility, salinity, and other physical and environmental conditions.

Because the vegetation planted on burial sites for coal combustion wastes will not be growing directly on the waste material, species-selection criteria will be based primarily upon both the chemical and physical characteristics of the soil mantle placed over the wastes and the site-specific considerations of precipitation, topography, and climate. Roots of plants growing over buried combustion wastes will, however, be in contact with the wastes either at the interface between the soil mantle and the wastes or by root penetration into the waste material. Some tolerance to the acidic or alkaline nature of the waste material is therefore desirable. In many instances, subsoil will be used to form the mantle, requiring the use of plants adapted to harsh, low-fertility conditions. If topsoil is segregated during waste-site construction and then reapplied over the waste material, species adapted to very different soil conditions will be needed.

Table C.1. Plant Species Potentially Useful in the Revegetation of Buried Coal Combustion Wastes[a]

Common name	Scientific name	Species[b] origin	Region of use in United States	Comments
Grasses and Legumes				
Alfalfa	*Medicago sativa*	I	East, Midwest, West	Legume; good growth in dry regions; high boron tolerance.
Alkali sacaton	*Sporobolus airoides*	N	West	Recommended for dry regions; well adapted to moderately alkaline and saline conditions.
Bahia grass	*Paspalum notatum*	I	Southeast	Recommended for warmer climates; volunteer on alkaline limestone strip mine spoil.
Barley	*Hordeum vulgare*	I	Northeast, Southwest	Annual species; yields fast cover; good growth on alkaline and saline soils.
Bentgrass	*Agrostis* spp.	N/I	East	Semitolerant of growth on fly ash; some strains tolerant of high soil Al, Cu, Fe, and Zn concentrations.
Bermuda grass	*Cynodon dactylon*	N	Southeast, Southwest	Recommended for dry regions and saline soils.
Big bluestem	*Andropogon gerardi*	N	East, Midwest, West	Strong, deep-rooted, with short underground stems; effective in controlling erosion.
Birdsfoot trefoil	*Lotus corniculatus*	I	East, Midwest	Legume; salt tolerant; good growth on soil with pH 4.0 or greater.
Blackseed needlegrass	*Stipa avenacea*	N	West	Good for loam or heavier soils with > 33 cm precipitation per year.
Buffalograss	*Buchloe dactyloides*	N	Midwest, West	Drought-tolerant; withstands alkaline soils but not sandy ones; will regenerate if overgrazed.
Buffel grass	*Cenchris ciliaris*	I	Southeast, Southwest	Good growth on alkaline and saline spoils.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species[b] origin	Region of use in United States	Comments
Grasses and Legumes (contd.)				
Canada bluegrass	Poa compressa	I	Northeast, Northwest	Does well on acid soils, droughty soils, or soils too low in nutrients to support good stands of Kentucky bluegrass.
Caucasian bluestem	Dothriochloa caucasica	I	Midwest, Northeast	Does well on moderately acid, droughty sites.
Cicer milkvetch	Astragalus cicer	N	West	Legume; adapted to dry conditions; does well on alkaline soils.
Clover	Trifolium spp.	I	East, Midwest, West	Legumes; tolerant of saline and alkaline soils; adaptable to dry conditions.
Crownvetch	Coronilla varia	I	East, Midwest	Legume; used extensively on both moderately acid and calcareous spoils; if seeded with cover crop, may be useful in erosion control; suppresses woody plant invasion.
Deertongue	Panicum clandestinum	N	Northeast	Recommended for acid soils; does not compete well with other grasses; shade-tolerant.
Field brome	Bromus arvensis	N	Northeast, Northwest	Good winter cover plant; extensive fibrous root system; annual; grows rapidly, easy to establish.
Flat pea	Lathyrus sylvestris	I	East, Northeast	Legume; recommended for acid soils in cooler climates; suppresses woody plant invasion.
Foxtail millet	Setaria italica	I	Midwest, West	Requires warm weather during growing season; cannot tolerate drought; good seedbed preparation important.
Gramma grass	Bouteloua spp.	N	West	Drought-resistant species.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species origin[b]	Region of use in United States	Comments
Grasses and Legumes (contd.)				
Indiangrass	*Sorghastrum nutans*	N	East	Good growth and vigor on some acid spoils.
Indian ricegrass	*Oryzopsis hymenoides*	N	West	Adapted to arid and semiarid regions.
Italian ryegrass	*Lolium multiflorum*	I	East, Midwest	Annual species; yields quick cover; adaptable to pH as low as 5.0.
Kentucky bluegrass	*Poa pratensis*	I	Northeast, Midwest	Recommended for cooler climates, moderate-pH soils.
Lespedeza	*Lespedeza* spp.	N/I	Northeast	Legumes; adaptable to a wide range of soil pH; good for erosion control.
Little bluestem	*Scizachyrium scoparium*	N	Northeast, Midwest	Slow to establish; good growth on moderately acid spoil.
Lovegrass	*Eragrostis* spp.	N/I	West	Recommended for dry regions; adapted to alkaline and saline conditions.
Oat	*Avena sativa*	I	East, Midwest, West	Bunch-forming; good winter cover plant; requires nitrogen for good growth.
Orchard grass	*Dactylis glomerata*	N	East, Midwest, West	Adapted to moderate-pH soils (pH 6-8); good for western, high-altitude sites.
Perennial ryegrass	*Lolium perenne*	I	East, Midwest	Highly adaptable to moderately acid and alkaline sites; can be developed for pasturelands; does well in mixtures with native grasses; good for rapid stabilization of soil and erosion control.
Prairie sandreed	*Calamovilfa longifolia*	N	Midwest, West	Tall, drought-tolerant; can be used on sandy sites; rhizomatous; seed availability poor.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species origin[b]	Region of use in United States	Comments
Grasses and Legumes (contd.)				
Redtop	Agrostis alba	I	Northeast, Midwest	Useful for erosion control; good on extremely harsh spoil; recommended for cooler eastern climates.
Reed canarygrass	Phalaris arundinacea	N	East, Midwest	Highly adaptable to moderate acid sites; can be developed for pasturelands; does well in mixtures with native grasses.
Rye	Secale cereale	I	Northeast, Southwest	Annual species; yields fast cover for erosion control during initial vegetative establishment.
Sand dropseed	Sporobolus cryptandrus	N	West	Recommended for desert areas.
Sheep sorrel	Rumex acetosella	I	East	Root sprouting perennial; produces better cover than grasses on low-fertility soils; weedy plant; no seeds available.
Smaller seabeach grass	Panicum amarum	N	East	Good on very sandy, droughty sites.
Smooth brome	Bromus inermis	I	East, Midwest, West	Good for rapid stabilization and erosion control; fairly drought-resistant.
Switchgrass	Panicum virgatum	N	East, Midwest	Drought-tolerant; good growth on low-fertility soil; adaptable to wide soil pH range.
Tall fescue	Festuca arundinacea	I	East, Midwest, West	Shade-tolerant; does well in mixtures with other grasses.
Tall oatgrass	Arrhenatherum elatius	I	East, Midwest, West	Short-lived perennial bunchgrass, maturing early in the spring; less heat tolerant than orchard grass except in Northeast; good on sandy and shallow shale sites.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species origin[b]	Region of use in United States	Comments
Grasses and Legumes (contd.)				
Timothy	Phleum pratense	I	Northeast	Good growth on soils with pH 5.0 or higher.
Western wheatgrass	Agropyron smithii	N	West	Sod-forming, spreads rapidly, slow germination; valuable for erosion control; drought-resistant.
Winter wheat	Triticum aestivum	I	Northeast, Midwest, Southwest	Annual species; tolerant to high salt and low moisture; may be good as cover crop during initial vegetative establishment.
Shrubs				
Big sagebrush	Artemisia tridentata	N	West	Adapted to growth on alkaline soils; rapid growth; effective soil stabilizer.
Black chokeberry	Pyrus melanocarpa	N	Northeast	Fairly good survival on acid soil.
Bladder-senna	Colutea arborescens	I	East	Nitrogen-fixing species; does well under alkaline conditions.
Blue paloverde	Cercidium floridum	N	Southwest	Drought-tolerant; will withstand alkaline conditions.
Bristly locust	Robinia fertilis	N	East, Midwest	Nitrogen-fixing species; does well on moderate pH soil; good for erosion control.
Common matrimony-vine	Lycium halimifolium	I	West	Recommended for dry regions; adaptable to alkaline and saline conditions.
Coralberry	Symphoricarpos orbiculatus	N	Midwest	Good growth on spoil with pH 5.0-6.5.
Desert-willow	Chilopsis linearis	N	Southwest	Withstands cold and drought; excellent results on fertilized saline-alkaline tailings.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species[b] origin	Region of use in United States	Comments
Shrubs (contd.)				
Elaeagnus	Elaeagnus spp.	I	East, Midwest, West	Adaptable to a wide range of soil pH; recommended for saline conditions in arid western climates; nitrogen fixers.
Gregg catclaw	Acacia greggii	N	Southwest	Desert plant; with proper management, adaptable to a wide variety of soils.
Grease-wood	Sarcobatus vermiculatus	N	West	Adapted for growth on saline-alkaline soils in dry regions.
Hopbush	Dodonacea viscosa	N	Southwest	Arid, dry-country shrub; resistant to cold; excellent growth on saline-alkaline copper tailings.
Honeysuckle	Lonicera spp.	N/I	East, Midwest, West	Does well on moderate pH soils; poor results obtained on wet, saline-alkaline soils.
Indigobush	Amorpha fruticosa	N	East, Midwest	Acid-tolerant; prefers neutral to slightly alkaline soils; nitrogen fixer.
Japanese barberry	Berberis thunbergii	I	Southeast	Tolerant of growth on alkaline soil.
Saltbush	Atriplex spp.	N/I	West	Arid, dry-country shrub; recommended for use on alkaline and saline soils; drought-resistant; varieties now available.
Rubber rabbitbrush	Chrysothamnus nauseosus	N	West	Adapted to alkaline-saline conditions; excellent growth on Arizona copper tailings.
Scotch broom	Cytisus scoparius	I	Northeast, Midwest	Very acid-tolerant; unable to withstand Pennsylvania and West Virginia winters; poor choice for long-term stands.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species origin[b]	Region of use in United States	Comments
Shrubs (contd.)				
Silver buffaloberry	*Shepherdia argentea*	N	West	Recommended for alkaline and saline conditions on wet soils; nitrogen fixer.
Silky dogwood	*Cornus amomum*	N	Northeast	Does well on moderate pH soil.
Southern arrowwood	*Viburnum dentatum*	N	East	Good survival on moderately acid spoil.
Sumac	*Rhus* spp.	N	East, Midwest, West	Eastern species are acid-tolerant; species used in West are adapted to alkaline and saline conditions in dry climates.
Tree tobacco	*Nicotiana glauca*	N	Southwest	Excellent growth on fertilized saline-alkaline tailings.
Trees				
Ash	*Fraxinus* spp.	N	Northeast, Midwest	Poor to good survival on moderate pH soils.
Arizona sycamore	*Platanus wrightii*	N	Southwest	Drought-tolerant.
Austrian pine	*Pinus nigra*	I	Northeast, Midwest	Good survival on acid sites.
Birch	*Betula* spp.	N	East	Good survival over a wide range of soil pH.
Black cherry	*Prunus serotina*	N	Northeast, Midwest	Does fairly well on acid embankments.
Black locust	*Robinia pseudoacacia*	N	Northeast, Midwest	Nitrogen-fixing species; produces fast cover; good nurse crop; excellent for erosion control; susceptible to insect attacks; good growth on alkaline overburden.
Black walnut	*Juglans nigra*	N	Northeast, Midwest	Fair survival on moderately acid soils; better growth on calcareous spoils.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species origin[b]	Region of use in United States	Comments
Trees (contd.)				
Eastern cottonwood	*Populus deltoides*	N	Northeast, Midwest	Fast growing in pure stand on spoils with pH 4.0-8.0.
Eastern redbud	*Cercis canadensis*	N	East, Midwest	Good survival on moderately acid spoil in Illinois; nitrogen fixer.
Eastern white pine	*Pinus strobus*	N	Northeast, Midwest	Tolerant to extreme acid conditions at some sites.
Eucalyptus	*Eucalyptus* spp.	I	Southwest	Drought-tolerant; adapted to dry regions.
European black alder	*Alnus glutinosa*	I	East, Midwest	Good for use in erosion control; tolerant of wide range of soil pH and of high salinity; nitrogen fixer.
Jack pine	*Pinus banksiana*	N	Northeast, Midwest	Superior growth on extremely acid sites.
Larch	*Larix* spp.	N	East	Acid-tolerant; requires moist soil with good drainage; some species are shallow-rooting.
Loblolly pine	*Pinus taeda*	N	East, Midwest	Superior growth on some acid-waste embankments.
Mesquite	*Prosopis* spp.	N	Southwest	Drought- and acid-tolerant.
Netleaf hackberry	*Celtis reticulata*	N	Southwest	Deep-rooting tree; very tolerant of drought and alkaline soil.
Norway spruce	*Picea abies*	I	Northeast, Midwest	Survives well on waste banks; slow early growth.
Oak	*Quercus* spp.	N	East, Midwest	Average to good survival on moderately acid spoil.
Osage-orange	*Maclura pomifera*	N	Northeast, Midwest	Grows well over a wide soil pH range; good growth on moist strip mine spoil.
Pitch pine	*Pinus rigida*	N	Northeast, Midwest	Superior growth on extremely acid soil; survives on shallow, dry, low-fertility soils.

(continued)

Table C.1. (Continued)

Common name	Scientific name	Species[b] origin	Region of use in United States	Comments
Trees (contd.)				
Red pine	*Pinus resinosa*	N	Northeast, Midwest	Tolerant of low fertility and dry soils; good growth on acid spoils.
Scotch pine	*Pinus sylvestris*	I	Northeast Midwest	Hardy species on dry and infertile sites.
Shortleaf pine	*Pinus echinata*	N	Northeast, Midwest	Good growth and survival on acid sites.
Siberian elm	*Ulmus pumila*	I	Midwest, West	Recommended for dry climates; adapted for alkaline and saline conditions.
Silver maple	*Acer saccharinum*	N	Northeast, Midwest	Survival only fair on acid embankments.
Sitka spruce	*Picea sitchensis*	N	Northeast	Occasionally used on acid embankments; extremely tolerant of alkaline and saline conditions; high boron tolerance.
Speckled alder	*Alnus rugosa*	N	East, Midwest	Fast-growing; tolerant of a wide range of soil pH, and of high salinity; nitrogen fixer; needs wet site for seeding.
Sweetgum	*Liquidambar styraciflua*	N	East, Midwest	In preliminary tests, appears to do better on neutral to alkaline soils than on acid soil.
Sycamore	*Platanus occidentalis*	N	East, Midwest	Adaptable to a wide range of soil pH; salt-tolerant.
Table mountain pine	*Pinus pungens*	N	Northeast	Slow growth; fair survival on higher acid shale.
Virginia pine	*Pinus virginiana*	N	Northeast, Midwest	Attains excellent height among conifers on some coal-waste embankments.

(continued)

Table C.1. (Concluded)

Common name	Scientific name	Species origin[b]	Region of use in United States	Comments
Trees (contd.)				
White spruce	*Picea glauca*	N	Northeast, Midwest	Good survival on acidic *anthracite spoil*.
Willow	*Salix* spp.	N	East, Midwest	Adaptable to a wide range of soil pH; *S. interior* and and *S. nigra* are volunteers on alkaline fly ash pits.

[a]Data from Coalgate et al. (1973), D'Appalonia Consulting Engineers (1975), Gonsoulin (1975), Donovan et al. (1976), GAI Consultants (1979), and U.S. Soil Conservation Service (*personal communication*).

[b]N = species native to United States; I = species introduced to United States (exotic); N/I = genus includes both native and introduced species.

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15. Supplementary Notes

16. Abstracts

Increased use of coal in the generation of electricity has become national policy. With the anticipated accelerated use of coal as an energy source, a concomitant increase can be expected in the potential for impacts to fish and wildlife resources.

The goal of this manual is to provide quantitative guidelines, where possible for evaluating the potential extent of habitat disturbance from waste constituent dispersal. Criteria are also provided for evaluating the potential for impact from trace elements in the waste.

This manual is designed to be used in conjunction with the technical report entitled "Handling of Combustion and Emission-Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources" (FWS/OBS-80/33).

This manual is limited to combustion and emission-abatement waste-handling systems and impacts of wastes on fish and wildlife resources.

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