Manual for Upgrading Existing Disposal Facilities

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ABSTRACT

This manual presents background information and guidance to the utility engineer for upgrading waste disposal sites. It is intended to provide (1) step-by-step instructions for assessing the adequacy of current site operation and (2) a catalog to describe state-of-the-art upgrading technology once specific remedial action requirements have been identified.

The manual presents current regulatory requirements for land disposal of nonhazardous utility wastes. Potential problems associated with land disposal are discussed, and guidelines for a preliminary assessment of possible regulatory-environmental issues are presented.

The manual describes detailed engineering data on available site upgrading techniques covering (1) surficial and subsurface corrective actions; (2) site closure, relocation, and design modifications; (3) conversion of wet to dry disposal; (4) liner selection, design, and installation; and (5) by-product recovery and reuse. Comparative cost analysis of upgrading alternatives is also presented.

Although the standards for nonhazardous waste disposal sites are still under development, the site assessment and upgrading techniques presented provide the utility engineer with a useful tool to diagnose and correct potential deficiencies in disposal site design and operation.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This document is one of a series of manuals published by the solids by-product disposal subprogram on the disposal of utility waste by-products. It serves as a companion to the FGD Sludge Disposal Manual, Second Edition, EPRI Final Report CS-1515, and the Coal Ash Disposal Manual--Second Edition, EPRI Final Report CS-2049. Whereas, the aforementioned manuals are intended for use in designing new disposal facilities, this manual is primarily intended for upgrading existing waste disposal facilities. The Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (commonly referred to as the "Superfund" law) will have a profound effect upon the waste disposal practices of the electric utility industry. Federal and state regulations that would support the intent of these laws are currently evolving and will be of great interest to all industries that presently dispose or at some time disposed of wastes on land.

The materials covered in this manual encompass six principal categories: (1) environmental issues associated with land disposal of utility wastes, (2) a review of proposed and promulgated federal regulations on solid-waste disposal and an analysis of their impact on utility-waste disposal practices, (3) an overview of available disposal site upgrading and site-closure procedures, (4) a review of available liners and installation practices, (5) cost-estimating techniques for upgrading disposal sites, and (6) a review of recovery and marketing of utility by-products as an alternative to retrofitting a disposal site.

PROJECT OBJECTIVE

The objective of this manual is to provide the industry with detailed information about design features, equipment selection, and specific procedures for evaluating current disposal system suitability and selecting optimal retrofit systems for existing disposal facilities. It is intended for use by utility designers and managers in the preliminary identification, cost analysis, ranking of candidate upgrading procedures, and system selection. A continuing objective of the EPRI solid by-product disposal subprogram is to maintain and update the manual series with regard to the evolving federal and state regulatory requirements, advances in technology, and changing costs or economic factors. For this reason, this manual is in a loose-leaf format, which will allow easy insertion of updated material from future EPRI projects.

PROJECT RESULTS

This manual provides a systematic and objective methodology for evaluating alternative disposal site upgrading procedures. It provides background information and references on existing disposal practices, regulatory constraints as well as alternative corrective actions and their associated costs.

Regulations governing the disposal of utility wastes are in a state of suspension at this time. Congress in the 1980 Amendments to RCRA requested a detailed study of the effects of utility waste disposal practices, and the EPA has a multimillion dollar project under way to address some of the questions. The answers are not expected to be known until late 1983. Until that time there will be no firm design or performance standards applicable to utility waste disposal that can be applied with confidence by the industry. At the present time state standards for nonhazardous wastes, which are also undergoing change, apply to utility waste disposal. For these reasons it may be premature for any utility to embark on a program to update their existing disposal facilities.

It is expected that within two or three years, when the federal and state regulations have been put in place, this manual will need to be extensively revised. At that time it may be possible to assess the impact of a given disposal operation using groundwater monitoring results and modeling techniques and to compare the results with specific disposal site performance standards. Today it is not possible.

Like the other manuals in the series, this manual contains a questionnaire to be completed by the users in order to provide EPRI staff with a feedback mechanism so that the subsequent revisions will be responsive to industry needs.

The intended audience for this manual is the utility designers and managers in order to aid them in the preliminary identification of upgrading alternatives, cost analysis, and ranking of alternatives.

Dean M. Golden, Project Manager
Coal Combustion Systems Division

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The project was headed by John P. Woodyard, Project Director, and Hang-Tan Phung, Project Manager. Technical staff included Jasenka Vuceta, Lam Van Ho, Earl G. Hill, Anthony J. DiPuccio, Dennis P. Gillespie, Howard L. Rishel, Tom Dong, Lynn M. Hildemann, and Michael W. McLaughlin. Sheila Kennedy edited the draft and final reports.

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SUMMARY

Disposal facilities accepting nonhazardous waste (including utility solid wastes) are governed by both federal and state regulatory standards. Federal standards, promulgated under the Resource Conservation and Recovery Act of 1976 (RCRA), currently remain in "proposed" status. If existing utility waste disposal sites are eventually required to conform to these stringent standards, many sites may need to be upgraded.

Potential environmental issues associated with land disposal of utility solid waste include fugitive air emissions, soil contamination, phytoxicity, and contamination of groundwater and surface water. Problems may arise unless a disposal site is properly selected, constructed, and managed, and the waste materials are properly processed before disposal.

This manual is designed to provide the utility engineer with background information, guidance, procedures and associated costs for upgrading waste disposal facilities at a coal-fired power plant. Using the manual, the engineer should be able to assess whether an existing site meets current standards for new sites. It can serve as a catalog of available technology for upgrading, if significant environmental impacts are identified and require attention.

Potential deficiencies in utility waste disposal practices can be identified through a cursory site inspection and by checking compliance status against specific federal and state regulations. A checklist was developed to help the engineer identify any deficiencies. Depending upon the deficiencies identified, the degree of upgrading could vary from minor modifications (such as posting signs) to remedial action to correct environmental damage at the site. These modifications or remedial actions should be developed with reference to the site's unique characteristics and subsurface conditions. The selection and design of a corrective action plan should be carefully evaluated in terms of the specific regulations, technical considerations, operational ramifications, and both short- and long-term economic feasibility.

Corrective actions discussed in detail in the report include grading, cover, surface water control (e.g., berms, ditches, flumes, etc), revegetation, fugitive dust control, and subsurface water control (e.g., gravity drains, groundwater collection structures, impervious barriers, etc.). It is imperative to fully evaluate the options available for corrective action at a particular site, to fully recognize the benefit that the action can provide, and to determine if indeed such action is warranted.

One promising upgrading technique is the conversion of a wet disposal system (pond) to a dry system (landfill). Such a conversion requires treatment of wastes already ponded to produce a material suitable for landfilling, plus conversion of the waste generation process to one which will generate a dry material. The conversion processes may include primary/secondary dewatering, drying beds, forced oxidation, ash blending, and fixation.

With more stringent requirements for groundwater pollution control, many high-integrity, low permeability liner materials will find increased application in the utility and other industries. Liners are intended for use at new or relocated storage/disposal sites. The utility engineer should be aware of the available lining materials, criteria for their selection, design and installation, and their applicability to the particular site and waste.

An alternative to land disposal is commercial recovery and sale of utility solid wastes (by-products) for various end uses. The manual provides background information on the physical and chemical properties of by-products, potential commercial by-product uses and use specifications, and by-product handling and storage characteristics. It also describes by-product market characteristics and discusses marketing structures.

Site closure and post-closure maintenance are considered the last phase of waste management at the site. The most common site closure practices used by the utility industry are (1) covering with soil followed by revegetation, (2) pond draining and backfilling with soil, and (3) pond abandonment. Recommended site closure procedures are provided in the manual. The degree of post-closure maintenance and monitoring required at disposal sites is largely dependent upon the post-closure use of the site, and the applicable federal and state regulations.

The ultimate choice between comparable upgrading techniques is often based on cost. The manual presents extensive cost estimating instructions and guidelines for a comparative economic assessment. Cost estimating equations were developed for each upgrading alternative discussed in the manual, as well as for total levelized annual costs as a comparative tool. An actual case study example is provided to illustrate the proper use of the cost equations and the annual cost methodology.

QUESTIONNAIRE ON THE MANUAL FOR
UPGRADING EXISTING DISPOSAL SITES, EPRI RP1685-2

To users of the "Upgrading" Manual;

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

I Overall Comments

II Comments on Specific Sections

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

Please return by Dec. 1, 1982.

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

Note: If you receive your manual after Dec. 1, 1982, please complete the questionnaire anyway. Your suggestions can be included in subsequent revisions.

I. Overall Comments

Format ______________________________

____

In view of the ever changing regulations, is a manual like this useful?

Yes ______; No______; Maybe______

Contents ______________________________

____

Ease of Reference ______________________________

____

Other ______________________________

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Comments: ______________________________

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Was information helpful? __________ Factual? __________

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Were these useful? __________ Factual? __________

Comments: ______________________________

Suggestions for improvements: ______________________________

Section 1

INTRODUCTION

BACKGROUND

For years, utilities operating coal-fired electric power generating stations have contended with the complex, ever-changing regulations governing air and water quality. Most utilities have achieved compliance using advanced treatment/control technologies, a majority of which generate some form of solid waste requiring disposal. The predominant forms of utility solid waste are fly ash, bottom ash, and FGD sludge.

In 1976, the U.S. Congress passed into law the Resource Conservation and Recovery Act (PL 94-580), which was designed to "close the loop" of environmental control by setting standards for the disposal of solid waste to land. Though the disposal of utility solid wastes was addressed in the regulations, it was not until late 1980 that these wastes were formally placed on an equal federal regulatory basis with municipal solid waste and other nonhazardous solid wastes. This regulatory status is tentative, pending the results of additional EPA research.

The standards for nonhazardous waste disposal sites are stringent. Many operating utility waste disposal sites may not comply with the proposed standards, if for nothing more than minor violations such as a lack of access control and warning signs. These sites may need to be upgraded in some fashion to conform to the standards.

An important underlying consideration is the need to control possible environmental degradation from older disposal sites designed under less stringent standards. Engineers have long recognized that selecting, designing, and operating a good land disposal site is sometimes as much an art as it is a science, and that the assignment of legal responsibility for environmental damage is difficult considering that standards of practice have changed so much in recent years. A utility confronted with such a problem will nevertheless have some control over how it is remedied. As a result, a knowledge of the available technology for remedial action is important to utility environmental engineers.

Perhaps the most important consideration in such circumstances is the determination of whether the site needs to be upgraded at all. The information presented in this manual presumes that the "need to upgrade" has already been identified by the reader. However, it should not be presumed that an old site must be upgraded to conform with RCRA. Legal opinion varies; EPA is thought by many to have regulatory authority under RCRA only over new operations. According to this view, EPA could not force compliance with the proposed standards upon existing operations.

Remedial action/upgrading has been required only at selected solid or hazardous waste disposal sites where the potential for significant environmental damage has been proved; to date, no utility waste disposal sites have been so categorized. The adequacy of site performance will probably be used by EPA and the states to determine the need to upgrade.

PROJECT OBJECTIVES

The Electric Power Research Institute (EPRI), recognizing the lack of documentary guidance for upgrading utility waste disposal sites, contracted with SCS Engineers, Long Beach, California, to develop this manual. The principal objective of the project is to provide utility engineers with information and guidance in the following subject areas:

- Regulations governing the design, operation, and closure of utility waste disposal sites.
- Potential environmental effects of land disposal and how to diagnose them.
- Corrective action techniques available for regulatory compliance and mitigation of environmental degradation.
- Disposal site closure, relocation, and design modifications.
- Conversion of wet to dry disposal.
- Liner selection and installation.
- By-product recovery and reuse.
- Comparative cost analysis of upgrading alternatives.

HOW TO USE THE UPGRADING MANUAL

This manual was prepared to serve two purposes. First, the manual provides the utility engineer with step-by-step instructions for assessing the adequacy of a particular site and for selecting the most appropriate upgrading methods. Second, the manual describes state-of-the-art upgrading technology for use by the engineer who has already identified the specific areas in which remedial action is required. It complements the engineering guidance provided in the EPRI Coal Ash Disposal Manual (1) and FGD Sludge Disposal Manual (2), which primarily address the development of new disposal sites.

Figure 1-1 depicts the overall organization of information presented in this manual. The first part of the manual (Sections 2, 3, and 4) provides specific background information on the regulatory requirements for, and environmental issues associated with, the disposal of utility wastes to land. Guidelines for a preliminary assessment of possible regulatory/environmental problems are then presented, including ten case study assessments performed as part of this project. Due to site-specific variations in the siting, design, and operation of waste disposal facilities, it is assumed that a detailed engineering investigation will be necessary once the preliminary investigation is completed and before substantial funds are committed for upgrading.

The second part of the manual (Sections 5 through 10) provides detailed engineering data on available site upgrading techniques. Section 5 summarizes these techniques, and provides guidelines for their applicability to specific problems. Corrective action techniques are described in Section 6, including both the necessary modifications to bring a site into compliance with regulations, and remedial action techniques for arresting or correcting environmental damage at the site. The technology for converting a wet treatment and disposal system to a dry system is presented in Section 7, and pond/landfill closure is reviewed in Section 8. Section 9 provides a detailed review of site liner design and installation, which is an important consideration when an existing site is being closed and replaced. Section 10 summarizes the state of knowledge on by-product recovery and reuse.

The third and final part of the manual (Section 11) presents cost analysis guidelines for all of the upgrading techniques described in Sections 5 through 10. Because several upgrades may be necessary at a particular site, some obvious redundancy will be eliminated during actual implementation. Cost estimating is therefore consolidated into Section 11 rather than being presented separately in each section. Equations for estimating capital and operating costs are included, as are guidelines for converting these estimates into comparable levelized annual costs.

Some of the upgrading procedures presented herein already represent common engineering practice, such as site closure, liner installation, and surface water controls. As a result, the design guidelines and cost estimates should be accurate. However,

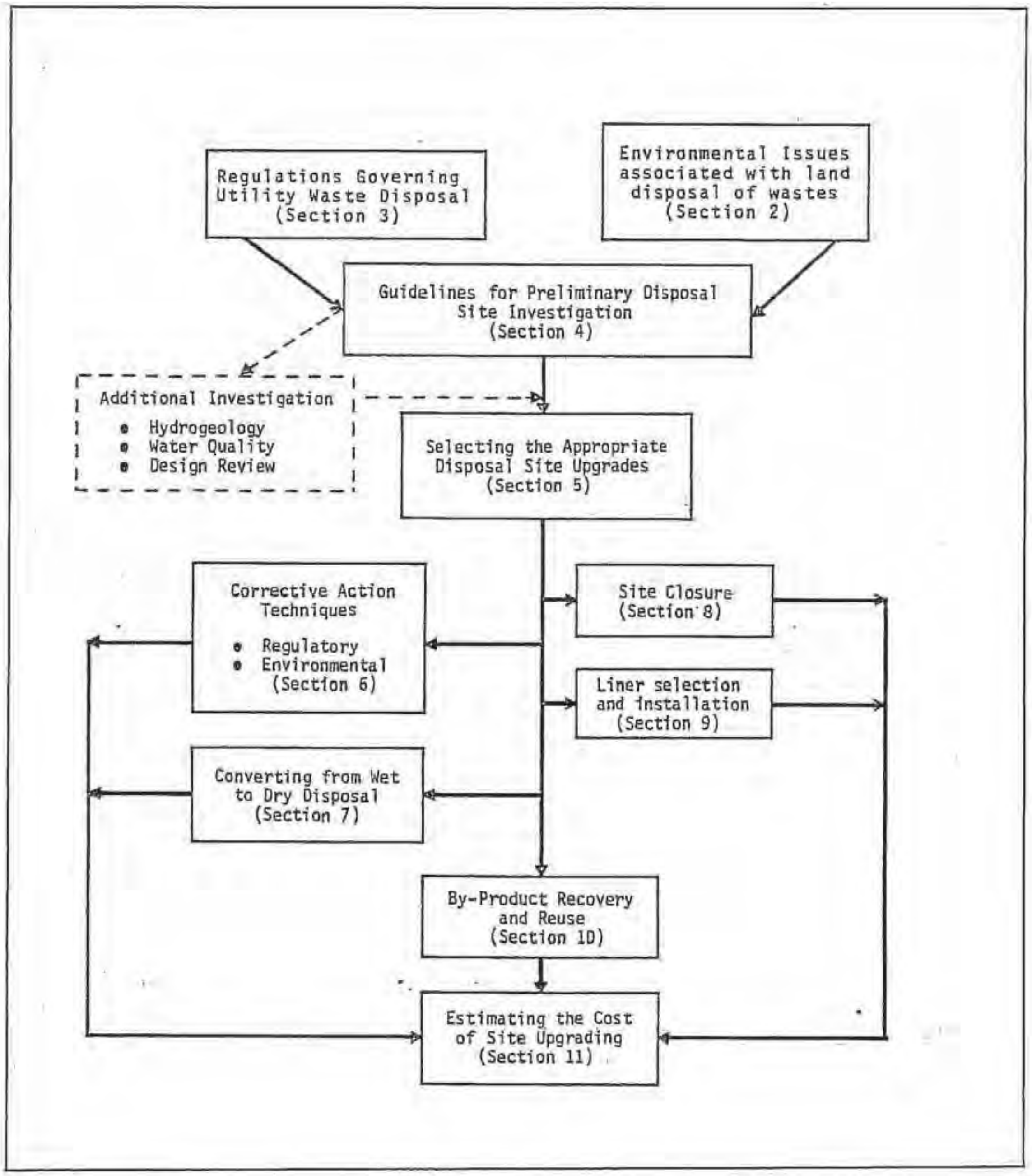

Figure 1-1. Organization of information contained in this manual.

some of the more elaborate techniques (e.g., groundwater control, wet-to-dry disposal conversion, etc.) are based primarily on conceptual systems rather than field experience. The cost estimates are therefore only approximations, and the technology is considered by many to be unproven. The huge expense associated with these elaborate corrective measures should nevertheless point up the risk of operating a substandard site. It is important for the reader to note that very few solid waste disposal sites have been shown to be so deficient as to require upgrading, either to comply with new RCRA regulations or to correct environmental damage.

LIMITATIONS OF THIS MANUAL

Standards governing the disposal of utility solid wastes are still being developed. EPA is still pursuing field research aimed at quantifying the environmental impact of utility waste disposal. These studies will not be completed for several years, and the results may show utility solid wastes to be best disposed of as Subtitle D solid wastes. Decision making within the context of this manual is difficult.

A means of assessing disposal site performance in light of federal standards should be an important part of this manual, but cannot be developed until the standards are approved. This important decision-making tool will be included in subsequent editions of this manual or as the standards are developed and approved.

REFERENCES

1. M. P. Bahor, R. J. McLaren, J. E. Niece, and H. C. Pedersen. Coal Ash Disposal Manual, Second Edition. Palo Alto, California: Electric Power Research Institute, October 1981. CS-2049.

2. R. G. Knight, E. H. Rothfuss, and K. D. Yard. FGD Sludge Disposal Manual, Second Edition. Palo Alto, California: Electric Power Research Institute, September 1980. CS-1515.

Section 2

ENVIRONMENTAL ISSUES ASSOCIATED WITH LAND DISPOSAL OF UTILITY WASTES

Coal ash production by electric utilities is expected to reach 71 million tons (64 million metric tons) per year by 1985, and nearly 94 million tons (85 million metric tons) per year by 2000; approximately 11 to 26 million dry tons (10 to 24 million metric tons) per year of flue gas desulfurization (FGD) wastes are expected to be produced by the mid-1980s (1, 2). Extensive utilization of coal ash is both technically and economically feasible, but less than 25% of utility ash (fly, bottom, and slag) produced in the United States is currently utilized commercially (3). FGD wastes are even less in demand. Most utilities find that disposal of these wastes to land is the most attractive, and in many instances, the only choice.

However, land disposal is not always an environmentally sound option. Unless disposal sites are properly selected, constructed, and managed, and the waste materials are properly processed before disposal, ground or surface water supplies could possibly become contaminated by hazardous constituents of the wastes (4).

The regulations governing waste disposal are intended to control the associated environmental impacts by requiring disposal sites to conform to state-of-the-art design practices. While these regulations are intended to have universal application, each disposal site poses different environmental risks, and requires a special design to control these risks. Some older sites may also need to be upgraded to conform to the regulations. An understanding of the environmental problems associated with land disposal is essential to the proper development of an upgrading plan.

This section provides a summary of current knowledge on waste disposal environmental impacts, with specific reference to large-volume utility wastes. A brief description of common waste disposal practices is provided, followed by a description of the associated environmental issues. Additional references are provided for each specific subject area.

It should be noted that this section intentionally highlights some "worst case" scenarios to prove a point. In practice, however, there is no documented case of environmental health problems directly attributable to fly ash or FGD sludge disposal.

OVERVIEW OF CURRENT UTILITY WASTE DISPOSAL PRACTICES

Disposal methods currently in use in the utility industry include landfilling, ponding (or impounding), and mine disposal (5, 6). Landfilling and mine disposal are used to dispose of solids and dewatered sludges, while ponding is used to dispose of slurries or to retain them temporarily prior to treatment.

Landfilling is the permanent placement of solid or semisolid wastes in a designated disposal site. Revegetation of the site is necessary after it is completed, and sometimes during operation to preclude fugitive dust emissions from the wastes. In areas of low rainfall, cover soil is placed over the wastes to allow revegetation, while in humid areas, vegetation may be established in the wastes with or without the addition of fertilizers. Revegetation provides an aesthetically pleasing appearance and prevents erosion. Watering is also used to minimize problems with wind erosion of wastes, especially at fly ash disposal sites. Proper landfill design will minimize the infiltration of water into and through the waste to the surrounding subsurface environment.

Ponding involves the depositing of liquid or slurried waste in a specially designed recess or impoundment. The pond supernatant may be recycled for in-plant use, treated, and/or discharged to surface waters. Ponding differs from landfilling in that the liquid provides a constant driving force for movement of potentially contaminated water (leachate) through the settled waste and into the surrounding soil. Although synthetic and natural liners are often used to control or temporarily retard the movement of leachate from the site, ponding is not considered a method of permanent disposal under the current regulations (see Section 3). Ponding is preferable to landfilling in certain areas due to topographic, economic, and geologic factors, but the increased land requirement and the eventual problem of site closure favor dry disposal.

In coal-producing areas, mine disposal presents an inexpensive disposal option for utility wastes. Underground mine disposal is currently used in the United States for disposal of fly ash and mining and coal processing wastes. At one utility, fly ash is pumped to an inactive mine in a 15% solids slurry. The fly ash settles in the mine voids, and the slurry water is pumped out along with the groundwater that seeps into the mine (7). Because this system is "blind" (i.e., the operator cannot know or control where the waste settles), the life expectancy of a single borehole is unpredictable. Although a recent study concluded that this technique is also promising for FGD sludge disposal (6), it has not yet been tested.

Utility wastes can also be deposited in inactive portions of surface mines. This technique is used for bottom ash, fly ash, and FGD sludge. In each case, the waste is deposited in the void left by the area or contour strip mine. The waste is transported either by truck or rail car, and is dumped into the pit bottom or a "vee" between mounds of mine spoil. The waste is then spread, or covered with mine spoil or overburden. Problems encountered include freezing of wastes in open trucks and rail cars during winter months, handling problems due to wastes sticking to metal surfaces, and delays due to mining/disposal scheduling conflicts.

Ash and dewatered FGD sludge are sometimes stored for long periods in piles without engineered environmental controls. Significant environmental effects may result if proper precautions are not taken. Such effects include fugitive dust and gaseous emissions, contaminated surface runoff, and infiltration resulting in leachate generation.

CHARACTERISTICS OF UTILITY WASTES

The principal constituents of coal ash are SiO_2, Al_2O_3, Fe_2O_3, and CaO, while those of FGD sludge solids are fly ash, $CaSO_4$, $CaSO_3$, $CaCO_3$, and $MgSO_4$. NaO, TiO_2, and K_2O are also present in significant quantities. The sulfur (S) contents of bituminous and subbituminous coals are higher than those of lignite coals. As a result, the former will normally produce low pH ashes. Lignite coals, however, are high in Ca and Mg, and produce characteristically high pH ashes.

Table 2-1 shows some measured concentrations of selected trace elements present in fly ash from bituminous, subbituminous, and lignite coals, and from native soils. Overall, trace element concentrations in fly ash and soil are comparable, except for boron (B), molybdenum (Mo), and selenium (Se). Concentrations of these biologically toxic elements (B is toxic to plants, and Mo and Se are toxic to animals) in fly ash greatly exceed their concentrations in soil. The more toxic metals (e.g., arsenic (As), cadmium (Cd), and mercury (Hg)) would not normally pose an immediate hazard to the environment when disposed of to land.

Table 2-1

TRACE ELEMENT CONTENTS OF FLY ASHES AND SOIL (ppm)*

	Fly Ash			
Element	Bituminous	Sub-bituminous	Lignite	Soil
As	82	2.3	34	0.1-40
B	36	50	500	2-100
Cd	0.3	0.3	0.3	0.01-7
Ce	300	160	112	50
Co	35	6.3	8	1-40
Cr	172	50	43	5-3000
Cs	10	3.1	3.1	--
Cu	132	45	75	2-100
F	8.8	1.4	20	30-300
Ga	100	54	20	15-70
Hg	0.1	0.04	0.1	--
I	1.3	4.2	2.6	--
La	99	54	48	30
Mn	145	309	543	100-4000
Mo	33	8.4	19	0.2-5
Ni	11	1.8	13	10-1000
Pb	15	3.1	12	2-100
Rb	220	49	83	30-600
Sb	2.2	0.8	2.6	0.6-10
Sc	22	7.3	8.1	10-25
Se	5.7	1.2	4.4	0.1-2.0
Th	68	39	49	--
U	12	0.8	4.6	20-250
V	256	73	94	50-1000
Zn	20	15	14	10-300

* Source: Adapted from D. C. Adrianno, et al. Journal of Environmental Quality, 9(3):333-344, July-September, 1980.

Utility solid waste leachates and pond supernatants are often high in alkalinity and total dissolved solids. Sulfite sludges are also frequently high in chemical oxygen demand. Because of these factors, the leachates and supernatants could exert a profound impact on the surface soil and surface waters if a rapid, high volume discharge (e.g., dike collapse) were to occur.

Overall, these potential contaminants in utility solid wastes are present near or below background levels. The regulations governing disposal site design and operation are based on a general interpretation of contaminant mobilization and transport. The actual design of a specific site requires a more detailed assessment of these mechanisms based on local meteorology, hydrogeology, soil characteristics, and ecology. The same conditions must be understood when a disposal site is being upgraded to conform with changing regulations.

POTENTIAL ENVIRONMENTAL EFFECTS OF UTILITY WASTE DISPOSAL

The potential effects of the various waste-environment interactions are numerous. Some of the trace elements which concentrate in coal ash are phytotoxic, some are toxic to fish and other aquatic organisms, and some have adverse effects on humans and animals.

Some trace components may dissolve in water already present in the wastes, or water which infiltrates the disposal site. From this soil solution, these waste components may migrate downward to groundwater or laterally to surface waters, from where they may also pass into vegetation growing in the area. Alternatively, the wastes may become part of the soil solid phase through precipitation, complexation, ion exchange, or adsorption on the surface of soil solids (Figure 2-1). This attenuation of the waste by the soil serves to protect groundwater and vegetation.

The migration of phytotoxic soluble salts and trace elements can lead to death or inhibited growth in the local plant population. Aside from the aesthetic considerations, reduced vegetation can lead to increased erosion, silting of streams, and possible flooding in subsequent seasons. Contamination of surface waters may first be noticed in its effects on fish and aquatic animals, which tend to be far more susceptible to poisoning by trace metals than other animals.

Terrestrial animals, including humans, can be affected by environmental contamination through many paths. Food crops, whether contaminated through groundwater, irrigation from surface waters, or uptake from soil, can concentrate trace elements

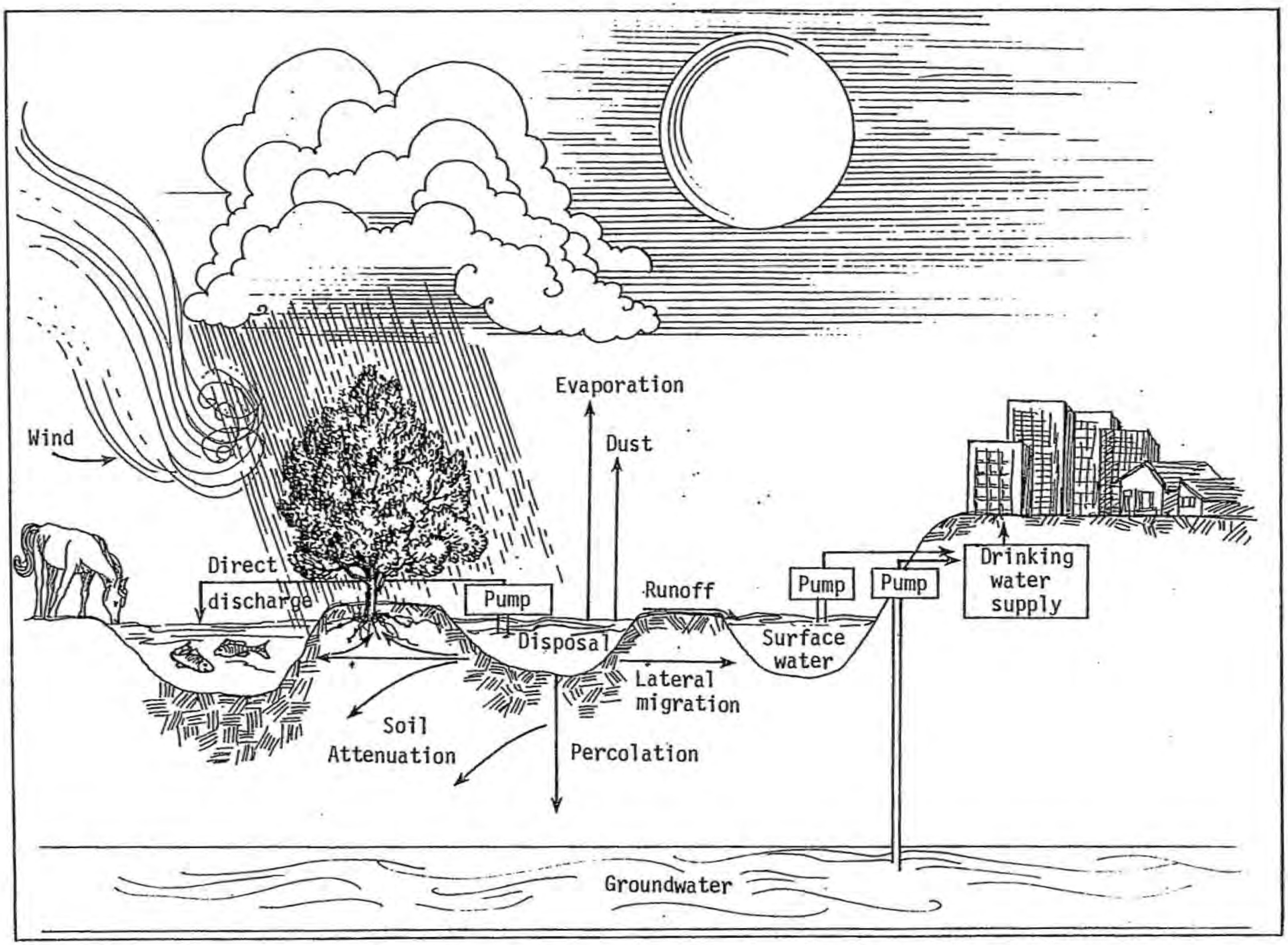

Figure 2-1. Overview of possible interactions between utility wastes and surface waters, groundwater, and air.

to levels well above those normally found. Drinking water may be affected, as may fish used for food. Any of these may also contribute to the concentration of trace metals in meats intended for human consumption.

The environmental problems associated with land disposal as they affect the various sectors of the environment are discussed on the following pages. Additional information pertaining to these effects is provided in the cited references.

Effects on Local Air Quality

Airborne transport of utility waste constituents occurs as fugitive dust emissions from uncovered ash landfills and from trucks during transportation (Figure 2-1). Dry fly ash is readily carried by wind during transporting, dumping, spreading, and burying. If the ash is not covered or watered, wind erosion can create a fly ash dust problem at the site. Similar problems have been encountered at FGD sludge disposal sites when the surface material dries or breaks up through freeze/thaw cycling. Since fly ash contains potentially toxic elements, it is possible that nearby soils and waterways not directly affected by runoff or leaching may become contaminated due to deposition of airborne particulates from the disposal operation. The extent of this problem has not been thoroughly studied.

In a recent study of sulfur gas emissions from the surfaces of 13 FGD solids storage sites, a wide variety of sulfur-containing compounds was detected (8). In all cases, the surface emissions (0.007 to 0.265 g $S/m^2/yr$) represented extremely small percentages of the total sulfur in the sludge or emitted through the combustion stack.

Effects on Soils and Vegetation

Soil Contamination. When utility solid wastes are deposited on land, the soil becomes enriched in salts (sulfite, sulfate, lime) and some trace elements (e.g., boron, molybdenum, arsenic). The physical and chemical properties of the soil mixture are changed accordingly.

The effects of fly ash on selected physical properties of soils are presented in Table 2-2. For most soils, mixing with fly ash will reduce bulk density and modulus of rupture (cohesiveness of particles). The soil's hydraulic conductivity improves at low rates of fly ash application (<10%), but deteriorates rapidly as fly ash volume increases (9).

Table 2-2

EFFECTS OF FLY ASH ON PHYSICAL PROPERTIES OF SOILS*

Soil Properties	Typical Agricultural Soil	Soil with Weathered Ash	Soil with Unweathered Ash
Bulk density	1.3 (avg)	Lower	Lower
Aeration	High	Higher	Higher
Water-holding capacity	High	Higher	Higher
Plant-available water	High	None to little effect	None to little effect
Hydraulic conductivity	High	Increased by low rates; decreased by high rates	Increased by low rates; decreased by high rates
Modulus of rupture	High	Lower	Lower
Wind erosion	Resistant	More susceptible	More susceptible
Water erosion	Resistant	More susceptible	More susceptible

* Source: Adapted from D. C. Adrianno, et al. Journal of Environmental Quality, 9(3):333-344, July-September, 1980.

Depending on the coal source and degree of ash weathering, fly ash varies widely in pH, soluble salts, and trace element contents. Generally major chemical changes following land application of coal ashes include increases in pH, salinity, and levels of certain elements (Table 2-3). As a result of the hydrolysis of CaO and MgO, alkaline coal ashes increase the soil pH, sometimes to as high as 8 or greater. However, soil pH can be lowered as a result of application of acidic fly ash derived from high-S coal (10). Soil salinity can increase substantially when soils are mixed with unweathered fly ash (11). Among the trace elements in fly ash, B, Mo, and Se accumulate in the soil mixture. These elements appear to be the most serious constraints associated with utilization of large quantities of fly ash in agriculture.

Phytotoxicity. The intrusion of utility waste constituents into soil systems becomes a problem for plant life in the area (both on and around a disposal site) because of the accumulation of soluble salts, as well as other trace elements originating in the wastes.

Vegetation is sensitive to soil salinity, and many plants, particularly fruit trees, will not grow in soils with high salt content (electrical conductivity 10 mmhos/cm). Since the alkali and alkaline earth metals, chlorides, and sulfates in fly ash and sludge are readily leachable, salinity in the soil beneath the waste materials can reach intolerable levels.

Plants exhibit varying degrees (0.5 to 10.0 ppm B in soil extracts) of tolerance to boron in soils. Once fly ash with available boron is added to the soil, the degree and duration of toxicity to plants will depend on the soil texture, clay, minerals, and pH.

Other trace elements of concern are Mo and Se. In soils, Mo and Se form anionic constituents; uptake of these elements increases significantly when plants are grown on fly ash-amended soils (9). Continuous consumption of forage with elevated levels of Mo and Se may induce physiological disorders in livestock.

Reduced plant growth at the disposal area may also leave the site denuded and aesthetically unpleasing. Loss of vegetative cover can also lead to increased erosion and increased silting of nearby streams. This may, in subsequent seasons or years, lead to changes in local flooding patterns.

Table 2-3

EFFECTS OF FLY ASH ON CHEMICAL PROPERTIES OF SOILS*

Soil Property	Typical Agricultural Soil	Soil with Weathered Ash	Soil with Unweathered Ash
Nutrient content	All nutrients present	Very low N; others present	Very low N; others present
Nutrient availability	Balanced supply of all nutrients	Deficient in N; may be deficient in P, Zn, Cu, Mn, etc.	Deficient in N; may be deficient in P, Zn, Cu, Mn, etc.
pH	6.0 - 7.5	<6.0 to = 8.0	<6.0 to = 12.0
Cation exhange capacity	Medium to high	Lower	Lower
Toxic salts	None	None	B and soluble salts of Ca, Mg, Na, and K
Salinity	Low	Moderate	High but diminished after 2-3 years
Temperature	Adequate	Higher	Higher
Microbial activity	High	No effect	Initially low

* Source: Adapted from D. C. Adrianno, et al. Journal of Environmental Quality, 9(3):333-344, July-September, 1980.

Effects on Groundwater

Leachate from improperly sited and designed waste disposal ponds and landfills represents a potential threat to groundwater supplies. In general, inadequately lined ponds provide a greater opportunity for groundwater contamination, because the soil immediately below the pond is always saturated and under a constant head of pressure from the overlying water (12). Consequently, seepage may be constant and greater in volume than leachate from a landfill.

On the other hand, most fly ashes have a high pozzolanic activity and tend to be self-sealing when wet. As a result, fly ash tends to serve as its own liner, becoming less permeable to water movement with time. Fly ash performs the same function in a mixed ash/FGD sludge pond. FGD sludge alone does not have the same self-sealing capabilities, and seepage tends to be more pronounced. The quality of leachate from a pond, prior to contacting the underlying soil, will stabilize over time, and is similar to that of the pond effluent. Theis, et al. (13), reported that rapid attenuation occurred for most metals very close to the ash pond itself. Many of the fly ash components, especially iron and manganese oxides, are also effective metal scavengers.

The quality of leachate from a land disposal site can differ from the quality of seepage from a pond. The soil can exert a buffering influence over the fly ash and can raise or lower the pH of the leachate. Solubility of most trace elements (probably with the exception of Se and As) tends to increase as the pH decreases (12). Even if the buffering effect is minimal, those constituents responsible for the alkaline pH tend to be the most soluble, and leach out most quickly. Thus, over time, the pH of the alkaline leachate will tend to decrease naturally, increasing the amounts of trace elements dissolved. It is therefore possible for a given quantity of ash or sludge to leach out a larger proportion of the trace elements than would be present in seepage from a pond, although it would occur over a longer period of time.

Stabilized sludges are not as susceptible to leaching as untreated sludges and fly ash. The overall solubility of the stabilized material is generally lower. Furthermore, stabilized sludge presents less surface area for water/sludge contact, reducing the total water contact with the sludge. Since such water contact is essential for solubilization, the total quantity of material dissolved is decreased. Over long periods of time, it is possible that the chemical bonding responsible for the stabilization may deteriorate, and the sludge will revert to its original state.

Research to date has not established the expected lifetime of stabilized sludge. If the rate of destabilization is slow, however, the contaminant release in leachate will be even more gradual than that experienced for nonstabilized sludges. In the case of either leachate or seepage, the potential impact of the harmful trace constituents on groundwater supplies will depend on their behavior in the soil, which in turn depends on the soil chemistry, loading rates, site hydrology, and the volume and quality of the groundwater.

Waste macroconstituents such as iron, aluminum, calcium, chloride, sulfate, and sulfite are not generally regarded as hazardous, although they can contribute to groundwater quality degradation. They can increase hardness, salinity, alkalinity, and dissolved solids, depending on the background water quality, but seldom to the point where the water is rendered nonpotable or unsafe to drink.

The soil factors which most strongly affect attenuation of trace elements are pH, hydrous oxides of iron and aluminum, clay content, and organic matter. In general, trace metals are less mobile in alkaline soils than in acid soils; the metals will precipitate and/or adsorb onto hydrous iron and aluminum oxides (13). Clay serves two functions: adsorption of metal ions from leachate, and retardation of water movement due to small pore size and low permeability. Soil organic matter can chelate metals, either immobilizing them or freeing them, depending on the nature of the organic matter.

Arsenic is not mobile in most soils, being readily adsorbed by soil colloids (12, 14). Arsenic is especially retained in fine-textured soils with high concentrations of hydrous iron and aluminum oxides. High pH values favor desorption of arsenic, and may result in its increased mobility in soils (15).

The mobility of cadmium, lead, and nickel in soils is limited. Both the organic and clay-organo fractions of soil have a high affinity for these heavy metals, leading to retention or immobilization (14). These metals readily precipitate in neutral to alkaline environments, as are typical in soils amended with ash or sludge.

Chromium can exist in soil in two oxidation states: trivalent and hexavalent. The hexavalent form is much more toxic and mobile in soil (16). Trivalent chromium, Cr(III), is readily immobilized by clay and organic matter, through precipitation of Cr(III) salts, and by adsorption on hydrous oxides. Hexavalent chromium, Cr(VI), is stable only in well-aerated alkaline environments; even then, a gradual conversion to the less soluble trivalent form can be observed (16). It does not appear that chromium in pond seepage is a problem. The attenuation of chromium in landfill leachate depends more on site conditions, but generally chromium should be relatively immobile.

The behavior of mercury in soils is strongly dependent on the chemical form of the mercury and the soil characteristics. As pH increases, mercury is readily adsorbed on soil minerals (14). Increasing organic content tends to mobilize mercury due to the formation of soluble complexes (14). These and other factors make prediction or conclusions of mercury behavior in soils difficult. The problem may not be significant, however, since the mercury concentration in fly ash and sludge is low and is not readily leachable.

The selenium in fly ash is present primarily as elemental selenium (16). The adsorption of selenium on iron oxides renders the element a very insoluble basic ferric selenite (17). Frequently, leached selenium is in the form of selenate or selenite, which are far more mobile, particularly under neutral or alkaline conditions (14). This fact, coupled with the leachability of selenium, makes the possibility of groundwater contamination with selenium a definite problem. The significance of the problem will depend on the selenium content of the waste, the volume and quality of the groundwater, and the rate of leachate movement. Trace quantities (<0.01 ppm) are not harmful.

Molybdenum is generally mobile in organic soils, and neutral to alkaline soils (16). Since molybdenum, like selenium, may be readily leached into groundwater, the site conditions must be evaluated to determine the extent of any real hazard which might exist.

Boron is readily leached from fly ash (not bottom ash) over a pH range of 6 to 8 (18). It is not as strongly sorbed by soils as are heavy metals (19, 20). This fact, coupled with its high content in fly ash, poses the greatest threat to groundwater quality among trace elements in ashes and sludges. Boron is associated with phytotoxicity rather than as a hazard to human or animal life.

In general, mercury-, lead-, cadmium-, or nickel-laden leachates and seepage from ash and sludge landfills and ponds do not present a threat to groundwater. Arsenic and chromium are readily leached, but will usually be attenuated by the soil and will not reach the groundwater. Molybdenum, selenium, and boron present the greatest threat to groundwater. The nature and extent of this threat will have to be evaluated for each waste and disposal site.

Effects on Surface Waters

Disposal of utility wastes, either in landfills or in ponds, can have a significant effect on nearby surface waters if sufficient precautions are not observed. These waters may be contaminated through surface runoff from a disposal site, lateral migration of leachate from an unlined pond or landfill, or discharge of pond effluents. A less frequent but potentially more serious contamination problem is washout of wastes due to flooding.

If a lake or stream does become contaminated, the effects may be noticed first in the fish and other organisms residing in the waters. Such contamination will also affect humans and terrestrial animals relying on these surface waters as drinking water supplies. Concentrations of trace elements in water considered toxic to aquatic organisms are, in many cases, lower than those considered toxic to terrestrial animals, humans, and higher plants. Concentrations of arsenic, cadmium, chromium, mercury, nickel, and lead as low as 0.01 µg/ml may have serious effects on certain aquatic species (21).

Surface Runoff. Surface runoff is a mechanism by which particulate ash or sludge is carried to nearby surface waters by precipitation running across the soil or waste surface. The soil moisture content strongly affects this process. When soil moisture is high, the infiltration capacity is low and surface runoff is higher than it would be if the soil moisture content were low (22).

Lateral Migration. While leachate from landfills and unlined ponds is primarily a problem for groundwater supplies, lateral migration of leachate to surface waters is also possible if the disposal site is near a river or other surface water, as is frequently the case. However, because of the dilute nature of the leachate and the dilution effect of the surface water, lateral migration is not a major contamination pathway. Much of the discussion of leachate migration to groundwater also applies to such lateral migration.

Discharge of Pond Effluents. The effluents (supernatants) from coal ash and FGD sludge settling ponds are often discharged to surface waters under NPDES requirements. The contamination of surface waters resulting from this discharge (if any) depends on the extent to which the waste is soluble, and whether the effluent is treated before discharge.

In general, a small fraction (2 to 5%) of fly ash is water soluble (12). The soluble fraction is primarily calcium oxide and oxides of other alkali and alkaline earth metals. The soluble fraction of scrubber sludges is primarily calcium sulfite, sulfate, and carbonate (4). Trace element contamination in scrubber sludges is primarily from fly ash trapped by the scrubber.

The leachability of trace metals from fly ash and bottom ash depends on the concentration of the element in the ash matrix, the chemical bonding in the ash, and the pH of the water (23). Trace elements can either be incorporated into the aluminosilicate matrix, in which case they are essentially insoluble as long as the matrix is intact, or they can be deposited (adsorbed or precipitated) on the particle surface where, because of greater contact with the wastewaters, they are more likely to dissolve when conditions are favorable.

Since fly ashes from western coals contain a high percentage of soluble alkali and alkaline earth oxides, leachate and pond effluents at plants using western coals tend to be alkaline (12). In general, the solubility of most trace elements tends to decrease as the pH increases (24). Concentrations of most trace elements in these leachates and effluents are generally less than drinking water standards at equilibrium pH (approximately 11.5) (24). Cox, et al. (18), reported that at pH 6 to 8, 50% of the boron in fly ash dissolved, while only 38% dissolved at pH 10. Several studies have been conducted to determine which trace elements will dissolve from fly ash under alkaline conditions. The leachability of several trace elements in alkaline ash sluice water has been ranked in the following descending order: B, Ba, Cr, Zn, Ni, Cu, Se, As (23). Chromium tends to be more soluble under alkaline, anaerobic conditions (16), although test results for chromium have been inconsistent between researchers. The same features generally hold true for western coal scrubber sludges, which also tend to be alkaline.

Table 2-4 presents analytical results for several ash pond effluents. Note that the effluents seldom exceed the water quality criteria for the trace elements of concern. Only pH, alkalinity, total dissolved solids, ammonia-nitrogen, and iron consistently equal or exceed these criteria. These parameters, however, are not particularly significant from a public health viewpoint. Minimal treatment and/or the diluting effect of a receiving water would bring the concentrations of these constituents within acceptable limits, and reduce these elements to insignificant levels. Consequently, with proper precautions to keep individuals and wildlife away from the ponds and the pond effluents, the effluents should have only a minimal environmental impact.

Table 2-4

EXAMPLE ASH POND EFFLUENT ANALYSIS

Constituent	Pond A*	Pond B*	Pond C†	Pond D†	Pond E†	Pond F†	Pond G†	Pond H†	Drinking Water Quality Criteria#
	mg/l								
pH Units	9.2	9.3	9.8	11.2	11.2	9.6	11.3	10.8	5-9
Total Alkalinity	45	60	45	154	113	47	150	95	20
Total Dissolved Solids	230	203	524	380	452	279	270	232	250
Aluminum	2.1	--	2.8	2.4	2.0	1.8	1.6	1.7	--
Ammonia-N	0.37	--	0.09	0.05	0.15	0.04	0.06	0.06	0.02
Arsenic	--	--	0.018	0.005	<0.005	0.029	0.005	0.012	0.05
Barium	--	--	0.1	0.2	0.2	0.2	0.2	0.2	1
Beryllium	--	--	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.011
Cadmium	--	--	0.003	0.001	0.001	<0.001	<0.001	<0.001	0.01
Calcium	44	42	63	129	115	78	103	87	--
Chloride	6	16	7	6	5	4	6	12	--
Chromium	0.009	--	0.01	0.019	0.043	0.012	0.024	0.021	0.05
Copper	<0.01	--	0.041	0.08	0.02	0.03	0.05	0.05	1
Cyanide	<0.01	--	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.005
Iron	0.9	0.46	5.98	0.3	0.23	0.95	0.29	0.24	0.3
Lead	<0.01	--	0.02	0.014	0.01	0.01	0.01	0.015	0.05
Magnesium	3.9	3.8	6.9	0.4	2	2.5	0.4	1	--
Manganese	<0.01	0.01	0.58	0.01	0.01	0.05	0.01	0.01	0.05
Mercury	0.0009	--	0.001	0.0002	0.038	0.0008	0.0002	0.0004	0.002
Nickel	<0.05	--	0.12	<0.05	<0.05	<0.05	<0.05	0.07	--
Selenium	--	--	0.011	0.009	0.016	0.01	0.004	0.011	0.01
Silica	5.6	5.3	7.7	6.6	6.1	4.8	8.1	7.4	--
Silver	<0.01	--	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
Sulfate	100	75	139	136	156	133	76	87	--
Zinc	0.04	--	0.14	0.05	0.04	0.03	0.08	0.05	5

Sources: * = N. P. Phillips, and R. M. Wells. Solid Waste Disposal: Final Report. EPA 650/2-74-033, Office of Research and Development, U.S. Environmental Protection Agency, May 1974.

† = T. Y. J. Chu, R. J. Ruane, and P. A. Krenkel. Characterization and Reuse of Ash Pond Effluents in Coal-Fired Power Plants. J. Water Pollution Control Fed., 50:2494-2508, November 1978.

= U.S. Environmental Protection Agency. Quality Criteria for Water. EPA 440/9-76-023, U.S. Environmental Protection Agency, Washington, D.C., July 1976.

The impact of a scrubber sludge disposal pond should not differ considerably from that of an ash pond. The sludges tend to be alkaline and, for a given weight, the sludge should have a lower trace element concentration than the ash. Sludge pond effluent would probably be higher in such constituents as alkalinity, dissolved solids, calcium, and sulfate; but, again, these would not represent a significant health hazard if treated minimally or diluted.

Chemically fixed or lime/fly ash stabilized sludges are seldom disposed in a pond except as a temporary expedient. Effluent from such a pond would not differ appreciably from the pond effluents just discussed, except that the concentrations of the constituents in the water should be lower. The stabilized sludges are not as susceptible to leaching during short-term ponding as nonstabilized sludges and fly ash.

Discharge of untreated ash or sludge pond effluent into natural water bodies may have an adverse effect on water quality and aquatic life if the receiving water is not of sufficient volume to rapidly dilute the effluent to near-natural levels. All of the major constituents of the effluent are present in natural waters, generally at lower levels than those in the effluents. Therefore, large volumes of effluents have the potential for changing the receiving water salinity, alkalinity, hardness, boron concentration, pH, etc., resulting in an adverse effect on aquatic life or subsequent water users. The extent of this impact must be assessed for each effluent and receiving water.

Disposal Site Washout. Current federal regulations restrict the disposal of utility wastes within certain floodplains. In the past, however, many disposal sites have been situated within reach of a major flood event on a nearby river. This has, on occasion, resulted in the washout of buried wastes. While far less common than the problems mentioned above, washout presents an immediate and substantial hazard in that large quantities of soluble toxic constituents come into contact with large volumes of water all at one time. The possibility exists, in such an event, for large-scale contamination of the river or stream.

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Section 3

CURRENT REGULATIONS GOVERNING UTILITY WASTE DISPOSAL

The management of utility wastes has traditionally been governed by the prevailing federal and/or state water pollution control regulations. The general nature of these regulations permitted a broad range of interpretation by state and local governments, resulting in a variety of approaches to waste management by utilities.

The complexion of waste management regulation has drastically changed since early 1980 with the passage of the following federal and state legislation:

- Resource Conservation and Recovery Act of 1976 (PL 94-580, RCRA).
- Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (PL 96-510, CERCLA).
- State regulations promulgated specifically for utility waste management.

The practical impact of these regulations is not yet well defined, but it is clear that the fate of utility waste management will be decided by these regulations.

The remainder of this section reviews the status of requirements under the three regulatory areas listed above. Subsequent sections of this manual further describe the prevailing design and operating requirements under the current laws.

FEDERAL REGULATIONS UNDER RCRA

The U.S. Environmental Protection Agency (EPA) promulgated the final hazardous waste management regulations under RCRA in February and May 1980. When combined with the solid waste management regulations promulgated in September 1979, the RCRA regulations constitute perhaps the single most ambitious environmental program ever conceived.

Overall, RCRA placed a greater emphasis on state solutions to solid/ hazardous waste problems than did previous air or water pollution control acts. A state-centered approach permits greater flexibility in dealing with these problems by allowing states to set their own priorities for enforcement. The greater flexibility given the states has resulted in a notable lack of uniformity in their different approaches to solid and hazardous waste management. There are already some federal regulations and guidelines in place under RCRA to assist the states in drafting regulations. Nevertheless, it is important to closely examine the state statutes and regulations (presented later in this section) to assure compliance with the applicable law.

RCRA Subtitles C and D include three distinct strategies for federal solid waste management rule-making. The first strategy is the presentation of "Subtitle D criteria," which provide performance standards for disposal of all solid wastes. A site which meets these criteria is classified as a "sanitary landfill" rather than an "open dump." The next Subtitle D strategy consists of "guidelines" presented to the states to illustrate acceptable solid waste disposal practices. The third and most stringent RCRA rule-making strategy is presented under Subtitle C, which addresses the management of those solid wastes defined as hazardous wastes. Subtitle C regulations constitute a "cradle to grave" management system for these hazardous wastes.

Large-volume utility wastes, such as fly ash and FGD sludge, have been specifically excluded from the hazardous waste category by the U.S. Congress until their hazard potential (specifically toxicity) can be proved. Legislative action on this issue is not expected until at least 1983, when the results of an extensive field investigation of utility waste disposal sites should become available.

Regulation of Nonhazardous Waste Management

Attention within the utility industry is presently focused upon the nonhazardous solid waste regulations promulgated under Subtitle D. As defined, solid wastes include all solid, liquid, semisolid, and contained gaseous material which is discarded or has served its intended purpose, or is a manufacturing or mining byproduct. Excluded by definition are domestic sewage, point source discharges, irrigation return flows, nuclear wastes regulated under the Atomic Energy Act, and in-situ mining wastes.

As noted previously, EPA has established criteria distinguishing sanitary landfills from open dumps. Basically, these criteria (summarized in Table 3-1) are standards of performance necessary to prevent unacceptable impacts (i.e., those having a "reasonable probability of adverse effects on health or the environment"). RCRA encourages the states to close open dumps operating within their jurisdictions. The

Table 3-1

FINAL AND INTERIM FINAL SUBTITLE D CRITERIA FOR SANITARY LANDFILLS*

Criterion	Standards
Floodplains	• No restriction of base flood. • No reduction of water storage. • No washout of solid waste.
Endangered Species	• No taking/adverse modification.
Surface Water	• No NPDES violation (point source, etc.). • No violation of Clean Water Act (Section 404). • No water quality violation (nonpoint source).
Ground Water	• No contamination beyond solid waste boundary, or if state has approved plan, then site can be boundary if no contamination of needed/used groundwater.
Disease	• Apply cover periodically (daily or as necessary). • Control disposal of sewage sludge and septic tank pumpings (interim final).
Air	• No open burning.
Safety	• No high concentration of explosive gases (methane). • Periodic cover (either daily or as necessary). • No uncontrolled public access. • No bird hazards to aircraft.
Land Application/Food Chain Crop (Interim final)	• Not acceptable unless - Cadmium application is limited - PCB application is controlled.

* Source: Federal Register, 44(179):53438-53468, September 13, 1979 (as corrected in Federal Register, September 21, 1979 and October 12, 1979).

criteria are intentionally general. More specific regulations are to be adopted by each state.

Another secondary RCRA strategy is for EPA to provide assistance to the states in the form of guidelines for the location, design, construction, operation, and maintenance of solid waste land disposal facilities [RCRA Section 1008(a)(1)]. The EPA guidelines, which are not yet final and complete, are summarized in Table 3-2.

Regulation of Hazardous Waste Management

EPA originally proposed to regulate low-hazard, high-volume wastes, such as FGD sludge, bottom ash, and fly ash, as "special wastes." Recordkeeping and reporting requirements for special wastes were to be identical with those for hazardous wastes under the December 18, 1978, proposed regulations. However, this proposal was criticized by the utility industry and the U.S. Congress as unjustified and inappropriate. As a result, utility wastes (FGD sludge, bottom ash, fly ash, and boiler slag) were expressly excluded from the definition of hazardous wastes in the final EPA hazardous waste regulations [40 CFR, Section 261.4(b)(4)].

Ongoing EPA research is attempting to develop a more extensive data base with which to categorize these wastes. Pending the completion of this work, changes in the regulations are not expected until at least 1983.

Not all electric utility waste streams are excluded, however. Other waste streams may be deemed "hazardous" under the regulations, if shown to possess one or more of the hazardous waste characteristics: ignitability, corrosivity, reactivity, or toxicity (40 CFR, Section 261.21-24). The following electric utility waste streams (or mixtures containing them) could therefore be deemed hazardous:

- Demineralizer regeneration wastes.
- Boiler cleaning wastes.
- Spent solvents.
- Chemical waste treatment system sludges.
- Runoff from coal piles.
- Wet scrubber system liquid blowdown (not returned to scrubber system).
- Cooling tower blowdown.

Table 3-2

PROPOSED 1008(a)(1) GUIDELINES FOR SOLID WASTE LAND DISPOSAL SITES*

Category	Guidelines
(1) Site Selection	• Environmentally sensitive areas shall be avoided. These include wetlands, 100-year floodplains, permafrost areas, critical habitats of endangered species, and recharge zones of sole-source aquifers. • Other sensitive areas should also be avoided, including active fault and karst zones. • Cost and socioeconomic analyses should be performed, including considerations of post-closure uses. • Regional solid waste management plans should be considered. • Subsurface conduits (sewage, storm, water, etc.) must be relocated as they are pathways for leachate and gas. • On-site suitability for cover and operations (vehicles) should be considered.
(2) Design	• Collect design data, including type and quantity of wastes, current and projected groundwater uses (present quality, depth, hydrogeology), surface water characteristics, 100-year floodplain, and water balance. • Plans must contain: - Evidence of regulatory compliance - Consistency with guidelines - Design and operation considerations - Discussion of separate areas for unusual wastes - Land use, topography, geography (airports, utilities), road system, screens/nuisance control, monitor well locations, sedimentation control, contingency plans, ultimate use of site, long-term maintenance.
(3) Leachate Control	• Bottom of landfill no nearer than 4.9 ft (1.5 m) from seasonal high groundwater table. • Site run-on should be prevented up to 10-year, 24-hour event. • Dike should be constructed, if necessary, to protect against 100-year flood. • Final cover grade between 2 and 30% to encourage runoff while preventing erosion. Should be seeded. • Soils should have shrink/swell characteristics to prevent cracking. • Four kinds of leachate control: - Natural conditions require little/no control (good)

Table 3-2 (continued)

Category	Guidelines
	- Natural conditions require addition of liner (medium) - Natural conditions require leachate collection (fair) - Natural conditions require liner and collection (poor). • Liners must have permeability of 3.28×10^{-9} ft/sec (1×10^{-7} cm/sec); ability to resist physical/chemical reaction; life equal to design life of the facility. • Minimum practical thickness = 1 ft (30.5 cm) for natural soil liners and 20 mils for synthetic liners. • Liner must be protected from puncture using 2 ft (61 cm) of material; 6 in (15 cm) must be gravel with high permeability. • Liner grade $\geq$1%. • Leachate treatment.
(4) Gas Control	• Leachate control aids gas control. • Volatile waste material should not be accepted. • Encapsulation should be coupled with ventilation. • Horizontal migration should be monitored.
(5) Runoff Control	• Location where low potential for run-on. • Ditches, berms, etc., to control and divert. • Well-compacted, fine-grained soils for cover. • Settling basin for siltation control. • Grades <30% to enhance drainage.
(6) Operation	• Accept only proper wastes, i.e., sludges may require dewatering unless a leachate control system has been installed. • Cover material should be applied, if necessary, to minimize fire hazards, odors, litter, vectors, gas, and infiltration. - Cover minimum = 6 in (15 cm) daily - If 90-day suspension = 12 in (30.5 cm) cover - Completed landfill cover of 6 in (15 cm) clay and 12 in (30.5 cm) other soil/vegetation. • Compaction to reduce volume and extend life. • Safety measures: - Safety manual should be available for employees - Safety equipment such as hard hats, gloves, safety glasses, and boots - Safety devices such as rollover protection, seat belts, audible direction indicators, and fire extinguishers - Fire equipment necessary to fight waste fires

Table 3-2 (continued)

Category	Guidelines
	- Communications equipment - Scavenging prohibited - Access should be limited - Appropriate signs for efficient operation. • Disease and vector control. • Recordkeeping, including quantity, quality, and location. • Source of water should be provided for fire protection, dust control, and employee convenience. • Should be aesthetically acceptable. • Long-term post-closure maintenance plan should be adopted and followed after closure.
(7) Monitoring	• Ground water/leachate monitoring should be installed: - Never through landfill itself (direct path to groundwater) - Should have baseline data prior to facility operation - Sample collection and analysis on at least an annual basis. • Gas monitoring in facility structures and surrounding soil.

* Source: Federal Register, 44(59):18138-18148, March 26, 1979.

Treatment, storage, or disposal of hazardous wastes requires compliance with a variety of Subtitle C provisions. There are certain interim standards which must be met by facilities continuing to treat, store, or dispose of hazardous wastes after November 19, 1980. More detailed standards are being promulgated for permitting of new facilities. Table 3-3 summarizes the general standards for permitted hazardous waste facilities. Table 3-4 summarizes standards for specific kinds of electric utility industry facilities.

With the exclusion of high-volume utility wastes from the Subtitle C regulations, the effects of the requirements outlined in Tables 3-3 and 3-4 are diminished. However, some of these standards may apply to utility waste disposal upon promulgation of specific requirements.

FEDERAL REGULATIONS UNDER CERCLA (SUPERFUND)

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (commonly referred to as the "Superfund" legislation) became law in December 1980. Under this legislation, generators, transporters, and disposers of hazardous substances in the United States are confronted with a new set of operating rules. Where previous environmental laws contemplated regulatory standards of practice, Superfund does not. Owners and operators of disposal facilities are liable under Section 107 of Superfund for certain kinds of environmental damage without regard to fault.

Liability Standard

Under the Superfund liability standard, a disposal facility owner or operator who employs the most advanced, careful methods available will be liable under Superfund if environmental damage results from a failure in the facility. Generators and transporters may also be liable for disposal site failure, if they selected the site, or acted negligently. Negligent acts include failure to disclose the contents of a toxic waste shipment (e.g., improper placarding and/or manifesting); failure to take precautionary measures to protect against foreseeable events (e.g., use of improper containers which rupture in an accident); or failure to cease shipments to a site which is known to be out of compliance. Some authorities contend that negligent acts might also include failure to inspect the design and operation of disposal sites utilized, whether or not the generator actually selects the site.

Table 3-3

GENERAL FACILITIES STANDARDS (SUBTITLE C) FOR HAZARDOUS WASTE MANAGEMENT*

Name of Plan	Description
General Waste Analysis Plan	• Before treatment, storage, or disposal, must obtain detailed analysis of representative sample of waste. • Must be repeated if process is changed or inspection of waste indicates waste received does not match description. • Written description of waste analysis plan, including sampling and analysis methods, must be kept on site.
Security Plan	• 24-hour surveillance system. • Fence or other barrier. • Entry is controlled by gates or guards. • Sign stating "Danger - Unauthorized Personnel Keep Out".
Inspection Plan	• Must develop and follow a schedule for inspecting all equipment which is important to prevent, detect, or respond to environmental or human health hazards. • Must maintain log of inspections. • Must remedy deficiencies noted during inspections. • Schedule and log must be kept on site.
Personnel Training Plan	• Training must be completed within 6 months for supervised employees or prior to working for supervisors. • Annual training review. • Documents must be maintained at facility, including job descriptions, training requirements, and training logs.
Preparedness and Prevention	• Internal alarm system easily accessible. • Communications equipment easily accessible • Portable fire fighting equipment. • Adequate water supply. • Adequate aisle space to permit access by emergency equipment and personnel. • Arrangements with local public safety officials for emergency response. • Testing and maintenance of emergency equipment.

Table 3-3 (continued)

Name of Plan	Description
Contingency Plan and Emergency Procedures	• Describes actions which personnel shall take in an emergency. • Lists names, addresses, and telephone numbers of those authorized to act as emergency coordinators. • Describes locations and capabilities of emergency equipment. • Must include evacuation plan. • Must be maintained at facility and submitted to local authorities. • Emergency coordinator must be on premises or on call at all times.
Operating Record	• Description of wastes and method of storage, treatment, and disposal. • Location of each hazardous waste within the facility. • Results of waste analyses. • Summaries of all contingency plan incidents. • Results of inspections. • Closure and post-closure cost estimates.
Location Standards (interim final)	• Treatment, storage, and disposal must not take place within 200 ft of a seismic fault. • Facility located in a 100-yr floodplain must be designed, constructed, operated, and maintained to prevent washout.
Closure Plan	• Description of how and when facility will be closed. • Estimate of maximum waste inventory. • Description of steps to be taken decontaminating equipment. • Schedule for closure with milestones (complete closure within 6 months of final waste receipt). • Must be kept at the facility and updated as required.
Post-Closure Plan (for land disposal facilities only)	• Description and frequency of ground water monitoring. • Description of maintenance activities. • Must maintain plan on site.
Financial Requirements (interim final)	• Must maintain and update estimate of cost for facility closure and post-closure care. • Must establish financial assurance for facility closure and for post-closure monitoring and maintenance.

Table 3-3 (continued)

Name of Plan	Description
Liability Requirements	• Demonstrate financial responsibility for claims arising from occurrences (sudden and non-sudden) that cause injury to persons or property.

* Source: Federal Register, 45(98):33154-33258, May 19, 1980, and amendments through May 20, 1981.

Table 3-4

INTERIM STATUS STANDARDS FOR MAJOR CATEGORIES OF HAZARDOUS WASTE LAND DISPOSAL FACILITIES*

Disposal Facility Type	Requirements
Surface Impoundments	• At least two feet of freeboard. • Earthen dikes must have protective cover. • Inspect freeboard daily. • Inspect dike weekly for leaks or other deterioration.
Waste Piles	• If waste may be dispersed by wind, must cover or otherwise protect. • If leachate or runoff evidences hazardous characteristic, must collect leachate or prevent its formation.
Land Treatment	• Cannot be used unless biological degradation or chemical reactions will lessen hazard in soil. • Run-on must be diverted. • Runoff must be collected. • Severe limitations on use of land for food chain crops. • Must monitor vertical migration of contaminants
Landfills	• Run-on must be diverted. • Runoff must be collected. • If waste may be dispersed by wind, must cover or otherwise protect. • Must maintain vertical and horizontal control and locations of wastes disposed. • Liquid wastes may not be disposed of in landfills unless either leachate is collected or liquid is stabilized. • Containers holding liquid wastes (i.e., drums) may not be disposed of in landfills. • Containers must be shredded or flattened before disposal.

* Source: Federal Register, 45(98):33245-33250, May 19, 1980, as amended through May 20, 1981.

Those responsible for the release of a hazardous substance to the environment are liable under Superfund for two kinds of damages:

- Response costs.
- Assessment, restoration, and rehabilitation of natural resources.

The controversial provision which would have permitted third-party personal injury claims to be judged under Superfund's strict standards was removed from the legislation prior to promulgation.

Notification Requirements

Two distinct forms of notification by industry to the federal government are provided under Superfund. First, any time a "reportable quantity" of hazardous substance is released either in transit or from any facility, the incident must be reported to the National Response Center. A "reportable quantity" is currently defined according to the 1 lb limit set by the Clean Water Act, Section 311, pending new EPA regulations.

The second notification requirement provides that by June 11, 1981, certain persons must notify EPA regarding the whereabouts of operating or abandoned hazardous substance disposal sites. Included are:

- Persons who own or operate a facility where hazardous substances are stored, treated, or disposed.
- Persons who, at the time of disposal, owned or operated a facility where hazardous substances were stored, treated, or disposed.
- Persons who accepted hazardous substances for transport, and selected a facility where hazardous substances were stored, treated, or disposed.

Facilities with RCRA Subtitle C permits or interim status are excluded from this second notification requirement. Specific information to be included in these notifications includes "the amount and type of hazardous substances to be found," and "any known, suspected, or likely releases of such substances" at the site [Section 103(c)].

"Hazardous substances" under Superfund [Section 101(14)] include:

- Substances defined as hazardous under Section 311(b)(2)(4) of the Clean Water Act (these do not include oil, except oils containing other hazardous substances).
- Substances designated by regulations under Superfund.

- Wastes exhibiting RCRA Subtitle C characteristics or listed under Subtitle C.
- Toxic pollutants, Clean Water Act, Section 307.
- Hazardous air pollutants, Clean Air Act, Section 112.
- Imminently hazardous chemical substances, Toxic Substances Control Act, Section 7.

Post-Closure Care

Superfund permits a transfer of liability for post-closure care of disposal sites. If a permitted hazardous waste disposal facility has been closed in accordance with its Subtitle C permit, and has been monitored for a 5-year period without any indication of contaminant release, then a special post-closure care fund will assume liability for post-closure care. The fund will be provided by a special hazardous waste disposal tax, imposed upon operating facilities. Provisions for the transfer of liability are a direct response by Congress to the concern of industry that a 20- or 30-year period for post-closure care (contemplated by RCRA regulations) is unrealistic.

STATE REGULATIONS

Although the EPA Subtitle C regulations took more than 3 years to develop after RCRA became law, the various states were not aware of the important changes contained in the final version of those regulations. As a result, several states propose to implement selected elements of the original December 18, 1978, draft RCRA regulations, including the special management requirements for bottom ash, fly ash, and FGD sludge. The state regulations therefore merit close attention.

A summary of selected state solid and hazardous waste management regulations pertaining to utility wastes is provided below. The reader is cautioned that most of this material will be subject to change in the next few years, as the states develop more definitive regulations for solid waste disposal in response to RCRA.

Tables 3-5 through 3-9 compare pertinent regulations from 10 states (Alabama, Illinois, Indiana, Kentucky, Missouri, North Carolina, Ohio, Pennsylvania, Tennessee, and Virginia) with the federal requirements previously discussed. The scope of each table is as follows:

- Table 3-5 - Regulatory Definitions and Special Features for Utility Waste Disposal Sites.

Table 3-5

REGULATORY DEFINITIONS AND SPECIAL FEATURES FOR UTILITY WASTE DISPOSAL SITES

PROMULGATING AUTHORITY	SOLID WASTE DEFINITION	HAZARDOUS WASTE DEFINITION	SPECIAL FEATURES: UTILITY WASTES
U. S. Environmental Protection Agency COMMENTS: Based upon Final Subtitle C and Subtitle D Regulations, and proposed RCRA Section 1008 (a)(1) Guidelines	All solid, liquid, semi-solid, or contained gaseous material which is discarded or has served its intended purpose or is a manufacturing or mining by-product; excluding domestic sewage, § 402 point source discharge, irrigation return flow, nuclear waste regulated by AEC, and in-situ mining waste. (40 C.F.R. § 261.2)	Two mechanisms for determing whether a solid waste is hazardous: 1) evidence of 40 C.F.R. §261 Subpart C characteristics of ignitability, corrosivity, reactivity, or EP toxicity. 2) listing upon 40 C.F.R. §261 Subpart D list of specific hazardous wastes.	Utility wastes, including fly ash waste, bottom ash waste, and, FGD sludge waste resulting primarily from fossil fuel combustion, are expressly excluded from definition of hazardous waste. (40 C.F.R. §261.4(b)(4))
ALABAMA Department of Public Health Environmental Health Administration (205) 832-6728 COMMENTS: Proposed hazardous waste regulations track the December 18, 1978 EPA proposal, and thus "had their legs cut out" by the May 19 FR version, especially as to "special wastes." Much political pressure will have to be resisted if Alabama proposal ever becomes final regulation, as written.	Discarded materials -- except household sewage and livestock and poultry wastes -- including industrial wastes not controlled by other agencies.	Proposed -- same as RCRA statutory definition at RCRA Section 1004(5)	-PROPOSED- FGD sludges, bottom ash, and fly ash wastes which are generated by fossil fuel fired steam power plants are special wastes if they evidence any of the four hazardous waste characteristics (ignitable, corrosive, reactive, or toxic). Toxic standard is 10x interim drinking water standard. Special wastes - must be subjected to detailed chemical and physical analyses, and - must be disposed of in facilities capable of preventing discharges to the environment - must undertake special monitoring.
ILLINOIS Pollution Control Board (217) 782-6760 COMMENTS: Has had "special" (hazardous) waste permit and manifest system in place for several years. Manifest system is computerized, including analytical data re special wastes.	Same as RCRA Section 1004(27) statutory definition. Excludes municipal waste.	Incorporates RCRA Section 1004(5) definition as it may evolve. Express reference to federal characteristics and hazardous waste listing.	"Special" wastes include (1) hazardous wastes (2) industrial process wastes (3) pollution control wastes Utility wastes will fall generally into categories 2 and 3, and will therefore be considered special wastes. Manifest and analytical requirements will therefore be imposed.
INDIANA State Board of Health (317) 633-0176 COMMENTS: State now drafting hazardous waste regulations. Traditionally have treated FGD sludge on a case-by-case basis; otherwise, utility wastes are often excluded from regulation as inerts.	Excludes human excreta.	Wastes with "inherent dangers" including toxic chemicals, explosives, pathological wastes, radioactive materials, materials likely to cause fires, liquids, semi-liquids, sludges containing <36% solids, pesticides and their containers, raw animal manure, septic tank pumpings, and raw or digested sewage.	Operators wishing to dispose of inert fill may petition Board for exclusion from solid waste regulations. Exclusion is voided if any other matter is accepted.
KENTUCKY Department for Natural Resources and Environmental Protection (502) 564-6716 COMMENTS: Solid Waste Regulations have been in effect since 1975; hazardous waste regulations now under development. Solid waste regulations permit wide flexibility in operations.	No exclusions -- all refuse in solid form.	"Special" wastes include explosives, pathological wastes, radioactive materials.	-NONE-
MISSOURI Department of Natural Resources (314) 751-3241 COMMENTS: Latest Missouri Revisions (effective January 1, 1980) track May 19 EPA regulations.	Excludes overburden, rock, mine tailings, matte, slag, or other mining, milling, or smelting wastes.	Same as federal definition, criteria, characteristics, and list (list is more extensive).	Fly ash, bottom ash, and scrubber sludge from fossil fuel burning power plants are expressly excluded from hazardous waste regulations. Semi-solids, sludges with free moisture, and industrial process sludges must have separate design/operation approval of specific procedures under solid waste regulations.

Table 3-5 (continued)

PROMULGATING AUTHORITY	SOLID WASTE DEFINITION	HAZARDOUS WASTE DEFINITION	SPECIAL FEATURES: UTILITY WASTES
NORTH CAROLINA Department of Human Resources Division of Health Services (919) 733-2178 COMMENTS: Existing hazardous waste regulations are to be significantly altered to reflect EPA's May 19 promulgation almost verbatim. State statute mandates that North Carolina regulations be no more stringent than federal regulations.	Same as federal regulation.	Same as federal regulation	Revisions presently being made to hazardous waste regulations will expressly exempt utility wastes from their provisions.
OHIO Environmental Protection Agency (614) 466-8934 COMMENTS: State intends to obtain interim status under federal program. State statute precludes regulations more stringent than federal regulations.	Unwanted solid or semi-solid material, excluding construction or mining wastes, slag, or non-toxic fly ash or foundry sands. Regulations do not apply to ponds or lagoons regulated under water act.	Same as RCRA statutory definition, Section 1004(5) with express reference to (and incorporation of) substances listed as hazardous by federal regulation.	"Non-toxic fly ash" provision came into effect March 19, 1979, over Ohio EPA objection. Ohio EPA urges compliance with solid waste regulations as to fly ash. If exemption is claimed, analyses (either by generator or by state) must show EP toxicity less than drinking water standards (if ground waters are affected) or 100x drinking water standards (if only surface waters are affected). Fly ash which will not be disposed of under organic acid conditions may rely on distilled water EP. Water pollution laws may impose more stringent requirements.
PENNSYLVANIA Department of Environmental Resources (717) 787-7381 COMMENTS: Solid waste regulations in place since 1970, with substantial re-write in 1977. Regulations provide for special treatment for utility wastes, with specific methods identified.	No exclusions -- all garbage, refuse, and discarded materials.	Same as RCRA statutory definition, Section 1004(5).	FGD sludge (if specially approved), fly ash, and bottom ash are subject to separate detailed disposal regulations.
TENNESSEE Department of Public Health (615) 741-3424 COMMENTS: -PROPOSED- Hazardous waste regulations contain two categories of hazardous waste: higher and lower risk wastes. Regulations for lower-risk wastes have been deferred for one year, pending further study.	Excludes common water pollutants.	Proposed definition is same as RCRA statutory definition, Section 1004(5).	Lower-risk wastes using EPA characteristics, but with different (less stringent) threshhold criteria. Utility wastes are probably lower-risk wastes, and thus excluded from proposed hazardous waste regulations. LOWER RISK WASTES Ignitability -- $100^{\circ}F \leq$ flash-point $\leq 140^{\circ}F$ Corrosivity -- $2 \leq pH \leq 12.5$ and corrosion rate ≤ 0.250 inches/year Toxicity -- $10x \leq$ EP concentration $\leq$ 100x interim drinking water standard.
VIRGINIA Department of Health (804) 786-5271 COMMENTS: Very general solid waste regulations have been in effect since 1971 without substantial revision.	Excludes common water pollutants, such as silt, suspended solids, dissolved solids, etc.	Same as RCRA statutory definition, Section 1004(5).	Inert materials -- including ash -- may be disposed of on land without cover.

Table 3-6

STATE SITE SELECTION, SITE DESIGN, AND LEACHATE CONTROL REQUIREMENTS

PROMULGATING AUTHORITY	SITE SELECTION	SITE DESIGN	LEACHATE CONTROL
U.S. ENVIRONMENTAL PROTECTION AGENCY	Environmentally sensitive areas, such as flood plains, permafrost areas, critical habitats of endangered species, and recharge zones of sole source aquifers, should be avoided. Facilities shall not restrict the flow of the base (100 yr.) flood, nor shall they reduce water storage, nor shall they permit washout of of solid waste. On-site soil suitability for both cover and vehicular operations should be considered. Underground utilities traversing the site should be avoided or relocated. Adequate socio-economic analysis should precede site selection. If site is to be land application, site used to produce food crops, special provisions apply.	Design shall include those features necessary to preclude water quality violations (non-point sources) and dredge/fill violations. Design must preclude ground water contamination beyond the solid waste boundary (site boundary in some cases).	Point source discharge must comply with CWA § 402 NPDES permit requirements. Bottom of landfill should be no nearer than 1.5 meters from seasonal high ground water table. Site run-on should be diverted or controlled up to a 10-year, 24-hour rainfall event. If constructed in floodplain, dike should be installed to protect against 100-year flood. Liners, if used, should be protected from puncture (6" gravel and 18" cover) and should be sloped $\geq$ 1%. Control system must prevent ground water contamination beyond solid waste boundary (site boundary in some cases).
ALABAMA Department of Public Health Environmental Health Administration	As approved by the Board.	As approved by the Board.	
ILLINOIS Pollution Control Board	No express location criteria.	Application must include: - Topo map if site with 5' contour intervals (if relief >20'), 2' contour intervals (if relief<20') - map showing land uses and natural and man-made features within ¼-mile of site - data from soil samples including soil classification, grain size distribution, permeability, compactability, and ion-exchange - description of hydrogeology; comprehensive analyses of water samples taken from on-site and off-site wells and surface waters - topo map showing ultimate grades and statement of post-closure use, if known - description of operations, and of wastes accepted	Must take adequate measures to monitor and control leachate.
INDIANA State Board of Health	Construction in 100-year flood plain requires separate approval of Natural Resources Commission.	Design based upon - - USGS topo map showing site. Must indicate whether any airport is located within 5 miles - map showing land use and zoning within ¼-mile; also natural and man-made features (especially utilities) - description of geologic origins of all earth materials - report of soils, ground water, and geology (borings 20' beneath lowest point) including permeability, compactability, and ion-exchange	As specified by the Board about perimeter of site.
KENTUCKY Department for Natural Resources and Environmental Protection	Preliminary site plan analysis can be submitted for review and comment. Site shall not be exposed to 5-year flood. If in high water table, must have 2' compacted fill between waste and maximum water table. Similarly, must have 2' separation between waste and bedrock.	Must be by PE and include: - USGS 7.5 minute topo map - detailed plot plan - description of disposal operations - description of soil conditions Landfills in 100-year floodplain must be protected.	If in high water table area, must take measures to prevent contamination regardless of soil conditions. Must take measures to prevent ground water or stream contamination unless sub-soil structure is sufficient to do so.

Table 3-6 (continued)

PROMULGATING AUTHORITY	SITE SELECTION	SITE DESIGN	LEACHATE CONTROL
MISSOURI Department of Natural Resources	Geology and hydrology of site must minimize impact on ground and surface waters. Soil must be suitable for landfill. Site access must not be subject to flooding.	Site development plan must be prepared by PE and include: - topo map with 5' contours - land use, zoning, natural and man-made features within ¼-mile of site - location of all utilities on, under, or over site - description of ultimate site use - current and projected uses for water resources within "zone of influence" - ground water elevation and separation - impact upon ground and surface water - baseline water quality data within "zone of influence" - description of soils and geology Design must prevent contact with 100-year flood.	Design must discuss leachate problems potential and control. Permit required for point source discharges.
NORTH CAROLINA Department of Human Resources Division of Health Services	Soils must be suitable for landfill operation, and be present in sufficient quantity for cover. Site must not have rock formations, water table, or zone of saturation near surface. Site must not be in a floodplain having a one percent or greater chance of flooding in any given year (100-year floodplain).	Design must be based upon subsurface investigation (soil borings), ground water sampling and analysis, and a geologic report. Plan must include map of surrounding land uses and natural and man-made features within ¼-mile of site. A buffer zone sufficient to confine visible siltation within one-fourth of the buffer zone must be provided.	Landfill must not contaminate adjacent water supplies; nor contravene assigned stream water quality standards.
OHIO Environmental Protection Agency	May not be located in floodway (channel pathway for regional 100-year flood). May not be located in sand or gravel pit, limestone or sandstone quarry. Minimum distances - 1,000' to nearest existing water well 200' to nearest stream 5' of seasonal high water table (if separated only by low permeability soil).	Plan must include USGS topo map and (1) land uses, roads and buildings within 1,000', (2) airports within 10,000', and (3) mines within 2,000'. Reports to include soils, geology and lithology, ground water flow and quality, direction of prevailing winds, nature of waste to be accepted (in detail if liquid or semi-solid). Person submitting plans must not now be, nor have been previously, in violation of solid waste regulations.	If leachate detected on site, or draining from site, and Director determines that a substantial threat of water pollution exists, then leachate shall be contained and treated, and action taken to minimize leachate generation.
PENNSYLVANIA Department of Environmental Resources	Geology foundation materials shall have minimum bearing capacity of one-and-one-half times the total design load to be applied.	Application for permit must technically describe soils, hydrogeology, topography, and climatology of site. Also, "detailed" chemical analyses of fly ash and bottom ash are required.	Soil seeps, springs and other waters on the surface of the site shall be collected and removed.
TENNESSEE Department of Public Health	Site shall not be subject to flooding (in re Noah's Ark notwithstanding). Detailed feasibility analysis required including background on region to be served, existing disposal facilities, anticipated future developments, and a cost and site evaluation of alternatives	Facilities to serve industrial concerns will be approved on a case-by-case basis for location, design, operations, and closure. System is highly flexible.	-NONE-
VIRGINIA Department of Health	-NONE-	-NONE-	Ground and surface water pollution shall be avoided.

Table 3-7

STATE GAS CONTROL, RUNOFF CONTROL, AND MONITORING REQUIREMENTS

PROMULGATING AUTHORITY	GAS CONTROL	RUN-OFF CONTROL	MONITORING
U.S. ENVIRONMENTAL PROTECTION AGENCY	Volatile substances should not be accepted. Where used, encapsulation should be coupled with ventilation. Horizontal migration should be monitored. No concentration of explosive gases (methane) in landfill structures.	Location should have low potential for run-on. Ditches, berms, etc., should be used to divert surface drainage around landfill site. Settling basin should be constructed for siltation control. Grades should provide good drainage while preventing erosion (generally <30%).	Ground water/leachate monitoring should be installed. - never through landfill itself (direct path to ground water) - should have baseline data prior to facility operation - sample collection and analysis on at least an annual basis Gas monitoring should be conducted in facility structures and surrounding soil.
ALABAMA Department of Public Health Environmental Health Administration	-NONE-	-NONE-	-PROPOSED- For special waste disposal: - at least 4 monitoring wells including at least 1 background well hydraulically upgradient and at least 3 wells hydraulically downgradient - at least 1 of the downgradient wells shall be immediately adjacent to disposal site - wells shall be cased and sealed - water table elevation shall be determined quarterly - baseline shall be established at least 3 months before disposal - samples to be minimally analyzed quarterly and comprehensively analyzed annually - must cease landfill operations and notify board if significant change is noted.
ILLINOIS Pollution Control Board	-NONE-	-NONE-	-NONE-
INDIANA State Board of Health	Gases generated shall be controlled on-site. No lateral migration or explosive concentrations shall be permitted.	Surface water courses and run-off shall be diverted from landfill.	-NONE-
KENTUCKY Department for Natural Resources and Environmental Protection	-NONE-	Surface contours shall minimize run-off onto or through site.	If landfill is in high ground water area, must monitor ground water.
MISSOURI Department of Natural Resources	Decomposition gases shall not accumulate to toxic or explosive concentrations.	On-site drainage control structures should be designed to minimize infiltration and erosion. Design should be for 20-year flood.	-NONE-
NORTH CAROLINA Department of Human Resources Division of Health Services		Surface water shall be diverted from operational area.	All streams on-site shall be monitored prior to operation and at least annually thereafter. Ground water monitoring is required where site has "marginal soil permeability characteristics" or where "good engineering practices" dictate.
OHIO Environmental Protection Agency	Ventilation structures shall be constructed as necessary to control gas migration.	Surface water shall be diverted from operations area (both current and former). Should ponding occur, operator shall take remedial action to correct grade.	Shall install monitoring wells as approved for ground water quality. Sampling and analysis twice annually.

Table 3-7 (continued)

PROMULGATING AUTHORITY	GAS CONTROL	RUN-OFF CONTROL	MONITORING
PENNSYLVANIA Department of Environmental Resources	-NONE-	Run-off shall be diverted around fly ash and bottom ash areas. A contingency plan for treatment of run-off from fill area shall be provided. Waste water shall be collected and treated as necessary. An erosion and sedimentation plan must be provided. See leachate control.	Ground water monitoring points shall be proposed for approval. Analytical results shall be submitted in accordance with permit.
TENNESSEE Department of Public Health	-NONE-	All surface water to be diverted around the operations area.	-NONE-
VIRGINIA Department of Health	-NONE-	-NONE-	-NONE-

Table 3-8

ACCEPTABLE WASTES, COVER, AND COMPACTION REQUIREMENTS

PROMULGATING AUTHORITY	OPERATIONS		
	Acceptable Wastes	Cover Requirements	Compaction Requirements
U.S. ENVIRONMENTAL PROTECTION AGENCY	Accept only proper wastes (sludges may require dewatering unless a leachate collection system has been installed).	Cover material should be applied if necessary to minimize fire hazards, odors, litter, vectors, gas, and water infiltration. - minimum daily cover = 6" - if 90-day suspension in operations, intermediate cover = 12" - final cover = 6" clay and 18" other material	Compact as necessary to extend landfill life.
ALABAMA Department of Public Health Environmental Health Administration	-NONE-	Final cover of 2', contoured to prevent ponding and erosion.	-NONE-
ILLINOIS Pollution Control Board	Special waste must be comprehensively analyzed for its hazardous characteristics as a first step in automated manifest system.	Unless permit provides otherwise, shall have 6" daily cover, 12" intermediate (lift to be inactive more than 60 days)cover, and 24" final cover within 60 days of final application to a given lift.	All refuse shall be deposited at top of working face or into bottom of trench, if used. Lifts shall be 2' or less working face slope shall not exceed two horizontal to one vertical (<50%).
INDIANA State Board of Health	Sign of at least 16 square feet shall identify operation, hours, etc.	Cover requirements are flexible, as approved by Board. Unless permit provides otherwise, daily cover required not less than 6", regardless of weather. Final cover to be at least 24", and to have final slope of at least 2% without depressions.	Working face slope shall be maintained at 3:1 or steeper(>33%).
KENTUCKY Department for Natural Resources and Evironmental Protection	-NONE-	Cover intervals sufficient to prevent fire hazards, unsightly appearance, and rodent harborage. See Closure/Postclosure/Financial	-NONE-
MISSOURI Department of Natural Resources	Lists of wastes not approved for disposal to appear at site entrance.	Air pollution control residues (fly ash and bottom ash) shall be incorporated into working face and covered as necessary to prevent them from becoming airborne. Otherwise, daily cover required (6"); intermediate cover required if lift is to be inactive for 60 days (12"). Final cover shall be 2', with grades shall not exceed 33 1/3%. Must have contingency plan for vector control.	Two-foot lifts, maximum. Must have preventative maintenance program for equipment.
NORTH CAROLINA Department of Human Resources Division of Health Services	Division must approve acceptance of liquid or hazardous wastes. Sign stating this limitation must appear at site entrance.	Daily cover, unless different frequency is specified by division. Final cover of 2' in thickness shall be applied and graded to prevent excessive erosion or siltation.	-NONE-
OHIO Environmental Protection Agency	May not accept semi-solids, liquid or hazardous wastes unless (1) special permit or (2) grandfathered (operations in place with approval under former rules).	In no event shall solid wastes be exposed more than 24 hours. Daily cover of 6"; intermediate (operations suspended 30 days) cover of 12"; final cover of 24". Cover to be loam, sandy loam, silty loam, clay loam, silty clay, and sandy clay.	Lifts shall be 2' maximum. When inclement weather precludes disposal at face, must have approved alternative area or method.
PENNSYLVANIA Department of Environmental Resources	FGD scrubber sludges may be incorporated with fly ash if approved by the Department.	See Closure/Postclosure/Financial	Lifts of fly ash or bottom ash shall not exceed 2 feet, and shall be uniformly compacted. Grades shall not exceed 15% without special measures, and in no event may they exceed 33% (except terrace benches). Terrace bench vertical slopes shall not exceed 50% and lengths shall not exceed 30'. Terrace bench horizontal slopes shall be toward the fill mass between 1 and 3%, and lengths shall be at least 10'.

Table 3-8 (continued)

PROMULGATING AUTHORITY	OPERATIONS		
	Acceptable Wastes	Cover Requirements	Compaction Requirements
TENNESSEE Department of Public Health	Shall have a sign at entrance "Sanitary landfills" (those serving municipalities) may not accept materials which are hard to manage (i.e., sludges) unless special provisions are made and approved. Approval requires report of waste characteristics to Department.	-NONE-	-NONE-
VIRGINIA Department of Health	-NONE-	Certain inert materials (including ash) may be disposed of on land without cover.	Substitute compaction equipment must be available on 24-hours notice.

Table 3-9

STATE SAFETY, RECORD-KEEPING. AESTHETIC, AND CLOSURE/POSTCLOSURE/FINANCIAL REQUIREMENTS

PROMULGATING AUTHORITY	OPERATIONS			
	Safety Measures	Record Keeping Requirements	Aesthetics	Closure/Postclosure/Financial
U.S. ENVIRONMENTAL PROTECTION AGENCY	Should provide: - safety manual available to employees - safety equipment such as hard hats, gloves, safety glasses, and boots - safety devices such as rollover protection, seat belts, audible reverse direction indicators and fire extinguishers - fire equipment as necessary - emergency communications - appropriate traffic control Public access should be limited and scavenging prohibited. Source of water should be provided for dust control, fire control, and employee convenience.	Should maintain records of both quantity and nature of wastes received.	Should be aesthetic.	A long-term postclosure maintenance plan should be adopted and followed.
ALABAMA Department of Public Health Environmental Health Admin.	-NONE-	-NONE-	-NONE-	-NONE-
ILLINOIS Pollution Control Board	Must submit safety programs for approval. Access must be controlled. Adequate shelter, sanitary facilities, and emergency communications equipment must be provided.	Records of water monitoring data shall be submitted within 15 days after each calendar quarter.	-NONE-	Postclosure care period is 3 yrs., during which former operator must continue monitoring gas, water, and settling and take any remedial action required. Upon closing, must file description and plat in county land records.
INDIANA State Board of Health	Operators shall be instructed in proper procedures and shall have available a reference manual. Emergency communications equipment shall be available. All rolling vehicles shall have roll bars and fire extinguishers. Access shall be limited to those times at which operating personnel are available. All on-site roads shall be passable by vehicles, including automobiles, regardless of weather. No vehicle shall be left unattended along routes.	Approved set of plans and up-to-date plot plan shall be maintained on-site. See Closure requirements.	No refuse deposit shall be made within 600' of a dwelling unless by written permission. Vegetation shall be cleared only to the extent necessary. Provision shall be made to prevent (or to clean up) vehicles tracking mud on public highways.	Description of site, including nature and location of disposed wastes, shall be recorded at county land records office. Owner or operator shall maintain surface grades, monitoring devices, and leachate or gas control devices.
KENTUCKY Department for Natural Resources and Environmental Protection	-NONE-	-NONE-	A buffer zone between fill area and surrounding land shall be provided. Litter fences to be used "as necessary."	If site is leased, lease agreement must provide a two-year right-of-entry after closure. Must post bond or escrow for life of landfill plus two years in the amount of $3,000 plus $500/acre. Final cover of 2' with vegetation shall be installed and maintained for two years after closing. Before removing equipment, operator must notify state for final inspection.

Table 3-9 (continued)

PROMULGATING AUTHORITY	OPERATIONS			
	Safety Measures	Record Keeping Requirements	Aesthetics	Closure/Postclosure/Financial
MISSOURI Department of Natural Resources	All-weather roads must be available leading to site. Assess shall be controlled and limited. Each piece of waste handling equipment shall have a fire extinguisher, and adequate emergency communication equipment shall be available.	Must maintain the following information: - major operational problems, complaints, or difficulties - results of quantitative and qualitative analyses for gas, surface water, and ground water - vector control efforts - dust and litter control efforts - quantitative record of wastes received - description of source, nature and volume of special wastes	Must have litter control program, including cover, portable litter fences around working face, preservation of natural windbreaks, and daily litter clean-up.	Upon closing, must file description or plat of site, including types and general locations of wastes, depths of fill, and leachate or gas control facilities. If leachate control is proposed, post-closure administration and financial provisions must be stated in original application.
NORTH CAROLINA Department of Human Resources Division of Health Services	Approach road shall be all-weather construction.	-NONE-	-NONE-	Division must be notified, and final inspection made before equipment is removed. Post-closure care shall be responsibility of owner.
OHIO Environmental Protection Agency	Access roads to be all-weather. Access shall be limited to employees except during hours of operation.	Must keep daily log in state-mandated format, and submit, upon request, copy of approved plans to be maintained on-site.	Litter control as necessary. Vegetation to be cleared only to the extent necessary for proper operation.	Must provide notice of intent to to close site at least 30 days prior to closure. Within 60 days of closure: - drainage structures to be constructed to divert surface water from site - except for sites receiving only wastes generated at site, sign to be erected (3' high letters) stating site is closed - Plat to be received stating nature and location of buried wastes - Post-closure care period of 3 years to monitor grade, cover, control structures
PENNSYLVANIA Department of Environmental Resources	Access shall be controlled.	See Monitoring.	Buffer zone of 50 feet shall separate toe of slope from property line.	A restoration plan for final cover shall be provided. Cover can be less than 24" if operator demonstrates that adequate vegetation can be established with less. Completed portions of landfill shall be revegetated as soon as weather permits. Site shall be maintained as long as necessary after closure, including maintenance of ground cover and wastewater treatment facilities. Bond of up to $1,000/acre may be required for disposal to an abandoned mine.
TENNESSEE Department of Public Health	Access roads shall be all-weather, or alternative disposal means developed for inclement weather. Access to be controlled by gate and (if necessary) fencing. Heated structure with nearby toilet facilities shall be provided for use of operating personnel. Fire protection shall be provided for the site.	-NONE-	-NONE-	-NONE-
VIRGINIA Department of Health	All-weather roads to and on-site. 50-foot wide firebreak shall be maintained around operations.	-NONE-	"Adequate" provisions shall be taken to prevent dust and blowing litter.	-NONE-

- Table 3-6 - State Site Selection, Site Design, and Leachate Control Requirements.
- Table 3-7 - State Gas Control, Runoff Control, and Monitoring Requirements.
- Table 3-8 - Acceptable Waste, Cover, and Compaction Requirements.
- Table 3-9 - State Safety, Record Keeping, Aesthetic, and Closure/Postclosure/Financial Requirements.

Most of the state solid waste disposal regulations are phrased in general language. Specific requirements for utility waste landfill operations often do not emerge from a reading of the actual regulations. For example, although a state regulation may require "daily cover" for landfill operations, the requirement is usually waived by the state where nonputrescible utility wastes are involved.

Variations between different state approaches to utility waste disposal may be seen in the above tables. Fortunately, there are only a few examples of outright conflict between different state requirements. One conflict involves working face slope requirements (see Table 3-8, "Compaction Requirements") in Indiana (working face slope >33%) and Pennsylvania (<15%). The steepest working face permitted for fly ash disposal in Pennsylvania is not steep enough to be permissible under Indiana law. This discrepancy arises because Pennsylvania, among all the states examined, is the only one with specific requirements for utility solid wastes.

The Pennsylvania regulations (Table 3-10) are based on research conducted in the early 1970's. The primary goals of the regulations are to assure disposal site stability, and to prevent the formation of leachate. Slope stability is governed by limiting grades to 15% or less (approximately 8.5° base angle), unless the disposer has taken special steps to increase stability. Unless terraces are used, slopes must not exceed 33% (approximately 18° base angle).

When terraces are used, the average slope grades of terrace benches may be as much as 50% (approximately 27° base angle), and may extend as much as 30 ft in length. Horizontal slope grades of terrace benches must be toward the center of the fill (between 1 and 3%), and must be at least 10 ft wide.

Groundwater must be protected against contamination by leachate. Surface water and runoff must be diverted from the disposal area, and any natural springs must be collected and diverted. In some cases, Pennsylvania will require water tables to be lowered to prevent contamination. Finally, groundwater quality must be monitored.

Table 3-10

PENNSYLVANIA STANDARDS FOR FLY ASH, BOTTOM ASH, OR SLAG DISPOSAL AREAS*

Section 75.37

Standards for flyash, bottom ash, or slag disposal areas.

(a) Compliance.

Flyash, bottom ash, or slag disposal operations shall conform to the applicable standards of processing and disposal area permits and permit application and issuance and plans for solid waste facilities and to the specific standards for fly-ash disposal contained in this Subchapter.

(b) Application for Permit.

Application for a permit shall include the following information and data in a format approved by the department.

(1) Physical and agricultural descriptions of soils.

(2) Detailed hydrogeologic descriptions of site characteristics.

(3) Physical analysis and description of geologic foundation materials.

(4) Detailed chemical analysis of flyash, bottom ash, or slag and leachate to determine all the constituents thereof.

(5) Topographic and surficial description of the site.

(6) Climatological data from the nearest station of record.

(c) Stability.

The geology foundation materials shall have a minimum bearing capacity one and one-half times greater than the total applied load in pounds per square foot.

(1) Special design factors and implementation of such shall be required for any of the following geological characteristics.

(i) The presence of clay horizons or unstable units in the strata.

(ii) The presence of saturated zones and strata subject to artesian pressures.

(iii) The presence of areas beneath or adjacent to the site which are subject to subsidence.

(d) Stability of flyash, bottom ash, or slag shall be assured by the limiting slope grades to fifteen (15%) percent; or by providing a special plan for slope stabilization if slope grades exceed fifteen (15%) percent.

(1) In no case shall slope grades exceed thirty-three (33%) percent. A buffer zone fifty (50') feet in width shall be maintained between the toe of the slopes and the property line upon which fly ash, bottom ash, or slag shall not be deposited.

Table 3-10 (continued)

(2) Terraces may be used to stabilize slopes.
   (i) The overall slope grade of the fill from the toe to the top of the slope shall not exceed thirty-three (33%) percent.
   (ii) Vertical slopes of terrace benches shall not exceed twenty-seven (27°) degrees (50%) and thirty (30') feet in length.
   (iii) The top of the benches shall be graded to slope toward the mass of the fill at more than one (1%) percent but less than three (3%) percent. The benches shall be a minimum of ten (10') feet in width.
   (iv) Surface runoff from the terraces shall be controlled to prevent erosion of the fill and infiltration and treated, if necessary, prior to discharge of the runoff.

(e) Surface Water Management.
Surface water runoff from the disposal area and adjacent areas shall be managed so as to assure compliance with the Clean Streams Law and the regulations pursuant thereto.
(1) Runoff from adjacent areas shall be diverted away from the fly ash, bottom ash, or slag pile.
(2) Runoff shall not be allowed to discharge freely onto the slopes of the fill.
(3) All runoff collection and diversion ditches and devices shall be constructed so as to prevent erosion of the ditches, devices, and outfall or discharge points.
(4) A contingency plan for the treatment of runoff from the fill, if necessary, shall be provided.
(5) Detailed cross-section drawings of collection and diversion ditches shall be provided to the Department.

(f) Groundwater Management.
Groundwater shall be protected from contaminants of the fly ash, bottom ash, or slag and leachate or any of the constituents of either.
(1) Soil seeps, springs, and other waters on the surface of the site shall be collected and removed from underneath the fill.
(2) Dewatering of saturated subsurface zones may be required.
(3) Groundwater quality monitoring points shall be proposed for department approval.

Table 3-10 (continued)

(g) Wastewater shall be collected and treated, if necessary, in accordance with the provisions of the Clean Streams Law and the regulations pursuant thereto.

(h) An erosion and sedimentation control plan approved by the County Conservation District shall be provided to the Department.

(i) The encroachment or obstruction of any stream or body of water shall require a permit to do so from the Department.

(j) A plan for restoration of the disposal area shall be provided to the Department. The plan shall include a layer of suitable cover soil twenty-four (24") inches in depth unless it is demonstrated to the Department that adequate permanent vegetation can be established with less than twenty-four (24") inches of cover soil.

(k) Operating Requirements.
Flyash, bottom ash, or slag disposal areas shall be operated in a safe and environmentally sound manner including the following:

(1) Access to the area shall be controlled to prohibit the entry of unauthorized persons.

(2) Flyash or bottom ash shall be deposited and spread in layers, not exceeding a thickness of two (2') feet, and compacted uniformly.

(3) Slag shall be spread uniformly so as to insure the stability of the pile.

(4) Surface water runoff and wastewater drainage shall be managed so as to prevent erosion of the area and pollution of the waters of the Commonwealth.

(5) Field changes of design plans, including fill configuration, must be approved by the Department prior to implementation of the change.

(6) Analyses reports of water samples taken from monitoring points shall be submitted as specified in the permit conditions.

(7) FGD (Flue Gas De-sulfurization) scrubber sludges may be incorporated with the fly ash if approved by the Department.

(8) Completed portions of the fill shall be revegetated as soon as weather conditions permit the seeding of rapid growing vegetation.

Table 3-10 (continued)

(9) The site shall be maintained for as long as necessary after completion of the operation to prevent health or pollution hazards or nuisances from occurring. Maintenance shall include but not be limited to repair of cracks, fissures, slumps and slides, repair or erosion areas, treatment of wastewater and runoff, and reseeding and soil treatment until adequate, permanent vegetation is established.

* Pennsylvania regulation pursuant to 35 P.S. Sec. 6006, Solid Waste Management Act; Title 25, Rules and Regulations; Part I, Department of Environmental Resources; Subpart C, Protection of Natural Resources; Article I, Land Resources, Chapter 75.

There is no indication that other states intend to regulate utility solid wastes as strictly as Pennsylvania. However, the utility considering its liability under Superfund and RCRA may wish to compare its disposal practices against Pennsylvania's regulations.

SUMMARY

Federal and state requirements governing the management of utility wastes are being promulgated, although uncertainties still exist. These requirements apply to both new and existing sites. In order to meet the new regulations, deficiencies in existing waste disposal operations will need to be identified and corrected. The regulatory definitions are now sufficiently clear to begin identifying these deficiencies, and planning appropriate actions.

Each utility should assess the current status of its waste disposal operation in light of the general guidelines presented here and in Section 4. In addition to individual assessment, each utility should consult with the appropriate state and federal officials for clarification and updates of the applicable regulations.

Section 4

POTENTIAL DEFICIENCIES IN DISPOSAL SITE DESIGN AND OPERATION

INTRODUCTION

The utility environmental engineer (or other individual responsible for waste disposal) must oversee the design and operation of on-site disposal facilities to ensure compliance with the prevailing regulations. For a new or proposed site, this responsibility requires straightforward adherence to the stated design and siting criteria. For an older operating or closed site, the responsibility for recommending costly changes and possible remedial action will be much greater (if the sites are ultimately required to comply with these regulations).

Some utility waste disposal sites may be out of compliance with the new regulations, and will require engineering assistance to upgrade their sites. The responsible utility engineer should be equipped to perform a preliminary investigation of the site, identify any possible deficiencies, and set aside those items which require outside assistance. This section provides guidance for identifying the most common problems. Subsequent sections of this manual provide detailed descriptions of the appropriate method(s) for correcting each of these problems. With this information on hand, the engineer can perform a proper preliminary investigation and draw his or her own conclusions.

IDENTIFYING DESIGN AND OPERATIONAL DEFICIENCIES

Potential deficiencies in utility waste disposal practices may be defined by two sets of standards:

- The disposal practice does not comply with specific federal and/or state regulatory requirements.
- The site has the potential to contaminate the environment.

This seemingly redundant statement is important to any assessment of disposal site deficiencies. Identification and correction of regulatory deficiencies do not necessarily preclude the possibility of past or future environmental degradation by the site. Conversely, known degradation cannot be corrected by simply conforming to the regulations. State and federal waste disposal regulations are directed at those designing a new site or closing an old site, not for those wishing to upgrade and continue operating a substandard site.

If evidence of contamination problems exists, the regulatory agencies overseeing the site design/operation may request information with which to assess the degree of contamination. The current federal regulations, promulgated under Superfund authority ultimately hold the operator liable for environmental degradation, regardless of what regulations applied or who permitted the facility. An engineering assessment of site adequacy must therefore address (1) whether the operation complies with prevailing regulations, and (2) whether the site poses a threat to the local environment. Both problems must be addressed simultaneously. The solutions are sometimes quite different, as will be demonstrated in Sections 5 through 10.

The first step in reviewing the disposal site design and operation is to compare the operation with each individual requirement stated in the regulations and identify existing environmental problems. A checklist prepared specifically for this purpose is shown in Table 4-1. The checklist is divided into two parts: (1) Regulatory Compliance, and (2) Environmental Problems.

Regulatory Compliance (Part 1)

This part of the form covers four subject areas, corresponding roughly to the areas set forth in the Solid Waste Disposal Guidelines (1):

- Site location.
- Site design features.
- Site operation.
- Site monitoring activity.

Appropriate regulatory standards, observable conditions, and sources of additional data for these areas are also summarized in the checklist. Specific aspects of concern are listed under each subject area. Two boxes are provided for checking the compliance status of each specific aspect (e.g., located in karst terrain). The first box indicates inadequate/unacceptable conditions, or the absence of a required activity (e.g., groundwater monitoring, dust control, etc.). If the inspector is not certain about the compliance status, he should look for documented literature or data for clarification. If the "Remarks" box is checked, the inspector should turn

Table 4-1

PHASE I CHECKLIST OF REGULATORY COMPLIANCE AND ENVIRONMENTAL PROBLEMS CONCERNING EXISTING UTILITY WASTE DISPOSAL SITE*
PART I: REGULATORY COMPLIANCE

Disposal Site			Regulatory Standard			
Aspect of Concern	Inadequate/ Unacceptable	See E, Remarks	Federal	State/Local (if different from Federal standards)	Observable Conditions (if any)	Source of Additional Data
A. SITE LOCATION						
• KARST TERRAIN	☐	☐	Environmentally sensitive area, must be avoided.**	TO BE COMPLETED BY THE INVESTIGATOR PRIOR TO SITE INVESTIGATION	Sink holes	U.S. Geological Survey publications
• PERMAFROST AREA	☐	☐	Same as above			Same as above
• ACTIVE FAULT ZONE	☐	☐	Same as above			Same as above
• RECHARGE ZONE OF A SOLE SOURCE AQUIFER	☐	☐	Same as above			EPA publications/ Federal Register
• CRITICAL HABITAT OF ENDANGERED SPECIES	☐	☐	Acceptable if site does not result in the destruction or adverse modification of the critical habitat of endangered species.##		Presence of federally protected plant/ animal species	EPA publications or Fish and Game Department's files
• 100-YEAR FLOODPLAIN AND:		☐	Acceptable if site does not restrict the flow of base flood, nor reduce water storage, nor permit washout of solid waste.##			USGS or U.S. Army Corps of Engineers publications; design plans†
-SITE WILL REDUCE TEMPORARY WATER STORAGE CAPACITY OF THE AREA	☐	☐	Unacceptable, must be avoided.##			Same as above

* Phase II consists of detailed engineering investigations in areas where data or observations are inadequate.

† Engineering design plans for existing disposal sites may be required by some state agencies.

** Proposed guidelines under Section 1008 (a)(1) of Resource Conservation and Recovery Act (RCRA).

Final rules under Subtitle D of RCRA.

†† NPDES requirements under Section 402 of Clean Water Act.

Table 4-1 (continued)

Disposal Site			Regulatory Standard			
Aspect of Concern	Inadequate/ Unacceptable	See E, Remarks	Federal	State/Local (if different from Federal standards)	Observable Conditions (if any)	Source of Additional Data
-SITE POTENTIALLY RESTRICTS THE BASE FLOOD FLOW	☐	☐	Same as above	TO BE COMPLETED BY THE INVESTIGATOR PRIOR TO SITE INVESTIGATION		Same as above
-DISPOSED WASTE CAN BE WASHED OUT DURING HEAVY RAIN	☐	☐	Same as above			Same as above
B. SITE DESIGN FEATURES						
• LINER INSTALLATION	☐	☐	May be required for leachate control. If required, liners must have:** -permeability of $\leq 1x10^{-7}$ cm/sec -ability to resist physical/chemical reactions -life equal to design life of the facility -minimum thickness = 30 cm (1 ft) for natural soil liners and 20 mils for synthetic liners -subgrade slope ≥1% -liner must be protected from punctures by use of 60 cm (2 ft) of cover material, 15 cm (6 ft) of which must be gravel.			Design plans†
• GROUNDWATER MONITORING WELL(S)	☐	☐	Required upgradient and downgradient wells to provide evidence of contamination.**			Design plans†

Table 4-1 (continued)

Disposal Site			Regulatory Standard			
Aspect of Concern	Inadequate/ Unacceptable	See E, Remarks	Federal	State/Local (if different from Federal standards)	Observable Conditions (if any)	Source of Additional Data
• LEACHATE MONITORING SYSTEM	☐	☐	Required when slurry or sludge is disposed.**	TO BE COMPLETED BY THE INVESTIGATOR PRIOR TO SITE INVESTIGATION		Design plans[†]
• SURFACE WATER MONITORING SYSTEM	☐	☐	Required under NPDES applicable to point source discharge.††			Design plans[†]
• RUN-ON CONTROL	☐	☐	Site run-on should be prevented up to 10-year, 24-hour event.**		Dikes, ditches are not well-constructed, damaged, or not constructed at all.	Design plans[†], USGS or U.S. Army Corps of Engineers publications.
• RUN-OFF CONTROL	☐	☐	Required to protect the site from a 100-year flood.**		Same as above	Same as above
-DITCH	☐	☐	-ditches, berms, etc., to control and divert			
-BERMS/DIKES	☐	☐	-well-compacted, fine-grained soils for cover			
-SILTATION BASIN	☐	☐	-settling basin for siltation control -grades <30% to enhance drainage			
C. SITE OPERATION						
• COVER			Cover material should be applied periodically if necessary to minimize infiltration.**		Sign of erosion	Design plans[†]
-DAILY COVER	☐	☐				

Table 4-1 (continued)

Disposal Site			Regulatory Standard			
Aspect of Concern	Inadequate/ Unacceptable	See E, Remarks	Federal	State/Local (if different from Federal standards)	Observable Conditions (if any)	Source of Additional Data
-INTERMEDIATE COVER	☐	☐	-intermediate cover if operation suspended for 90 days. Thickness of intermediate cover = 30 cm (12 in)	TO BE COMPLETED BY THE INVESTIGATOR PRIOR TO SITE INVESTIGATION		
-FINAL COVER	☐	☐	-final cover = 15 cm (6 in) clay plus 30 cm (12 in) of other material. Vegetation is also required.			
• COMPACTION	☐	☐	Recommended to reduce volume and extend site life.**			Design plans†
• SAFETY MEASURES						Design plans†, contingency plans
-SAFETY MANUAL AVAILABLE FOR EMPLOYEES	☐	☐	Required**			
-SAFETY EQUIPMENT (e.g., HARD HATS, GLOVES, SAFETY GLASSES, ETC.)	☐	☐	Required**			
-SAFETY DEVICES (e.g., AUDIBLE DIRECTION INDICATORS, FIRE EXTINGUISHERS)	☐	☐	Required**			
-COMMUNICATION EQUIPMENT	☐	☐	Required**			
-ACCESS CONTROL	☐	☐	Required##			
-APPROPRIATE SIGNS FOR EFFICIENT OPERATION	☐	☐	Required**			

Table 4-1 (continued)

	Disposal Site		Regulatory Standard			
Aspect of Concern	Inadequate/ Unacceptable	See E, Remarks	Federal	State/Local (if different from Federal standards)	Observable Conditions (if any)	Source of Additional Data
• RECORDKEEPING	☐	☐	Record of waste quantity, quality, and location must be kept.**	TO BE COMPLETED BY THE INVESTIGATOR PRIOR TO SITE INVESTIGATION	Record incomplete or unavailable	
• WATER SUPPLY FOR FIRE CONTROL	☐	☐	Source of water must be provided for fire protection, dust control, and employee convenience.**			
• AESTHETIC APPEARANCE	☐	☐	Required**			
• CLOSURE/POST-CLOSURE PLAN	☐	☐	Must be prepared and approved.**		Are there such plans and/or are the plans adequate?	
D. SITE MONITORING ACTIVITY						
• GROUNDWATER MONITORING	☐	☐	Standards:** -never through landfill itself -should have baseline data prior to facility operation -sample collection and analysis on at least an annual basis		No monitoring wells installed, or wells are not for monitoring purposes	Baseline data may be available from Soil Conservation Service (USDA) -State Geological Services -State/local health departments
• LEACHATE MONITORING	☐	☐	Same as above			
• SURFACE WATER MONITORING	☐	☐	Sampling points, monitoring parameters, and monitoring frequency are specified on a case-by-case basis.††			

Table 4-1 (continued)

E. REMARKS (Use back page of the checklist if additional space is needed).

Table 4-1 (continued)

PART II. ENVIRONMENTAL PROBLEMS

Disposal Site Environmental Problems		Indicator		Corrective Action (briefly describe): Done	Planned	No Action	Remarks
Surface Water Contamination		Fish Kills	☐	☐	☐	☐	
Yes	☐	Unhealthy Vegetation	☐				
No	☐	Complaints	☐				
See Remarks	☐	Seeps	☐				
		Water/Leachate Analysis	☐				
Groundwater Contamination		Unhealthy Vegetation	☐	☐	☐	☐	
Yes	☐	Complaints	☐				
No	☐	Seeps	☐				
See Remarks	☐	Water/Leachate Analysis	☐				
Air Pollution		Unhealthy Vegetation	☐	☐	☐	☐	
Yes	☐	Complaints	☐				
No	☐	Dust	☐				
See Remarks	☐						

Table 4-1, Part II (continued)

Unsightliness

Yes ☐

No ☐

See Remarks ☐

Complaints ☐ ☐ ☐ ☐ ______

Uncontrolled growth of weeds and vegetation ☐ ______ ______

to the last page of Part I, explain the reason(s) and cite the site's unique conditions. If neither box is checked, that specific aspect of the site does not warrant further investigation.

Regulatory Standards. To facilitate the regulatory compliance inspection, federal guidelines proposed and/or promulgated under RCRA and the Clean Water Act are summarized and provided on the checklist (1, 2, 3). Space is also provided for inclusion of the state/local standards (see Section 3). These standards should be compiled and reviewed prior to inspecting the site. Note that if there are differences between federal and state/local standards, the more stringent criterion must apply, whether it is promulgated by the U.S. EPA, a state agency, or a local board.

Observable Conditions and Additional Data Sources. Deficiencies in an existing or closed disposal site can be identified by noting observable symptoms during inspection, by reviewing documented data, or both. The last two columns of the form list common, observable symptoms and data sources. In general, documents useful for determining siting, design, and operational deficiencies can be obtained from:

- U.S. and state geological surveys.
- U.S. Army Corps of Engineers.
- Fish and game departments.
- U.S.D.A. Soil Conservation Service.
- State water resource agencies.
- Site design plans; engineering and hydrogeologic reports.

Environmental Problems (Part II)

This part of the form addresses four types of environmental problems:

- Surface water contamination.
- Groundwater contamination.
- Air pollution.
- Unsightliness.

General indicators for each type of problem are provided in the checklist. A box is provided to check the occurrence of each environmental problem and to describe the corrective action status for each existing problem. If the inspector is uncertain about a specific environmental problem, he should check the "Remarks" box and give his explanation under Remarks.

The checklist presented in this section serves only as a guide to a preliminary investigation. When a suspected deficiency is identified, a detailed engineering and/or hydrogeologic study should be conducted to provide a basis for formulation of an appropriate corrective action plan.

POTENTIAL DEFICIENCIES IN UTILITY WASTE DISPOSAL

In an effort to identify the potential deficiencies germane to utility waste disposal sites, a telephone/mail survey, and selected site visits were conducted in 1980. Since utility waste management is regulated by local/state, as well as federal regulations, an attempt was made to select from each state at least one utility-operated disposal site. In those states where coal is the major energy source, two sites were often selected. Fifteen states failed to provide a representative site because of the following reasons:

- No coal-fired power plant is operating in the state.
- Utility waste is being disposed of at a commercial landfill.
- The operators contacted could not provide the necessary information.

In general, coal consumption at these plants ranges from 296,000 to 9,400,000 t/yr (269,000 to 8,530,000 mt/yr); these plants produce FGD sludge, fly ash and bottom ash at rates of 3000 to 774,000 t/yr, 3000 to 10,387,000 t/yr, and 3000 to 373,000 t/yr (2700 to 702,000, 2700 to 9,420,000, and 2700 to 338,000 mt/yr), respectively.

Telephone/Mail Survey

Siting, design, and operational characteristics of the 58 disposal facilities that were surveyed, are summarized in Table 4-2.

The number of disposal sites in compliance with design and/or operational standards is much lower than that for facilities meeting siting criteria. For instance, most of the surveyed landfills have runoff control systems installed and have groundwater monitoring systems. Forty-seven percent or fewer of the surveyed sites satisfied record keeping, contingency, and closure/post-closure plan requirements.

Fewer than 10% of the sites surveyed were constructed in an environmentally sensitive areas (karst terrain, recharge zones of sole-source aquifers, and critical habitats). The number of landfills located in floodplains was also well under 10%,

Table 4-2

SITING, DESIGN, AND OPERATIONAL CHARACTERISTICS OF UTILITY WASTE DISPOSAL FACILITIES SURVEYED

	Number of Sites*		Percent of Site Surveyed	
Facility Features	Pond	Landfill	Pond	Landfill
Site not located in Karst terrain	28	35	93	97
Site not located in the recharge zone of a sole source aquifer	30	36	100	100
Site not located in a floodplain	19	35	63	97
Site not located in a critical habitat	29	36	97	100
Design				
Site access is controlled	24	16	80	44
Site is lined with:				
• clay	14	12	47	33
• synthetic membrane	2	0	7	0
• other material	1	1	3	3
Site has runoff diversion structures	26	18	87	50
Site has runoff collection basin	6	19	20	53
Site has a groundwater monitoring system	19	21	63	58
Site has a surface water monitoring system	N/S†	N/S	-	-
Site has a leachate monitoring system	N/S	N/S	-	-

Table 4-2 (continued)

Facility Features	Number of Sites		Percent of Site Surveyed	
	Pond	Landfill	Pond	Landfill
Operation				
Waste disposal record is maintained	18	17	60	47
Contingency plan is available	12	3	40	8
Closure/postclosure plan is available	4	15	13	42

* Twenty-two sites have ponds, 28 have landfills; in addition, 8 have both ponds and landfills.

† Not surveyed.

but ponds were more frequently in violation of this rule (37%). Under current federal regulatory standards, a site located in a floodplain is acceptable, provided that the disposal facility meets all of the following requirements (2):

- The facility does not restrict the flow of the 100-yr flood.
- The facility does not reduce the water storage capacity of the area.
- The facility does not permit washout of the solid waste.

In general, all of the 58 sites surveyed need some sort of upgrading to comply with prevailing federal/state regulations. The degree of upgrading varies widely, with many sites requiring only minor modifications to conform to the new regulations.

Site Visits

The purpose of the ten site visits was to provide on-site observation of existing utility waste disposal practices and to utilize the checklist of Regulatory Compliance and Environmental Problems for identifying potential deficencies in design and operation of each site. Pertinent features of the ten sites are summarized in Table 4-3. For detailed descriptions of each site, the reader is referred to Appendix A.

A majority of the sites use wet disposal methods. Ash slurries and FGD sludges are piped to settling ponds and supernatant water is then discharged to a nearby surface water body. In some cases, the settled waste is dredged and landfilled. Pond effluents are monitored according to the NPDES requirements.

Other pollution control efforts found in the case studies include:

- Installation of liners for the disposal sites.
- Diking of ponds to levels above the 100-year flood level.
- Collection and treatment of surface runoff prior to discharge.
- Monitoring of groundwater and/or leachate.

These efforts reflect site specific needs and/or prevailing federal/ state regulatory requirements. However, potential deficiencies do exist. These deficiencies are identified by comparing each site design or operational feature with the corresponding criterion shown in the checklist (see Table 4-1).

Table 4-3

SUMMARY DESCRIPTION OF UTILITY WASTE DISPOSAL CASE STUDY SITES*

	Disposal Site Description			Waste Disposal Practice		
Site No.	Plant Size#	Site General Location	Environmental Setting†	Type of Waste**	Type of On-Site Facility	Ongoing Pollution Control Effort
1	Medium	Eastern seaboard	Groundwater is a few feet below the pond bottom P = 41 in/yr (104 cm/yr) ET = 33 in/yr (84 cm/yr)	Fly ash, Bottom ash	Unlined pond	Characterize wastes. Monitor pond effluent. Close existing pond in 1982.
2	Large	Southern reaches of the Appalachian highland	Groundwater table is at a depth of 80 ft (24.4 m) P = 46 in (117 cm/yr) ET = 38 in/yr (98 cm/yr)	Fly ash, Bottom ash	Unlined pond	Monitor pond effluent. Recirculate some of the pond's supernate.
3	Medium	Midwest	Flood plain Groundwater is at 125 ft (38 m) P = 57 in/yr (145 cm/yr) ET = 38 in/yr (98 cm/yr)	Fly ash, Bottom ash	Unlined pond	Monitor pond effluent. Dike to above the 100-yr flood level.
4	Large	Midwest	Flood plain Soil permeability = 10^{-4} cm/sec Groundwater is at 10 ft (3 m) P = 87 in/yr (221 cm/yr) ET = 28 in/yr (71 cm/yr)	Fly ash, Bottom ash	Unlined pond	Dike to above the 100-yr flood level. Monitor pond effluent.
5	Medium	Great Plains	Active fault zone Low permeability soil P = 51 in/yr (132 cm/yr) ET = 27 in/yr (69 cm/yr)	Fly ash Bottom ash FGD sludge	Landfill (fly ash) Pond (bottom ash, leachate, and FGD sludge	Monitor leachate and groundwater.

Table 4-3 (continued)

	Disposal Site Description			Waste Disposal Practice		
Site No.	Plant Size[‡]	Site General Location	Environmental Setting[†]	Type of Waste**	Type of On-Site Facility	Ongoing Pollution Control Effort
6	Medium	Great Plains	Groundwater recharge area P = 55 in/yr (140 cm/yr) ET = 35 in/yr (89 cm/yr)	Fly ash Bottom ash FGD sludge	Mine pit V-notch between spoil ridges Unlined storage pond	Monitor leachate. Collect surface runoff.
7	Small	Western region	Very low permeability soil Groundwater is around 20 ft (6 m) P = 84 in/yr (214 cm/yr) ET = 42 in/yr (106 cm/yr)	Fly ash Bottom ash	Unlined pond	Monitor pond effluent.
8A	Medium	Rocky Mountains	Very low permeability soil Groundwater is found between 700 and 1500 ft (200 to 460 m) P = 46 in/yr (116 cm/yr) ET = 31 in/yr (80 cm/yr)	Fly ash Bottom ash FGD sludge	Clay lined landfill	Collect surface runoff. Monitor groundwater, leachate.
8B	Medium	Rocky Mountains	Not available	Fly ash Bottom ash	Mined-out area	None
9	large	Desert Southwest	Soil permeability is about 10^{-4} cm/sec Groundwater depth is 1000 ft (305 m) Active fault zone P = 7 in/yr (18 cm/yr) Et = 59 in/yr (151 cm/yr)	Fly ash Bottom ash	Landfill	Monitor groundwater, leachate. Compact disposed ash. Collect surface runoff.

Table 4-3 (continued)

	Disposal Site Description			Waste Disposal Practice		
Site No.	Plant Size#	Site General Location	Environmental Setting†	Type of Waste**	Type of On-Site Facility	Ongoing Pollution Control Effort
10	Medium	Desert West	Groundwater is at 5 to 6 ft (1.5 to 1.8 m)	Fly ash Bottom ash FGD sludge	FGD sludge settling pond Evaporation pond Landfill	Monitor ground- and surface waters.

* See Appendix A for detailed site descriptions.

\# Plant size is indicated according to the following scale: "Large" plants are those whose plate capacity exceeds 1,000 MW; "medium" plants fall in the 200 to 1,000 MW range; and "small" plants have capacity of less than 200 MW.

† P is total annual precipitation (including both annual snowfall and rainfall); ET is annual evapotrainspiration.

** Only fly ash, bottom ash, and/or FGD sludge are shown.

Table 4-4 summarizes the information on the checklists on potential deficiencies and associated environmental problems found in the case study examples. The following potential deficiencies were noted during several of the site visits:

- Groundwater monitoring was inadequate or nonexistent.
- Leachate monitoring was not practiced.
- Record keeping was inadequate.
- Closure/postclosure plans were inadequate or nonexistent.

An assessment of a site as "deficient" must be tentative, due to the lack of final federal criteria applicable to the surface impoundment of nonhazardous wastes. This is particularly true for record keeping and closure/postclosure plan preparation recommendations, which still remain "proposed guidelines" at the present time (1).

On the other hand, although the requirement for groundwater and leachate monitoring is not specified in federal standards for solid waste disposal facilities, the regulations do emphasize groundwater protection (2). While groundwater can be protected and leachate generation can be minimized with sound engineering design and site operation, monitoring of groundwater and leachate, is nevertheless necessary to provide convincing proof of a safe disposal practice. Many states do require groundwater and/or leachate monitoring (see Section 3).

Finally, the potential for groundwater degradation should be noted, especially when an unlined ash pond is constructed on a site with relatively permeable soils and a shallow groundwater table (e.g., sites 3 and 4). The existence of a constant hydraulic head (standing water) in the pond makes leachate generation and migration inevitable. Although the presence of settled ash, particularly fly ash, can retard the leaching process, leachate will gradually migrate into the subsurface water and may contaminate both surface and groundwater supplies.

REFERENCES

1. Landfill Disposal of Solid Waste - Proposed Guidelines. Federal Register, March 26, 1979.

2. Criteria for Classification of Solid Waste Disposal Facilities and Practices: Final, Interim Final, and Proposed Regulations. Federal Register, September 13, 1979.

3. Federal Water Pollution Control Act, as Amended by Clean Water Act of 1977, 33 U.S.C. 1251, Section 402.

Table 4-4

POTENTIAL DEFICIENCIES IDENTIFIED DURING CASE STUDY SITE VISITS

Potential Deficiency/Problem	Number of Cases*
Groundwater monitoring	8
Leachate monitoring	7
Runoff control	2
Waste cover	2
Safety measure	
Access control	4
Safety manual for site operator	6
Record keeping	6
Closure/postclosure plan	8
Aesthetic appearance	1
Potential waste washout	0
Potential degradation of groundwater quality	2
Potential degradation of surface water quality	1
Potential air pollution	1

* Maximum number of cases is 10.

Section 5

OVERVIEW OF AVAILABLE DISPOSAL SITE UPGRADING PROCEDURES

The term "upgrading" has two connotations with respect to utility waste disposal sites. First, the recent changes in regulations governing solid waste disposal have placed new design and operating requirements on most waste disposal systems. Those sites which are still in operation may need to be brought into compliance. Second, disposal sites (operating or closed) that may be potentially damaging to the environment must be modified to correct the hazard and prevent any further occurrence. The status of a site is best determined through the two phases of investigation described in Section 4. Both forms of upgrading are described in detail in the remainder of this manual.

Upgrading a disposal site involves (1) improving the quality of the site, or (2) substituting a product or procedure of higher quality. Upgrading procedures range from simple measures (e.g., grading) to complex actions (e.g., construction of a groundwater barrier). Table 5-1 presents a general matrix for preliminary selection of the proper upgrading procedure for a given problem, and reference the section(s) of the manual in which these procedures are discussed. This table serves as only a general guide, since many of the problems encountered are more complex and may require a site-specific evaluation. This "Phase II" evaluation is particularly important when a utility is considering a major upgrading measure, such as eliminating a groundwater contamination plume, conversion of a pond to a landfill, or the installation of a lining system.

Terms such as "retrofit," "remedial action," and "corrective action" are often used interchangeably with "upgrading." For the purpose of clarity, upgrading is discussed herein according to the following three categories:

- Corrective action.
- Site improvements.
- Site conversion or relocation.

The reader should also note that most of the environmental problems associated with a disposal site occur in groups. A formal site upgrading program will often include

Table 5-1

MATRIX FOR PRELIMINARY SELECTION OF PROPER UPGRADING PROCEDURES

Problem(s)/Purposes of Upgrade	Appropriate Upgrading Option												Install Liner		
	Cover Grading	Revegetation	Berms/ Ditches	Extensive Groundwater Monitoring	Subsurface Investigation	Groundwater or Leachate Extraction	Groundwater Barrier	Watering/ Sprinkler	Site Conversion or Relocation	Stabilization	Forced Oxidation	Process Conversion	Cover	Bottom	Market By-Product
Control run-on, run-off, erosion	●	●	●												
Reduce erosion and enhance aesthetics	●	●													
Control erosion; reduce infiltration and leachate generation	●														
Suspected groundwater contamination				●	●										
If groundwater contamination is detected:															
• Remove contaminated water						●	●								
• Contain contaminated water							●								
• Prevent further contamination	●		●				●						●		
Improve local air quality	●	●						●							
Convert wet disposal site to dry disposal site									●	●					●
Convert in-plant wet system to dry system									●	●	●	●			
Close disposal facility															
• Wet system	●	●	●						●	●					
• Dry system	●	●	●												
Reduce waste disposal cost and environmental pollution															●
Reduce surface water erosion and infiltration													●		
Contain leachate in a new site; attain zero seepage									●					●	
MANUAL SECTION OR REFERENCE	6,8	6,8	6	6,8	6,8	6	6	6	7	7	7	7	9	9	10

several of the upgrading procedures discussed in the manual, most of which will fall into only one of the three upgrading categories mentioned above. Definitions of these categories are presented below.

CORRECTIVE ACTION

The primary focus of corrective action procedures (Section 6) is on the control of specific environmental impacts (surface water contamination, groundwater contamination, and fugitive dust control). Corrective actions which are taken before any impact is realized are generally also a requirement of the federal and state regulations. Examples of a priori corrective action include monitoring wells, runon-runoff diversion, sedimentation basins, and revegetation.

Corrective action procedures which serve to remedy a relatively extensive existing environmental problem are typically much more exotic, and more expensive, while the benefits of their implementation are less certain. Examples include groundwater extraction and treatment systems and subsurface groundwater barriers. The corrective action technology presented in Section 6 is by far the most important part of the manual, as the associated environmental problems and corrective actions discussed are expected to be the most common encountered at utility sites.

SITE IMPROVEMENTS

Site improvements are defined herein as changes made at a disposal site after its completion to facilitate subsequent use of the land for other purposes. The major category of site improvement addressed in this manual is site closure (Section 8).

Standard site closure requirements for landfills are mandated under RCRA, including cover specifications, and slope, revegetation, and monitoring requirements. Many of these requirements and recommendations are discussed in Section 6, and included in Section 8 by reference.

SITE CONVERSION AND RELOCATION

Some utilities may find it appropriate to make significant changes in their current disposal practices. The necessary guidance is therefore provided in this manual under the following headings:

- Wet-to-Dry Conversion (Section 7).
- Liner Selection and Installation (Section 9).
- By-Product Recovery and Utilization (Section 10).

One of the upgrading alternatives, conversion of a wet disposal site or system to a dry operation, can provide substantial benefits. Wet-to-dry conversion improves waste handling characteristics, land use efficiency, and reduces the risk of groundwater and surface water contamination. The conversion can be achieved on the site or in the plant. The latter conversion, necessary for continuous dry disposal, results in the generation of potentially usable by-products (Section 10). Since dry disposal (landfilling) generally proves to be more cost-effective and environmentally sound than wet disposal (ponding), on-site and in-plant conversion will likely be more widely practiced in the future.

When a site poses an immediate threat to water resources, it can be relocated by removing the waste from the existing site and placing it in a new disposal facility. Site relocation is not fully addressed in this manual since it is analogous to construction of a new disposal facility. The reader is referred to the Coal Ash Disposal Manual (1) and the FGD Sludge Disposal Manual (2).

Upgrading a site to minimize surface water infiltration may require the installation of a cover (either a clay cap or a synthetic membrane) prior to placement of a cover soil and vegetation. In a few instances, the bottom of a disposal site may need to be lined to minimize or eliminate leachate migration to local water supplies. The types and characteristics of soil, admix, and membrane liners, their selection criteria, site preparation and installation procedures, and various lining systems are presented in Section 9.

The by-product marketing information presented in Section 10 represents the current state of knowledge based on U.S. research and experience abroad. Recognizing the lack of experience among both U.S. utilities and commercial markets, EPRI has contracted for the development of a coal combustion by-product marketing manual (RP-1850). The manual, due to be completed in 1982, will provide a more extensive treatment of the subject than is possible here.

COST OF UPGRADING A DISPOSAL SITE

As noted earlier, a formal upgrading plan will usually include the implementation of several corrective measures. These measures will probably be interactive. As a result, their costs and designs will be highly interdependent.

A method of calculating the cost of a corrective action plan has been developed for this manual, and is presented in Section 11. Separate cost estimating equations are not presented separately in each section of the manual to avoid redundancy and to combine cost estimates for common upgrade combinations. The cost estimating details are consistent with the first-phase engineering investigation guidelines presented in Section 4. The reader should note that the cost estimates associated with the less-frequently practiced corrective actions (e.g., groundwater control, wet-to-dry conversion, etc.) are first approximations due to the site-specific nature of these techniques.

REFERENCES

1. M. P. Bahor, R. J. McLaren, J. E. Niece, and H. C. Pedersen. Coal Ash Disposal Manual, Second Edition. Palo Alto, California: Electric Power Research Institute, October 1981. CS-2049.

2. R. G. Knight, E. H. Rothfuss, and K. D. Yard. FGD Sludge Disposal Manual, Second Edition. Palo Alto, California: Electric Power Research Institute, September 1980. CS-1515.

Section 6

CORRECTIVE ACTION

INTRODUCTION

As stated in Sections 2 and 4, most environmental problems that occur at land disposal facilities are associated with improper siting, poor site design, and/or operational deficiencies. The reasons for undertaking corrective action at a disposal site are to correct existing environmental problems, prevent the occurence of future environmental problems, and thereby bring the site into compliance with the current regulations.

The first step in any such endeavor is to identify a site's existing and/or potential environmental problems and its deficiencies with regard to the regulatory requirements. A corrective action plan can then be developed and implemented to address these specific problems and/or deficiencies with specific reference to the site's unique characteristics and subsurface conditions.

It is important to emphasize that seldom, if ever, will the implementation of a single corrective action technique be effective in correcting all the environmental problems that may exist at a given site. Rather, it will usually be necessary to design and implement an integrated corrective action program or strategy consisting of several techniques. In most cases, an understanding of the following factors is prerequisite to the proper design and implementation of an effective corrective action program:

- Climate.
- Site and subsurface conditions

  --topography

  --geology

  --hydrogeology

  --pedology

  --engineering properties of the subsurface materials.

- Engineering properties of the waste materials.
- Existing environmental problems and/or potential problems.
- Operational procedures required in the continued use of the site.

In addition, it is necessary to clearly define the goals of the corrective action program with regard to facility compliance with the regulatory requirements governing continued site use. (See Section 3 for a detailed discussion of the current regulatory requirements.)

Briefly stated, the goal of designing and implementing a corrective action plan for a particular site is to allow continued use of the site in accordance with the regulatory framework, by:

- Developing feasible alternatives to current disposal practices as appropriate.
- Correcting existing environmental problems.
- Preventing the reccurrence of the existing or new environmental problems.

The following is a partial list of important considerations in any corrective action plan:

- Implementation of a corrective action plan can represent a substantial investment.
- The site specific factors delineated previously will have a profound influence on the practicality and effectiveness of the various corrective action techniques.
- Following implementation of the plan, the site must be maintained and monitored over the long term.
- The corrective action plan may interfere with site operation and management.

The selection and design of a corrective action plan should be carefully evaluated in terms of its regularatory requirements, technical considerations, operational ramifications, and both short- and long-term economic feasibility. Except in the most straight-forward cases, a corrective action plan should be established by a multidisciplinary team of professionals including environmental, civil, and soils engineers, geologists, hydrogeologists, utility engineers, and other specialists as warranted.

In this section, a number of commonly used and potentially useful corrective action techniques are described. The purposes and applications for the individual techniques are also discussed. Factors that should be evaluated in designing and implementing a corrective action plan are presented in four major subsections:

- Design Considerations. This will provide an introduction to the environment's pertinent characteristics, the physical and engineering properties of the soil materials, and the physical and chemical properties of utility waste materials.
- Surficial Considerations for Corrective Action. This will provide an overview of techniques used to isolate a land disposal site from the land surface environment.
- Subsurface Considerations for Corrective Action. This will provide an overview of techniques used to isolate a land disposal site from the groundwater system or remove contaminated water.
- Selecting a Corrective Action Plan. This will provide an overview of the input necessary to allow the design and implementation of effective site specific corrective action plans.

DESIGN CONSIDERATIONS

The design and implementation of a corrective action plan at an existing land disposal site require an evaluation of the site, as a whole, and of the sites impact on the environment. Usually, such an evaluation will include a thorough investigation of the surface and subsurface conditions at the site, including the physical and engineering properties of both the soils and waste materials. An estimate of the present and future impacts of the site on its environment will follow from this investigation and be an integral part of the corrective action plan.

This subsection provides an overview of the usual factors that should be evaluated during the design of a corrective action plan. The most pertinent properties of natural soils and waste materials are defined and discussed, along with selected characteristics of the natural environment.

Characteristics of the Natural Environment

When developing engineering criteria for corrective action, the processes and characteristics of the sites natural environment should be assessed. These processes and characteristics are grouped into three classes: climatic conditions, surficial features, and subsurface features. These distinctly labeled classes are in reality highly interrelated by the dynamic processes of the hydrologic cycle as portrayed on Figure 6-1. Because of their complexity and importance in the corrective action plan, subsurface properties are discussed in more detail.

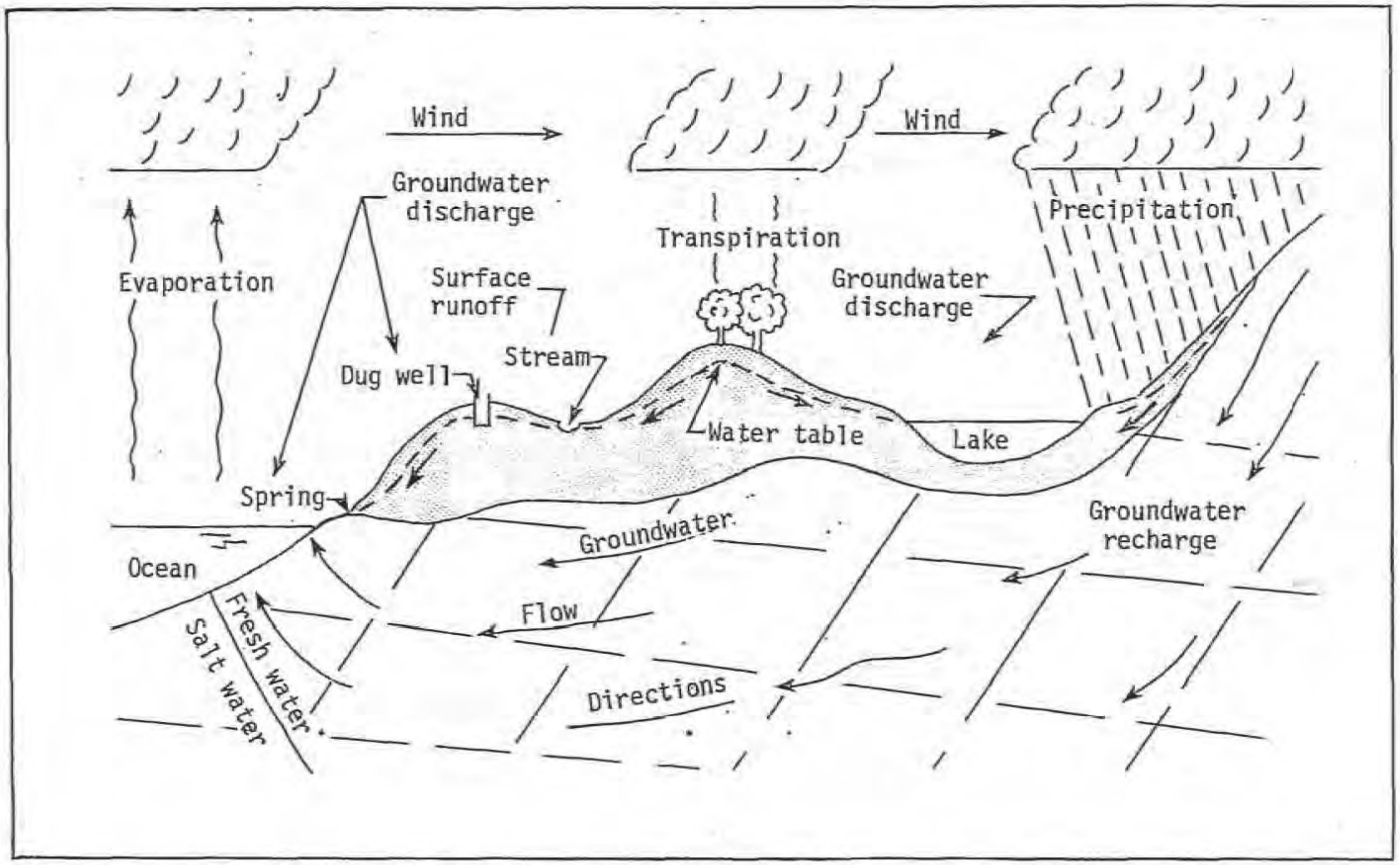

Figure 6-1. The hydrologic cycle.

Source: W.B. Caswell. Groundwater Handbook for the State of Maine. Maine Geological Survey, 1978.

Climatic Conditions. These include precipitation, temperature, evaporation/evapotranspirtation, and wind.

Precipitation falling as rain either infiltrates the ground surface and subsequently enters the groundwater system, or is transpired by plants evaporated; infiltrates or flows across the ground surface as runoff. Precipitation is commonly measured in terms of intensity (inches per hour), duration (hours), frequency, and magnitude as well as type (rain or snow). Snow is usually measured in its water equivalent except for its depth.

The characteristics of a precipitation event (i.e., duration and intensity) strongly influence runoff and infiltration. For a given situation, a high intensity, short duration rainfall will produce more runoff and less infiltration than a less intense event of greater duration but of the same magnitude.

Temperature must be considered, as it significantly affects plant growth, infiltration and runoff, and the weathering of many materials. Weathering effects are seen in chemical as well as mechanical processes, as most chemical reactions are temperature dependent. An important factor in mechanical weathering is the effect produced upon materials exposed to freezing water. As water, even in small amounts, freezes, it expands, cracking and deteriorating surrounding materials and structures (e.g., differential frost heaving in roadways).

Under most circumstances, only the upper 5 ft (1.5 m) of surface soil are affected by temperature variations. Even in this narrow range, temperature strongly influences evaporation and plant growth. If an area is sufficiently cold, the runoff and infiltration effects of precipitation (as snow) can be delayed several months until the spring thaw, and the accumulated effects of several months of precipitation will be experienced in a brief period.

Wind is a significant climatic factor. It strongly influences evaporation. Wind intensity, direction, and duration vary on a seasonal, regional, and local basis. Many factors regulate the influence of the wind at a given site, including topography, prevailing wind patterns, and the degree of forestation. Usually its effects are stronger in open flat areas, in coastal areas, and in areas where the topography tends to channel it in certain directions.

Evaporation and evapotranspiration are significant processes in the loss of surface water and near surface groundwater (usually from the unsaturated zone). Evaporation is quite simply the vaporization of surface and soil water. Evapotranspiration is the combined process of evaporation and the transpiration of water by plants. Both processes are strongly influenced by temperature, prevailing humidity and wind. The effects of evapotranspiration on the hydrologic budget are significant and may seasonally and/or locally exceed precipitation.

The relationships between precipitation, evaporation, air temperature, stream flow, and groundwater level fluctuations, including snow accumulation and melt effects, are illustrated on Figure 6-2.

<u>Surficial Features</u>. These generally encompass topography (including surficial drainage) and pedology (soil science).

Topography refers to the configuration of the land surface including its relief and the shape and position of its natural and manmade features. Topography controls surface drinage and exerts a strong influence on groundwater flow, wind direction and intensity, runoff, and infiltration. Topography is generally depicted by contour maps showing the ground surface elevation referenced to mean sea level or an arbitrary datum. The surficial drainage pattern of an area is a direct result of its topography, although the topography is continually modified by flowing water.

Pedology, or soil science, is concerned with the nature, properties, formation, behavior and response to use and management of soils. Although developed primarily in response to the needs of the agricultural community, it is equally applicable to land management at utility waste disposal sites.

The pedologic characteristics of a site govern the rate of surface water infiltration in undisturbed areas and determines whether vertical or lateral flow dominates subsequent to infiltration. An understanding of a site's surficial soils is necessary to properly plan and successfully implement a revegetation plan in disturbed areas.

Overall, the runoff, infiltration, and evapotranspiration characteristics of a site are a function of its topography, vegetation and pedology. The U.S. Department of Agriculture's Soil Conservation Service has prepared soil maps of many areas of the United States. These maps address the physical and chemical properties of the surface soils, including texture, fertility, erodibility, infiltration rates, and other useful parameters. These maps are interpretive in nature and the conditions they

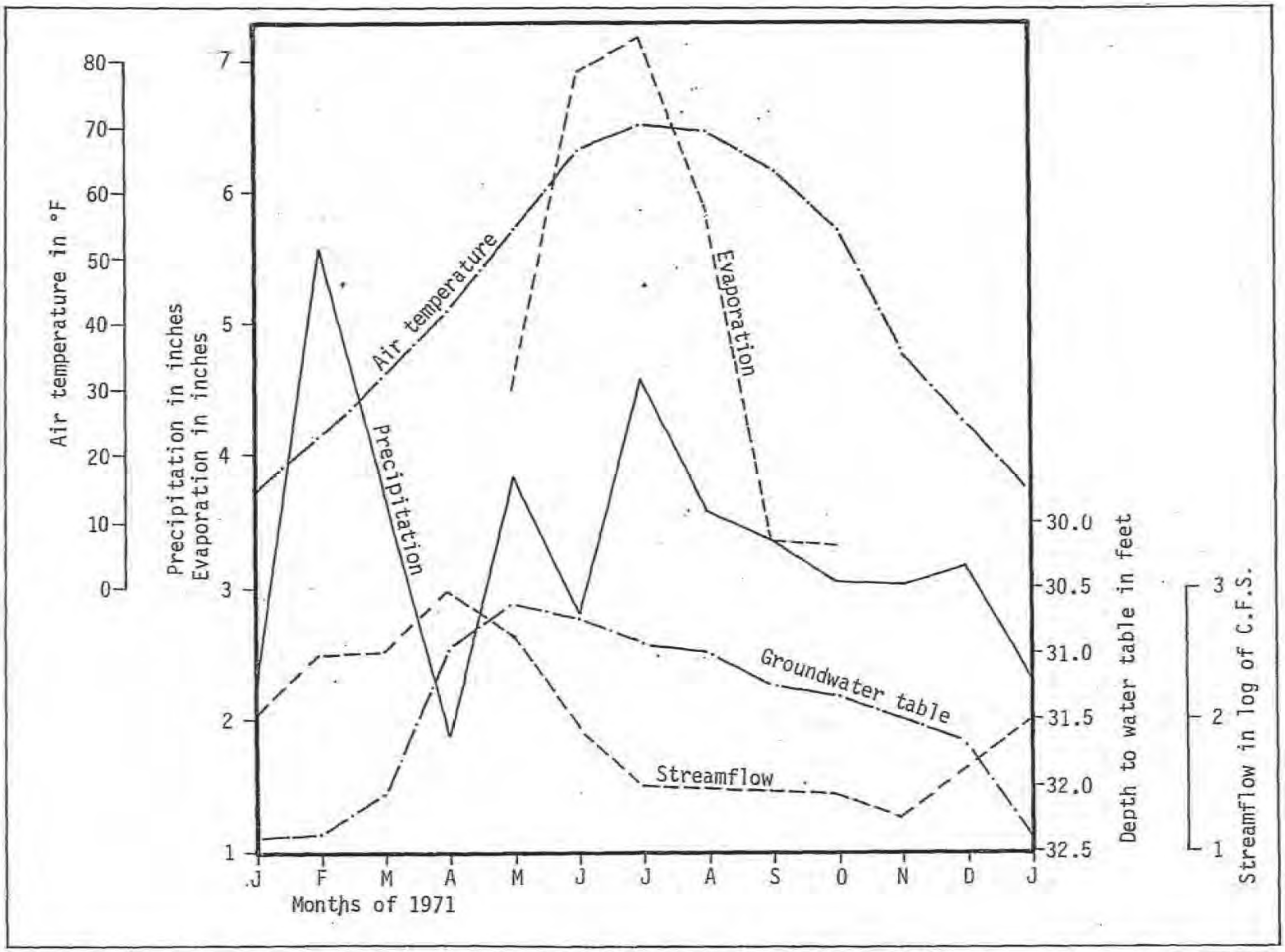

Figure 6-2. Comparison of hydrologic measures for typical year in Maine, illustrating the relationship between climate, groundwater, and surface water in a cool, moist climate.

Source: W.B. Caswell. Groundwater Handbook for the State of Maine. Maine Geological Survey, 1978.

report should always be substantiated by site investigations. They are, however, extremely useful tools during preliminary planning of corrective actions.

Characteristics of Subsurface Materials

Characteristics of interest include geologic and hydrogeologic conditions. Most sites are unique and, at best, only similar to other (even adjacent) sites. This subsection considers the primary subsurface conditions which relate to corrective actions at utility waste disposal sites. These conditions include the stratification and areal distribution of the geologic units; groundwater depth, movement, recharge and discharge; and the in situ properties of the subsurface materials.

Subsurface Investigation Considerations. Proper delineation and evaluation of a site's subsurface conditions are important because:

- The subsurface conditions have a strong bearing on a site's potential to cause pollution.
- Many times a site's environmental problems exist solely in the subsurface environment.
- The subsurface environment is complex and largely hidden from view, thus often ignored or misunderstood.
- The subsurface materials in the vicinity of a site are often borrowed for use as construction material during the implementation of a corrective action plan.
- The nature and distribution of the site's subsurface materials have a strong bearing on the suitability of the various surficial and subsurface corrective action techniques and their area of applicability.

Thus, it is usually necessary to complete a hydrogeologic and geotechnical investigation of the site during the early stages of planning for corrective action. The importance of such investigations is obvious when one considers the cost differential between using on-site borrow and imported borrow material. Normally, such an investigation will encompass the following:

- The review of information available on pedologic, geologic, hydrologic, topographic, and climatic maps and documents.
- The completion of a field investigation designed to (1) reveal the vertical and areal distribution of the geologic units; and (2) document the groundwater conditions and in situ properties of the subsurface materials.
- Data interpretation and preparation of a technical report.

It is often beneficial to stage a subsurface investigation in two or more phases to allow evaluation of the preliminary efforts and to provide guidance for subsequent phases.

Common subsurface exploration techniques include soil and rock borings, test pits and trenches, and geophysical techniques such as seismic and resistivity profiles. The properties of the subsurface materials are determined by field and laboratory testing and observation (inspection) of the explorations by experienced personnel as they are made.

The site's groundwater conditions are revealed by water level observations. Commonly, small diameter observation wells (or piezometers), are installed in borings to permit observation of the groundwater table levels.

The complexity of the geologic environment will have a direct bearing on the number, location, and depth of these groundwater observation devices. It is not uncommon for multiple groundwater flow systems (aquifers) to underly a given site. This possibility requires that small diameter observation wells be installed at several levels within the geologic profile to permit measurement of groundwater levels in each aquifer. These multiple observation devices are usually referred to as piezometer nests. In some instances, groundwater flow may possess a strong vertical component; again piezometer nests are required to define the characteristics of the groundwater flow system. If properly designed, small diameter observation wells can be used to obtain samples for water quality analyses. Subsurface exploration programs can be costly and should be undertaken only by experienced professional geologists, and geotechnical engineers.

<u>The In Situ Properties of the Subsurface Environment</u>. The properties most pertinent to utility disposal sites are the distribution and permeability of the geologic units, depth to groundwater and factors that control groundwater flow such as:

- Permeability or hydraulic conductivity.
- Hydraulic potential or groundwater gradients.
- Direction and rate of groundwater flow.
- Texture of the subsurface materials.
- Consolidation or cementing of the geologic units.
- The uniformity of the geologic conditions.
- The presence or absence of discontinuities.

These factors are evaluated by subsurface sampling and field and laboratory testing of the subsurface materials. Effective interpretation of the hydrogeologic characteristics of a site usually calls for the judgment of experienced professionals. A basic understanding of these factors and their relationship to one another and to the subsurface environment is necessary to effectively plan and implement a corrective action plan. These factors are briefly defined and discussed below. For a more thorough discussion standard references or text books should be consulted (1, 2, 3).

"Permeability" (or "hydraulic conductivity") is a measure of the ease or difficulty of fluid flow through a porous material. It is commonly expressed as a velocity term (distance/time). It is a function of the characteristics of both the fluid (water) and the material through which the fluid flows. Usually, in groundwater work, the properties of the fluid (water) are assumed to remain constant. "Primary permeability" refers to flow through porous, usually unconsolidated materials. "Secondary permeability" refers to flow dominated by secondary features such as cracks, fissures and faults through porous or nonporous materials.

"Hydraulic gradient" (or potential) is a measure of the energy available to cause groundwater to flow. Hydraulic potential or gradient is measured in terms of elevation by observing the water level in wells. The difference in water level elevation across an area or with depth defines the hydraulic gradient between the observation points. Hydraulic gradients represent a dynamic situation. They are maintained by recharge from precipitation and surface water infiltration on a regular basis. During periods of drought and when recharge is eliminated or reduced, the hydraulic gradients will flatten out and the groundwater system will move more slowly than when recharge is plentiful or enhanced. The relative permeability of a number of soil types are shown on Figure 6-3. The coefficient of permeability is determined by measuring the rate of water flow through a unit volume of soil in response to a unit hydraulic gradient.

"Groundwater flow" (direction and rate) is a function of permeability (hydraulic conductivity) and hydraulic gradient (hydraulic potential). Hydraulic potential controls the direction of groundwater flow from areas of higher groundwater elevation (potential) to areas of lower groundwater elevation (potential). The magnitude of the gradients and permeability of the subsurface materials control the rate of flow. An analogy with the flow of electric current through a wire is useful in understanding the relations between groundwater flow, hydraulic potential, and permeability. Permeability is analagous to the resistance or conductivity of the wire,

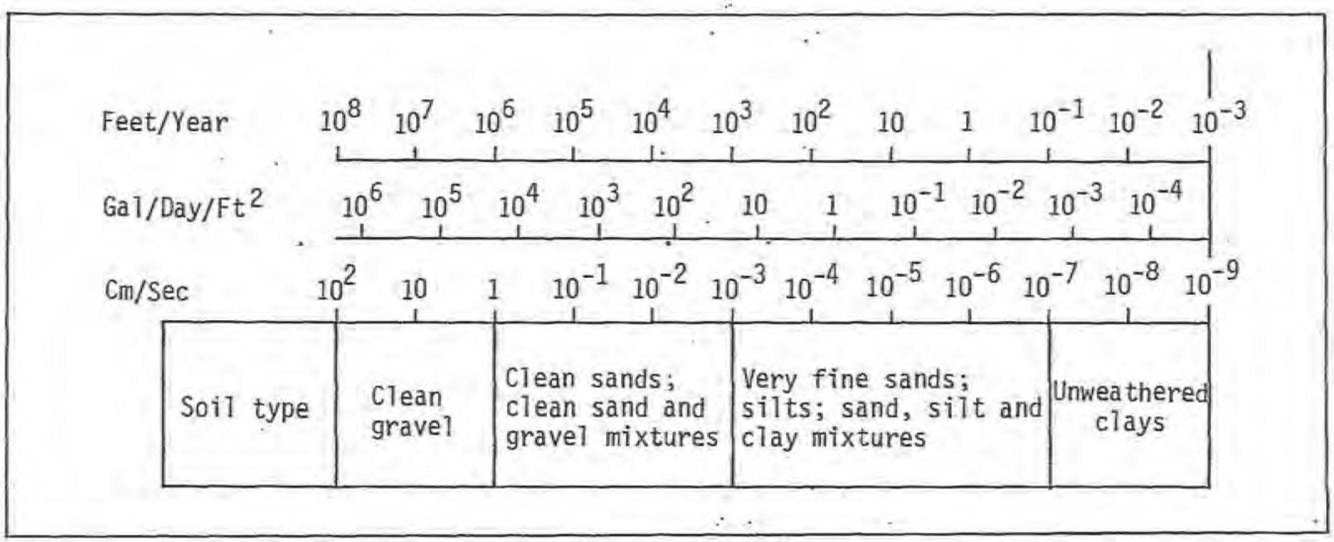

Figure 6-3. Coefficient of permeability for different soil types.

Source: Adapted from R.G. Knight, et al., <u>FGD Sludge Disposal Manual</u>, <u>Second Edition</u>, Palo Alto, California: Electric Power Research Institute, September 1980. CS-1515.

the hydraulic gradient is analagous to the voltage applied across the circuit. Current flow through the wire is a function of both its resistance and the potential applied, and requires an expenditure of energy.

Ground water exists under both water table and confined (artesian) conditions. Water table conditions occur when the elevation of the top of the zone of saturation coincides with the water level revealed by wells. This water table is referred to as a "phreatic surface." Confined aquifers exist under pressure greater than atmospheric. The water level in wells penetrating a confined aquifer will rise above the level at which water is encountered. Confined systems exist due to the presence of impervious materials above and below them. The water pressure distribution in a confined aquifer is commonly shown in terms of elevation and is known as a potentiometric surface. Examples of water table and confined aquifers are shown on Figure 6-4.

The depth to groundwater is a function of both regional and site specific factors, including topography, permeability, recharge and subsurface conditions and is best evaluated on a site specific basis.

"Soil texture" is a function of particle size distribution and partick shape. Natural subsurface materials are comprised of lithic fragments of various sizes ranging from boulders to extremely small fragments (<0.001 mm in diameter). A number of systems have been developed for classifying geologic materials on the basis of their texture. The most widely used of these systems, the unified classification, is presented on Table 6-1.

The size and distribution of the particles that comprise a geologic unit have a strong bearing on the pore space between the soil particles through which water flows, and thus its permeability. Soil texture also influences other properties of the geologic material including:

- Its susceptibility to erosion by wind, surface water, and groundwater.
- Its strength and compressibility.
- Its potential for use as construction material (borrow).
- Its chemical attenuation characteristics.

The properties listed above are also strongly influenced by the consistency of the subsurface material and its degree of consolidation or cementation. The consistency of a soil is related to its density or degree of compaction. Consolidation refers

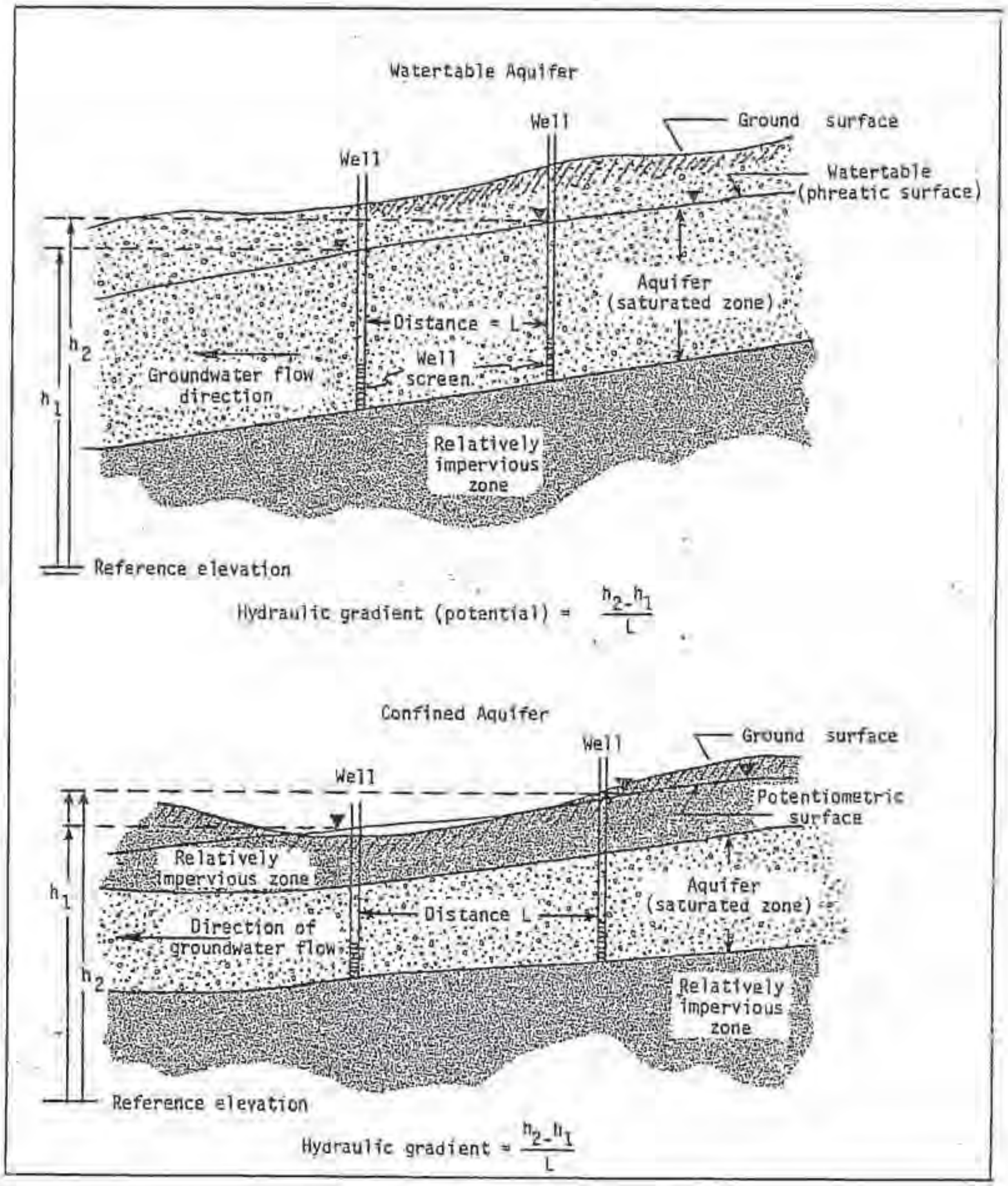

Figure 6-4. Water table and confined aquifers.

Table 6-1

UNIFIED SOIL CLASSIFICATION SYSTEM
(Laboratory Classification Criteria Excluded)

Major Divisions 1		Major Divisions 2		Group Symbols 3	Typical Names 4	Field Identification Procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights) 5			Information Required for Describing Soils 6
Coarse-Grained Soils More than half of material is larger than No. 200 sieve size	The No. 200 sieve size is about the smallest particle visible to the naked eye	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the ¼-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. Give typical name; indicate approximate percentages of sand and gravel, max. size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Silty sand, gravelly; about 20% hard, angular gravel particles ½-in. max. size; rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).
				GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			
			Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity. (for identification procedures see ML below)			
				GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below)			
		Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			
				SP	Poorly-graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			
			Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity. (for identification procedures see ML below)			
				SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below)			
Fine-Grained Soils More than half of material is smaller than No. 200 sieve size						Identification Procedures on Fraction Smaller than No. 40 Sieve Size			
						Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)	
		Silts and Clays Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses. For undisturbed soils and information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. Example: Clayey silt, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML).
				CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to Very slow	Medium	
				OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	
		Silts and Clays Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium	
				CH	Inorganic clays of high plasticity, fat clays.	High to Very high	None	High	
				OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to Very slow	Slight to medium	
Highly Organic Soils				Pt	Peat and other highly organic soils	Readily identified by color, odor, spongy feel and frequently by fibrous texture.			

Source: U. S. Bureau of Reclamation (USBR), Design of Small Dams, 2nd Edition, 1973.

to the bonding between particles of the material resulting from intergranular crystal growth or cementation.

During natural or artificial compaction of a soil, the particles will tend to become more tightly packed, resulting in a decrease in pore space and permeability and an increase in density and strength. As a material becomes more compact, the influence of particle size on permeability increases. Even a small percentage of fine particles may have a strong influence; highly compacted granular soils may exhibit permeabilities more normally associated with much finer soil types. The susceptibility of soil materials to surficial erosion and scour is a function of both texture and compactness, as is their susceptibility to subsurface erosion or piping. Piping occurs when soil particles migrate, due to seepage forces, to an outlet. Although piping begins with the erosion and transport of the finer silt and clay sized particles, it can rapidly accelerate. It is difficult to detect and, if detected, can be very difficult to control.

"Consolidation" refers to the compaction and cementation (bonding) of the grains or particles which comprise the subsurface. Unconsolidated materials are generally poorly cemented (e.g., soils and recent sedimentary deposits such as alluvial fans). Consolidated materials such as limestone, and shale are well compacted and bonded and/or cemented.

"Uniformity" of the geologic environment refers to the horizontal and vertical consistency of the subsurface materials and implies no concept of scale. Many of the methods used to analyze the geology and hydrogeology of an area assume a certain degree of uniformity or predictability of conditions from exploration to exploration. Many of the more sophisticated techniques used to model groundwater flow demand a good understanding of the uniformity of a site's characteristics. The uniformity of a site's subsurface conditions can be viewed as directly related to the ease with which those conditions can be described. Variations of all the properties discussed here contribute to a site's uniformity or lack thereof.

"Discontinuities" are abrupt, anomalous, changes in a site's subsurface conditions. Although potentially difficult to detect, discontinuities are important in that they can act as barriers or drains and drastically affect the groundwater flow pattern in an area.

<u>Properties of Earth Materials Used for Construction</u>. The in situ properties of the subsurface materials already discussed are analogous to the properties of earth

materials when used as construction materials. The main difference involves a change of perspective from measuring the material's properties to assessing its behavior. Only by means of proper preliminary and construction control testing can the properties of natural soil materials be optimized with regard to their desired use in corrective action plans. A summary of typical laboratory soil tests and their use is presented on Table 6-2.

Evaluation of soil material for use as borrow usually includes evaluation of some or all of the following:

- Permeability.
- Texture.
- Plasticity.
- Compressibility.
- Shear strength.
- Moisture-density relationships.
- Natural moisture content.

Permeability and texture have, in general, been adequately discussed earlier. The other listed geotechnical properties are discussed below.

"Plasticity" in a concept that applies to fine grained, cohesive soils or the fine grained portions of coarser soils. Plasticity is the ability of a material to be quickly deformed without rupturing or crumbling and to maintain the deformed shape upon removal of the deforming force. The "plastic limit" is the water content below which a material no longer exhibits plastic behavior.

"Compressibility" refers to the reduction in volume of a material due to the reduction of pore space when the material is subjected to loading.

"Shear strength" is the result of cohesion and intergranular friction acting on a mass of soil material. It is useful in assessing the stability of cut slopes and excavations, and the strength of earthen structures.

"Moisture-density relationships" describe the degree of compaction of a material that can be achieved by practical means. The degree of compaction of a soil is dependent upon the material's texture, moisture content, and the compactive effort expended. Compaction is perhaps the most critical consideration in achieving high

Table 6-2

SUMMARY OF TYPICAL LABORATORY SOIL TESTS FOR VARIOUS MATERIALS

TEST	TYPE OF MATERIAL			USE IN DESIGN	ASTM DESIGNATION
	FINE-GRAINED SOILS	FINE-GRAINED SOILS	CRUSHED ROCK		
1. Classification of Index Property Tests				Evaluation of feasible configurations	
A. Water content	a	a	–	Correlation of materials	D2216
B. Natural density	c	–	–	Selection of samples for other tests	–
C. Specific gravity	b,c	b,c	b	Selection of borrow areas	D854, C127, C128
D. Atterberg limits	b,c			Specification of construction procedures	D423, D424, D427
E. Grain-size analysis	b,c	b,c	b	Determination of filter and drainage requirements	D422, D2217
2. Compaction Tests:					
A. Standard Proctor	b	–	–	Evaluation of sample preparation for other tests	D698
B. Modified Proctor, and/or	b	–	–	Specification of placement requirements	D1557
C. Relative density	–	b	b		D2049
3. Permeability:	c,d	d	–	Seepage analyses Determination of pore pressures for stability	D2434
4. Consolidation:	c,d	–	–	Settlement analyses	D2435
5. Shear Strength:					
A. Direct shear	c,d	d	d		D3080
B. Triaxial compression, and	c,d	d	–	Stability analyses	D2850
C. Unconfined compression	c,d	–	–	Structure foundation design	D2166

Legend: The types and numbers of tests conducted will vary, depending on the purpose of the testing program and the conditions being investigated. The use of these guidelines should not be substituted for site-by-site evaluation by a qualified geotechnical engineer.

a – indicates tests normally conducted on all samples
b – indicates tests normally conducted on representative disturbed samples
c – indicates tests normally conducted on representative undisturbed samples
d – indicates tests on specially prepared samples to simulate as constructed-behavior

Source: E. D'Appolonia Consulting Engineers, Inc., Engineering and Design Manual, Coal Refuse Disposal Facilities, U. S. Department of Interior, Mining Enforcement and Safety Administration, 1975.

shear strength, low permeability, resistance to erosion and piping, and generally stable earthen structures. During compaction of a soil, some water is required to act as a lubricant to allow the articles to be forced tightly together. Too much water, however, will have the opposite effect and prevent good compaction.

The moisture-density relationships are determined by means of proctor tests. These tests involve the compaction of a soil at various moisture contents by application of a constant compactive effort. Measurements are made of both the moisture content and density achieved. If the permeability of the compacted material is of concern, it should be tested at various moisture contents and densities.

It should be noted that although many factors influence the permeability of natural materials, the degree of compaction or the density of the materials usually have a pronounced effect. Thorough compaction of relatively clean granular materials can reduce their permeability by orders of magnitude below the permeability of the same material in a loose condition. The density achieved during compaction of a borrow material directly effects its performance and the density achievable is dramatically influenced by its moisture content during the compaction operations.

The optimum moisture content for different soils varies considerably, as does the density that can be achieved by practical means. Thus, the uniformity of a borrow source is important.

The "natural moisture content" of borrow materials is often second in importance only to texture when evaluating the potential usefulness of a proposed borrow source. If the natural moisture content is not in an acceptable range for proper compaction, then the material will need to be moistened or dried prior to its use. Modifying the moisture content of fine grained materials can be a time comsuming and costly process.

Chemical Properties of Waste Materials

The wastes generated by coal-fired power plants consist principally of fly ash, bottom ash, boiler slag, and flue gas desulfurization sludges. The Coal Ash Disposal Manual (4) and FGD Sludge Disposal Manual (5) contain sections which specifically address the chemical properties of these wastes.

In general, the chemical properties of a waste are not critical to the selection of a corrective action technique, but the chemical constituents and their concentrations do impact specific design and construction aspects. Examples of the chemical characteristics of concern include concentrations of sulfate and salts, pH, and total dissolved solids of various utility waste liquors and elutriates. For example, a high sulfate content may require the use of Type II (ASTM C150) or possibly Type V (ASTM C150) portland cement. Concrete is attacked by a number of sulfate compounds including those of calcium, potassium, sodium, magnesium, aluminum, and ammonia (5). Salts such as calcium chloride can cause spalling and scaling of concrete, and sodium chloride can corrode unprotected metallic surfaces. The pH of the waste ranges from 3 to 12. When the pH falls outside the 6 to 9 range, serious corrosion of concrete and metal can occur. The TDS concentration is an indication of the potential for clogging of screens and filters, and of the abrasive character of the liquids. Abrasions in pump and gravity systems can lead to failure of pumps and pipelines, particularly at bends.

Physical and Engineering Properties of Waste Materials

The wastes deposited in a pond or landfill are subject to change from exposure (or weathering), mixing (or blending), and leaching. The properties of mixed or blended waste vary substantially from those of the individual waste categories.

Fly Ash/Bottom Ash. The properties of power plant ash which are of concern in selecting a corrective action procedure at a dry disposal site are described below.

"Grain size distribution" is important due to the influence of particle size on many engineering properties. The grading, density, shear strength, and permeability characteristics of a waste can often be estimated from the grain-size distribution curve (particle diameter vs. % by weight). A waste material is labeled uniformly graded or poorly-graded if its curve is steep; i.e., if it has a very small particle size range. A waste which has a flat curve is well-graded and has particles whose sizes are well distributed. Well-graded wastes are readily compacted and develop greater shear strength and lower permeability than poorly-graded wastes.

The range of fly ash particle size is $4x10^{-5}$ to $4x10^{-3}$ in (0.001 to 0.100 mm) for glassy spheres and $4x10^{-4}$ to 10^{-2} in (0.010 to 0.300 mm) for angular carbon particles. Particle sizes for bottom ash and boiler slag are generally larger than for fly ash, and are comparable in size to particles ranging from fine sand to fine gravel. Generally, boiler slag is more uniform in size than bottom ash.

"Moisture content" is a measure of water present in the voids. It is particularly important for fly ash due to its small particle-size (compared to bottom ash/boiler slag). A particular fly ash can be a dusty powder or a watery mud depending upon its moisture content. The moisture content affects the compaction or consolidation and shear strength of the fly ash.

There are two moisture contents relevant to ash compaction: the in-place moisture content and the optimum moisture content. The in-place moisture content should be determined in order to bring the ash to its optimum moisture content for maximum compaction. This adjustment can be accomplished by addition or removal of water or the addition of dry ash.

"Bulk density" is a measure of the relative volumes of voids and solids. It is an indirect measure of the total pore space. The density of fly ash is important because it affects the permeability and strength of the ash. These are directly related to the settlement and stability of dry fly ash. Bulk density of fly ash ranges from 1.12 to 1.28 g/cm^3 (6), although values from 0.55 to 1.73 g/cm^3 have been reported (7).

"Shear strength" is the shear stress in a waste mass when failure along a slip plane occurs. It is also defined as the shear stress when continuous displacement along a slip plane occurs at a relatively constant stress.

The strength of an ash is used to determine the steepness of a fill or cut slope shich can be safely constructed and the magnitude of loads (including equipment associated with the corrective action technique), which can safely be supported. The strength of an ash is related to two engineering properties: cohesion and the angle of internal friction. Cohesion is a measure of the shear strength developed by the attraction of individual particles to one another. The angle of internal friction is a measure of the frictional resistance between particles. Ashes possess no real cohesion, although self-hardening fly ashes develop chemical bonding similar to cement. For comparison purposes, the angle of internal friction of bituminous fly ash varies from 25° to 40° and that of bottom ash/boiler slag from 38° to 42.5° (4).

"Compressibility" determines the rate and magnitude of settlement of the landfill and of any structures which may eventually be founded on the landfill. In contrast to its shear strength behavior (where it behaves as a cohesionless material), fly ash behaves very much like a cohesive soil in terms of consolidation and settlement. Upon application of vertical pressure, the stress is initially shared by the fly ash structure and pore water. The excess pore water pressure gradually decreases as the water is squeezed out of the pores. As the pore water pressure decreases, the load is transferred to the fly ash structure, producing a volume change. Laboratory consolidation tests have indicated that compaction can significantly reduce the compressibility of fly ash.

"Permeability" was previously discussed for soils. The same discussion applies for ash. The "coefficient of permeability" refers to the flow of water and is used for estimating the quantity of water which will seep through a mass of waste in a given time. In laboratory tests, the permeability of bituminous fly ash compacted to its maximum dry density varied from 10^{-4} to 10^{-7} cm/sec (10). Bottom ash is more permeable than fly ash.

"Capillary rise" is a physical phenomenon in which a liquid, such as water, is drawn into a tube of very small diameter due to surface tension forces. This same process will occur in fly ash. Capillary rise is of concern in a fly ash fill because the fly ash can become saturated by groundwater which is drawn up into the ash. If this occurs, the ash will lose some of its strength and the landfill could become unstable. To eliminate the problem of capillary rise, an extraction system can be placed between the fly ash and the existing groundwater to intercept the groundwater before it enters the fly ash.

"Frost susceptibility" is a concern at many utility landfills because materials with grain-size distributions similar to that of fly ash are generally susceptible to frost heave if moist when exposed to freezing temperatures. Frost heave in soil is caused by the freezing and expansion of the water in the material's pore space. Self-hardening fly ashes are less susceptible to the problems of frost heaving than are the non-self-hardening ashes. The only means of accurately determining if a particular fly ash will be frost susceptible is to perform laboratory tests under freezing conditions or observe in-field conditions. Bottom ash and boiler slag have a lower susceptibility to frost heaving when well drained.

FGD Sludge. FGD sludges are generally fluid or semi-fluid, retain a high percentage of water and are difficult to handle. Sludges which have a high proportions of fly ash and/or high oxidation rates are less fluid and easier to handle.

Pertinent properties of FGD sludges in releation to corrective action are described below.

"Moisture content" is computed as the ratio of the weight of the sludge liquid to the weight of the sludge solids, expressed as a percentage. This is not directly related to percent solids which is the total weight of sludge due to the solid constituents.

While settled fly ash may achieve a solids content greater than 60%, FGD sludge solids contents are generally 20 to 45%. This corresponds to moisture contents ranging from 400% to 120%, respectfully, of the dry weight of the sludge solids.

"Bulk density" is expressed as either dry bulk density or set bulk density. Dry bulk density is the dry weight of in-place solids that occupy a unit volume. Wet bulk density is the weight of a unit volume of dewatered sludge containing both liquid and solid phases.

Table 6-3 illustrates typical density values and corresponding solids content for five settled sludges. The bulk densities indicate supporting capabilities and water content as well as volume of liquids and solids.

"Permeability" of untreated FGD sludges is normally 10^{-4} to 10^{-5} cm/sec (5). These values are equivalent to those for fine to very fine sand, with drainage characteristics rated as good to poor. The importance of permeability is in its influence on the volume of leachate which may drain from the sludge. A permeability reduction from 10^{-3} to 10^{-4} cm/sec will reduce the volume of leachate by a factor of ten.

FGD sludge permeability is dependent upon size distribution, particle shape, and density. Settled sulfite sludge is generally less permeable than sulfate sludge because of the irregular shape of the sulfite crystal aggregates. Settled and drained FGD sludges exhibit permeabilities of 3.9 x 10^{-4} to 3.9 x 10^{-5} in/sec (10^{-3} to 10^{-4} cm/sec); light compaction will decrease this to 3.9 x 10^{-6} in/sec (10^{-5} cm/sec). Table 6-4 lists the permeabilities of several FGD sludge samples.

"Compressibility" of sludge is indicated by a Compression Index which is directly proportional to the compressibility of the material under an applied load. While typical compression index values for soils range from 0.2 to 0.5, values for FGD sludge are as much as 4 to 10 times higher. Thus, the expected settlement of the disposal areas where FGD sludges predominate may be severe.

"Shear strength" is an indicator of the steepness of the slope to which the sludge can be placed and the loads that the sludge will support without failure.

Table 6-3

UNTREATED SLUDGE BULK DENSITIES*

	Sludge Condition					
	Dewatered		Maximum Density		Dry	
Company/Plant/Reagent	lb/ft^3	%	lb/ft^3	%	lb/ft^3	%
TVA/Shawnee/Limestone	91	52.9	104	66.8	69	100
TVA/Shawnee/Lime	85	43.4	97	59.4	58	100
Duquesne Light/Phillips/ Lime	87	47.6	98	60.8	60	100
Arizona Public Service/ Cholla/Limestone	87	46.7	105	67.1	70	100
Southern California Edison/Mohave/ Limestone	103	66.6	110	72.5	81	100

1 lb/ft^3 = 16.02 kg/m^3.

* Source: J. Rossoff, R. C. Rossi, R. B. Fling, W. M. Graven, and P. P. Leo. Disposal of By-Products from Nonregenerable Flue Gas Desulfurization Systems; Second Progress Report. Washington, D.C.: U.S. Environmental Protection Agency, May 1977. EPA 600/7-77-052.

Table 6-4

PERMEABILITIES OF UNTREATED FGD SLUDGES*

			Settled		Compacted	
Location	Process	Sample No.	Void Radio	Permeability (cm/sec)	Void Radio	Permeability (cm/sec)
Eastern	Limestone	1	1.53	1.02×10^{-4}	1.27	7.78×10^{-5}
		2	2.07	3.37×10^{-5}	1.56	1.11×10^{-5}
Eastern	Lime	1	1.83	1.74×10^{-4}	1.68	5.27×10^{-5}
		2	1.65	6.01×10^{-5}	1.42	1.07×10^{-5}
		3	1.25	1.28×10^{-4}	0.97	7.4×10^{-5}
Western	Limestone	1	0.96	3.25×10^{-5}	0.63	1.44×10^{-5}
		2	1.20	1.85×10^{-5}	1.20	1.11×10^{-5}
		3	0.75	8.3×10^{-4}	0.50	9.1×10^{-5}
Eastern	Dual-alkali	1	5.11	7.81×10^{-5}	4.17	2.51×10^{-5}
		2	2.19	2.46×10^{-4}	1.95	8.06×10^{-5}
Western	Dual-alkali	1	2.77	9.8×10^{-4}	2.61	1.33×10^{-4}

1 cm/sec = 0.39 in/sec

* Source J. Rossoff, R. C. Rossi, R. B. Fling, W. M. Graven, and P. P. Leo. Disposal of By-Products from Nonregenerable Flue Gas Desulfurization Systems; Second Progress Report. Washington, D.C.: U.S. Environmental Protection Agency, May 1977. EPA 600/7-77-052.

As previously stated, shear strength is composed of two components: cohesion and angle of internal friction. Cohesion is the shear strength which exists when no load is applied to the sludge and is equal to one-half the unconfined compressive strength. The cohesion of untreated FGD sludges is considered zero; this may be compared with saturated clays with the cohesion of up to 1000 lb/ft^2 (4,882 kg/m^2). The greater the angle of internal friction, the greater the shear strength of the sludge. Tests indicate that untreated FGD sludge has an angle of internal friction of approximately 20°, compared to loose sand with a 30° angle and saturated silts with a 20° angle (5).

SURFICIAL CORRECTIVE ACTION TECHNIQUES

The existing and/or potential environmental problems typically encountered at utility waste disposal sites include:

- Air pollution.
- Surface water pollution.
- Groundwater pollution.

The corrective action techniques described herein are each potentially applicable in controlling one or more of these problems. The description of each technique covers the following key aspects:

- Definition.
- General Application.
- Limitations or special applications.
- General comments as appropriate regarding suitability of the technique under varying site and subsurface conditions.

The synthesis of pertinent corrective action techniques into corrective action plans is also discussed.

Grading

Grading is defined as leveling to a smooth horizontal or sloping surface. As a corrective action technique, its purpose is to artifically create a general topographic pattern at or around a site that (1) diverts surface water runoff; (2) reduces infiltration of surface water; (3) minimizes surface water ponding; and (4) minimizes erosion (see Figure 6-5).

Grading is a corrective action technique that applies to almost all land disposal sites. Site grading is an operation that should be considered and implemented

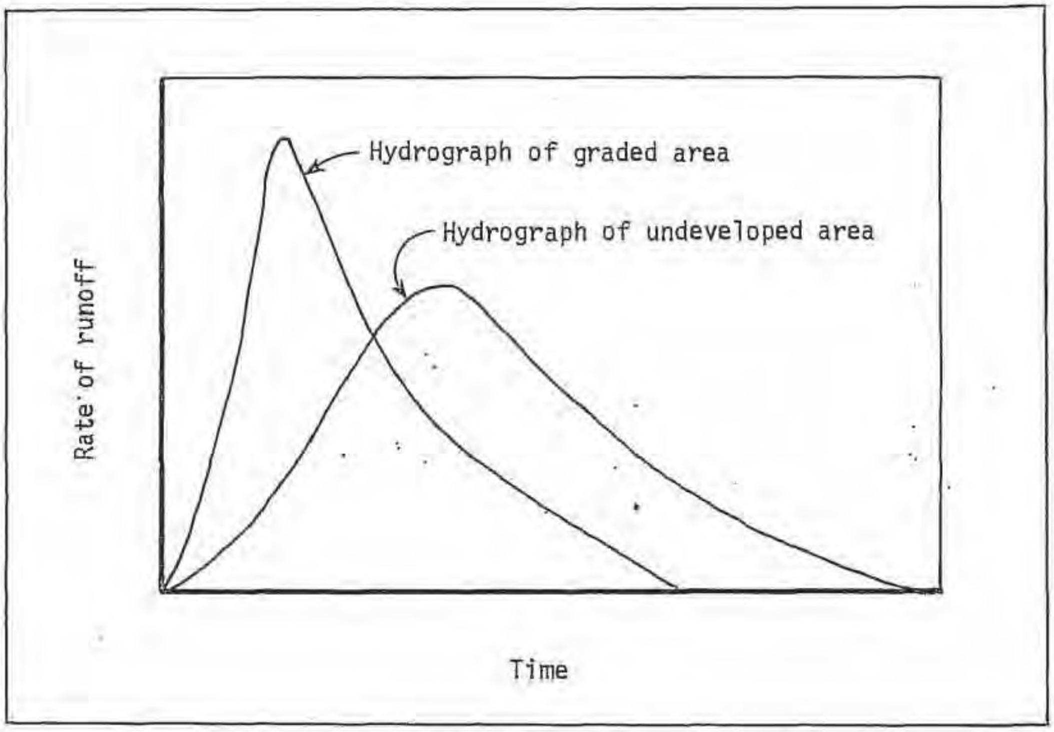

Figure 6-5. Schematic portrayal of the effects of site grading and surface water controls on runoff rates.

Source: W.B. Caswell. Groundwater Handbook for the State of Maine, Maine Geological Survey, 1978.

throughout the active life of such facilities as well as during the closure phase. Ideally, site grading is planned prior to site development since the configuration of the land disposal area is influenced by both the original and post-closure site topography. Factors influencing the grading configuration include general site topography, soil type, rainfall intensity, size of the drainage area, vegetative type, slope stability, and use of the graded area.

Site grading normally consists of excavation of earth materials at one location and the placement of the excavated materials at another. It involves the modification of slope lengths, grades, and surface roughness to achieve its objectives. The nature of the materials requiring excavation and the depth to which excavation is necessary have a strong bearing on the economics of site grading. Usually, the excavation of extensive quantities of bedrock (ledge) materials is impractical. Excavation below the water table, particularly in granular soils, may be considerably more difficult than excavation in the dry.

Site grading involves the construction of sloping surfaces in both cut and fill areas. In general, top slopes on landfills should be graded to between 6 and 12%; steeper side slopes of up to 18% are common. Equipment accessibility, slope stability, and erosion potential are the practical considerations governing the steepness of slopes erected by landfilling and grading at disposal sites.

At dry disposal sites it may be beneficial to grade the waste surface to promote runoff thereby reducing infiltration of precipitation falling directly on the exposed waste materials. In any event, it is desirable to grade the waste sufrace at dry disposal sites to facilitate the placement of both interim and final cover.

Cover

Cover is defined as "something that protects, a lid, or top." As a corrective action technique, it involves the placement of either synthetic or natural materials over the waste deposited at a disposal site. Properly designed cover controls waste dust, reduces infiltration of surface water and precipitation, supports vegetation, and potentially provides a base for future site use.

The design and placement of cover at a site must be integrated with the design and implementation of surface water controls, revegetation, and site grading schemes. Many of the comments under "Grading" are equally pertinent to the placement of cover. To be effective, cover placed at a site should consist of relatively impervious, durable material and must be suitably graded to promote rapid runoff and resist erosion. Careful consideration of the engineering properties of the cover material is needed to determine its suitability and define the construction practices required for effective installation.

Interim cover is placed to provide the benefits described above on a short-term basis. Final cover is a permanent site feature constructed subsequent to the completion of all or a portion of a land disposal site. Thus, the nature of the materials and construction practices utilized for interim and final cover may differ considerably. Typical sections of soil cover are shown on Figure 6-6.

Interim cover is quite often used as a working surface to support vehicular traffic and allow access to the working face. Normally, final cover should not be used as a pavement unless it has been designed to allow such use. If it is necessary to operate heavy equipment on final cover, an appropriate soil pad or working surface should be provided. The thickness of the protective pad should be adequate to reduce loading on the cover material to tolerable levels and prevent cracking, heaving, puncture, and rutting which would adversely affect its performance.

Ideally, soils available at the site can be used as both interim and final cover. Cover material can be stockpiled at the site and placed If suitable soils are available on-site, the required excavation should be incorporated into the site grading plan. However, in many cases, suitable soils may not be available or, if present, their excavation may be impractical in view of site grading requirements. Thus, the use of imported natural soil materials, admixtures or synthetic materials may be required. Following is a brief description of each of these categories. The reader is referred to Section 9 (Liner Selection and Installation) for additional discussion of these materials.

Natural Soil Materials. The natural soils normally considered appropriate for final cover construction include clayey or silty soils and well graded soils with an appreciable fines content (silt and clay sized particles).

Properly placed and thoroughly compacted clayey soils will exhibit very low permeabilities. However, certain characteristics of clay and clayey soils can cause them to be extremely difficult to work with under certain situations. The moisture content of clayey soils during placement is usually the most critical factor affecting their workability, the degree of compaction, and the permeability that can be achieved. If they are placed too dry, it will be impossible to achieve adequate compaction and thus the desired low permeability. If placed too wet, they will

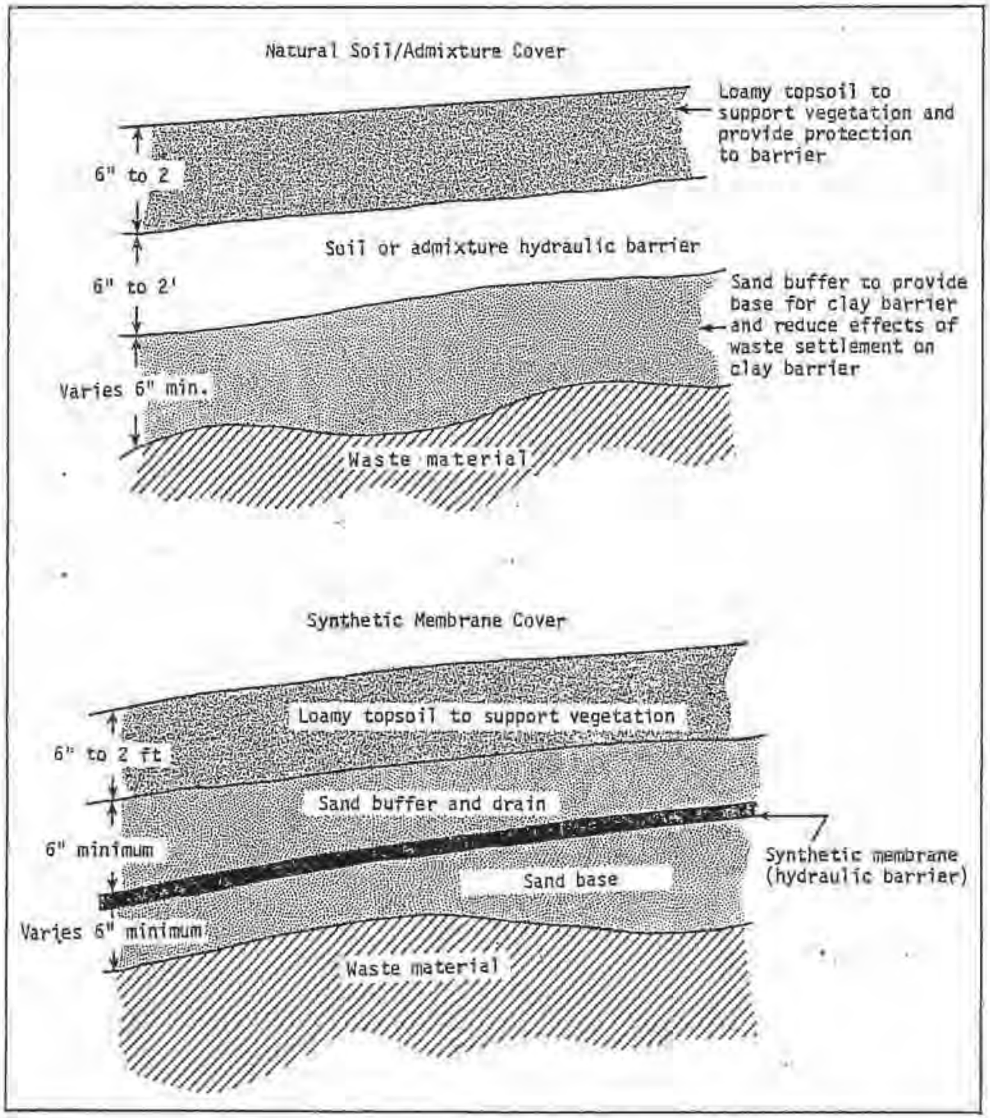

Figure 6-6. Natural soil, admixtures and synthetic membrane covers.

adhere to equipment, be unstable, difficult or impossible to compact, and have very poor trafficability.

Although many factors influence a soil's permeability, its density, plasticity, and moisture content are the most important properties that should be considered in evaluating the suitability of a specific soil for use as cover material.

The optimum moisture content is determined by proctor tests (moisture content density testing). The degree of compaction required needs to be specified, usually as a percentage of maximum dry density (also determined by proctor tests). Due to their natural water holding properties, clayey soils will dry slowly even when aerated or tilled. Likewise, once dessicated a substantial effort may be required to reintroduce water to achieve the optimum moisture content for proper placement and compaction.

Compacted clayey soils are not particularly suitable for supporting plant growth and are susceptible to dessication cracking if allowed to dry. Thus, a protective soil cover or buffer layer should be provided to prevent dessication and support vegetation (Figure 6-6).

Some natural clayey soils (those with an appreciable content of bentonite or montmorillonite) will expand when they become wet due to hydration of their crystal structure. These materials should be placed at a moisture content that provides for hydration and suitable compaction; in this condition, they need to be protected from dessication. In general, these materials should not be placed dry and allowed to hydrate in place because they will fluff and become loose, resulting in higher permeabilities than the materials would normally possess.

The criteria for placement and compaction of well graded soils with appreciable fine content is in many respects similar to the placement and compaction of granular soils. The permeability of covers constructed of well-graded soils depend upon the degree of compaction achieved and their grain-size distribution, and plasticity.

Admixture Cover Materials. Because of their engineering properties, a wide range of natural soils are unsuitable for use as final cover. However, under some circumstances, soil conditioners can be added to improve the properties of these materials to the point where the admixture can perform satisfactorily. Commonly used soil conditioners or additives include Portland cement, clay minerals (i.e., bentonite), pozzolan, and other chemical agents that reduce the permeability of natural soils.

Normally, the soil portion of the admixture is spread and graded over the disposal site. The additive is then spread on top of the soil and thoroughly blended or tilled into a uniform mixture. The mixture is then compacted. The application of a cover constructed of soil cement differs primarily in that after mixing the relatively dry mixture is wetted to activate the cement.

The placement and compaction of admixture cover material is subject to the same considerations as natural liners. The application rates for the additives are a function of the characteristics of the natural soils they are to be mixed with. The admixtures that require compaction need be compacted to design densities at suitable moisture contents to achieve suitably low permeabilities. Expansive additives need to be hydrated prior to compaction of the admixture. If a bentonite cover is placed and compacted at too low a moisture content it will fluff when it becomes wet. Fluffing will seriously affect the performance of the cover.

Synthetic Cover Materials. When suitable natural materials are not available for use as cover, synthetic materials may be used instead (also see Section 9). Synthetic materials potentially usable as cover include:

- Asphalt pavement.
- Hot sprayed asphalt.
- Asphalt sealed fabric.
- Polyethlene (PE).
- Polyvinyl chloride (PVC).
- Butyl rubber
- Hypalon® (Dupont).
- Ethylene propylene diene monomer (EPDM).
- Chlorinated polyethylene (CPE).

The installation of most synthetic cover materials requires specialized construction equipment not normally available at land disposal sites. Asphalt pavement is applied with conventional paving machines. If it is necessary to seal the asphalt, either hand sprayers or truck mounted equipment can be utilized effectively.

Hot sprayed asphalt membranes are applied to large areas with a truck mounted spray bar and to smaller areas with portable equipment. The asphalt is applied at rates ranging from 1.5 to 2 gal/yd^2 (6.8 to 9.1 l/m^2) resulting in a continuous membrane in the order of 0.25 to 0.75 in. (0.64 to 1.91 cm) thick.

Asphalt sealed fabric requires a three-step installation process. Rolls of polypropylene fabric are spread over the site and spliced into one continuous sheet. The fabric is then sprayed with a mixture of water, asbestos and asphalt emulsion. This mixture is allowed to dry and a second application is sprayed over the fabric to complete the seal.

Plastic and rubber membranes are generally available in large rolled sheets. The material is spread over the site and spliced to form a continuous sheet. It should be anchored by burying the edge in a shallow trench. Butyl rubber requires a two part adhesive, EPDM a single part adhesive, and Hypalon®, P.E. CPE, and PVC are all solvent sealed. These plastic and rubber materials are available reinforced with fabric, usually nylon, dacron, or fiberglass. Reinforced membranes provide greater puncture resistance and better overall strength characteristics than their nonreinforced counterparts.

Synthetic membranes are classified in two groups depending on their resistance to deterioration when exosed to ozone and ultraviolet radiation. Exposable materials, (e.g., butyl rubber, EPDM, hypalon® and CPE) can tolerate direct exposure to atmosphere and sunlight. Unexposable materials, (e.g., VC and PE) will deteriorate and become ineffective unless provided with suitable protection such as an earth cover. In practice, most manufacturers recommend protecting the membrane with an earth cover 1 to 2 ft (30 to 61 cm) in thickness regardless of liner type. The earth cover should be free of sharp objects and jagged rocks.

Summary. The design and implementation of suitable cover at land disposal sites is an important practice in effecting corrective action and minimizing and/or preventing future air, surface water, and ground water pollution. Cover is perhaps the single most important factor in correcting and preventing pollution at disposal sites. Thus careful consideration should be given to the selection of proper cover material as well as the placement and maintenance of cover.

In addition to minimizing air emissions and surface water contact with the waste material, in some situations placement of final cover can exert a moderate influence on ground water level and patterns. Its effectiveness is derived from the expeditious removal of surface water and precipitation. In brief, to optimize its functions, a cover should be:

- Relatively impervious, restricting rapid infiltration of precipitation and surface water.
- Suitably graded to prevent run-on of surface water and expedite runoff.

- Resistant to both surface erosion and subsurface erosion (piping), preventing exposure of the waste material.
- Chemically inert with regard to the waste materials.
- Protected from mechanical disturbance and puncture.
- Properly maintained.

When properly installed, land disposal site cover should be an intergal part of the site grading scheme. Cover must provide suitable support to minimize disturbance from settlement of the waste material. In some cases, a buffer zone is required to provide protection from chemical deterioration. Usually it is necessary to install a surficial buffer to provide mechanical protection and support vegetation. In many cases, land disposal site cover is a multi-layered relatively complex structure and warrants detailed evaluation during its design and careful monitoring during construction. A good understanding of the engineering properties of the cover material is necessary including its permeability, moisture density characteristics, plasticity, uniformity, strength, and resistance to chemical and mechanical deterioration.

The design of appropriate cover for utility land disposal sites can be a complex problem and warrants the attention of experienced professionals.

Surface Water Control

Surface water control is an inherent feature of effective site grading and cover placement. Surface water control is a corrective action technique applicable at both wet and dry disposal sites. The objectives of implementing surface water control are:

- To prevent surface water from entering the waste material.
- To reduce the potential for erosion and subsequent exposure of waste material or disruption of the site grading scheme.
- To expedite surface water flow off the land fill cover and away from the disposal site to minimize infiltration.
- To prevent site activities from causing siltation of surficial waterways.

Design of Surface Water Control Structures. Berms, ditches, flumes, chutes, levees, pipes, culverts, and other hydraulic structures are used to control surface water. These structures are normally constructed using compacted soil materials, concrete, asphalt, or metal.

Berms are elongated mounds, usually constructed of compacted soil, and are used to intercept and divert surface water as it flows across the land surface. Ditches are relatively shallow elongated excavations that serve the same purpose. Often, ditches and berms are used in conjunction with each other (see Figure 6-7). For example, berms can be used to direct surface water flow into ditches or can even form the downslope portion of a ditch crossing a slope. Flumes, chutes, pipes, and culverts are used when ditches or berms are inappropriate due to excessive flows, steep slopes, erosion potential or other practical considerations.

The types of surface water controls used on highways and roads are illustrative of the techniques and structures available for controlling surface water. However, in these applications, the purpose of surface water control is usually limited to the expeditious removal of the surface water in a manner that minimizes erosion. At disposal sites, it is important to minimize the infiltration of surface water into the ground water system in addition to effecting its removal and preventing erosion. The usual design considerations for hydraulic structures apply to surface water controls at land disposal sites. These include an accurate assessment of surface drainage areas and rates, site topography and slopes, precipitation frequency, magnitude and duration, infiltration rates, and erosion potential. Evaluation of these factors is necessary to accurately predict runoff volumes and rates. The design and sizing of surface water control structures is predicted by the rate and volume of runoff they must control.

Thus, the methods used to design surface water controls at land disposal sites should be carefully selected to assure that predicted runoff rates and volumes are accurate.

Many emperical methods and a number of models are used to size and design the hydraulic structures comprising a surface water control system. However, land disposal sites are designed to promote rapid runoff, unusually low infiltration rates; and concentrate surficial drainage. Many of the common methods used to size and design hydraulic structures cannot accommodate these unusual conditions. If improperly sized and/or designed, surface water control structures are likely to overflow and may fail. Consequently, extensive maintenance of the surface water control system would be required.

Ideally, surface water control structures are for the most part constructed from natural soil materials found on site. However, due to the unavailability of suitable natural materials, existence of excessive slopes, anticipated large volume

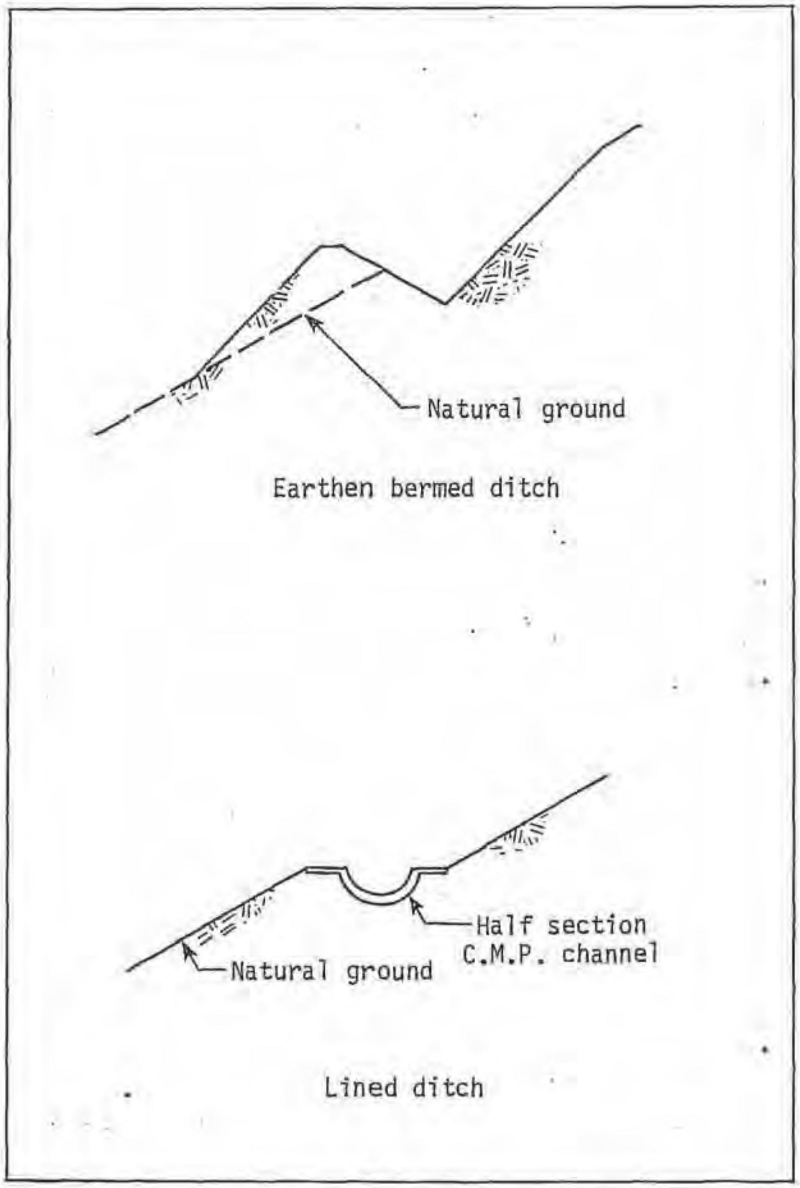

Figure 6-7. Typical ditches and berms (dimensions are site-specific).

Source: Adapted from R.G. Knight, et al., FGD Sludge Disposal Manual, Second Edition. Palo Alto, California: Electric Power Research Institute, September 1980. CS-1515.

runoff, or anticipated high runoff velocities, the construction of surface water control structures of durable artificial materials may be necessary. Materials commonly employed for this urpose include concrete, asphalt and galvanized metal. In other instances, compacted soil structures provided with appropriate protection from erosion and infiltration are adequate. Effective methods of controlling erosion include:

- Establishment of vegetation.
- Paving of areas unusually succeptible to erosion.
- Placement of protective gravel, stone, riprap or armour at appropriate locations.
- Reduction of runoff velocity.
- Proper maintenance of surface water control structures.

Effective methods of reducing the surficial permeability of surface water control structures to reduce infiltration have been discussed previously.

One of the areas where effective surface water controls are necessary and where their construction and maintenance are relatively difficult is on the landfill itself. Exposed waste materials, waste materials provided with only interim cover, and completed portions of an active landfill can pose difficult surface water control problems.

The types of problems that can be encountered in this situation include:

- Nonuniform settlement of the landfill surface, hence disturbance of the cover and disruption of the intended surface water flow patterns.
- Exposed wastes and those provided with only interim cover may be difficult to drain properly and highly succeptible to erosion.
- The fact that the landfill is incomplete may make it difficult or impractical to implement the final surface water control scheme. In this case, interim measures are necessary.

Careful planning of the landfilling activities, a well designed and properly implemented surface water control scheme, proper and timely maintenance and suitable site operational practices are required to effectively compensate for these potential problems.

Flood Control. Normally, surface water controls are used to remove precipitation and runoff from the disposal site and to allow surface water originating upgradient to bypass the disposal site harmlessly. In some unusual situations, it may be necessary to protect land disposal sites from flooding and washout. It would be unwise and probably not feasible from a regulatory viewpoint to site a new land disposal site in a floodplain or other area subject to flooding. It may, however, be feasible to provide protection from flooding as a corrective action.

Properly designed levees and dikes and/or measures designed to stabilize stream channels and banks may be effective in flood control. However, it is necessary to consider both the immediate and long-term ramifications of such efforts. Additionally, the risks associated with a failure scenario in such a situation should be carefully evaluated. Usually such modifications of stream and river floodplains and valleys will involve additional federal permitting requirements and may require state and local approval as well. The disruption of floodstage flow in rivers and streams may have disasterous consequences upstream by causing unusual flooding and erosion and could result in substantial property and environmental damage. The U.S. Army Corps of Engineers' jurisdiction extends to the headwaters of rivers and their tributaries. Thus, their requirements in a given situation should be evaluated as a matter of course in determining the feasibility of flood control structures.

Control of Erosion and Sedimentation. One indirect impact of implementing surface water controls is the effect of such controls on the surface water down stream from the site. The primary concern is erosion in the vicinity of the disposal site due to the intentional concentration of surface water and runoff, and subsequent deposition of the eroded materials down stream. The siltation of streams and waterways is a significant environmental problem and must be avoided. Land disposal sites are particularly vulnerable to this type of problem, particularly during the implementation of corrective actions. This is due, in part, to the following:

- Extensive areas of exposed soils resulting from site grading.
- The land disposal site design objective of expeditiously removing surface water and runoff to reduce infiltration.
- The exposed potentially erodable soil and waste material commonly found at the active portion of the disposal site.
- The common practice of stockpiling cover on site.

Thus, the prevention of erosion and subsequent siltation becomes a very significant consideration. Common practices employed to prevent or reduce the potential for erosion include both temporary and permanent features:

- Hay or straw mulch, jute mats, fabric, spray-applied emulsions, and other techniques are used for temporary stabilization of slopes and newly graded areas.

- Slopes created by filling and/or excavation should be stable to preclude slumping and sloughing.
- Riprap and other protective covers are used as appropriate.
- Vegetation may be established.
- Surface water control structures are stabilized, as described previously.

Since it is virtually impossible to eliminate all erosion, particularly around an active site, it will usually be necessary to provide sediment basins or traps at appropriate locations to intercept the surface waters sediment load. Several types of sediment retention basins are commonly used. These generally consist of shallow flat-bottomed lagoons or basins retained by a dike or berm or a series of such structures.

Sediment retention basins operate on the principal that the sediment load carried by flowing water will settle out if the velocity and turbulence of the flowing water are adequately reduced. The removal of suspended silt and clay-sized particles requires a properly designed sedimentation basin with adequate storage to provide sufficient retention time for runoff from peak events to clear. A number of techniques have been developed to allow the water retained by the basin to escape slowly; standpipes and intentional dike overflow are relatively common. Normally, sediment basins are allowed to remain dry or nearly dry when not in use. They require regular maintenance including the removal of accumulated sediments. The proper design of sediment basins requires a thorough understanding of the drainage area and rates; precipitation frequency, magnitude and duration; infiltration rates; and erosion potential.

Revegetation

Vegetation includes grasses, legumes, shrubs, and trees. Proper site vegetation decreases wind and water erosion, contributes to soil stabilization and dust control, and improves the appearance of the disposal site.

Vegetative cover reduces wind erosion by buffering winds, helps to maintain soil moisture, and strengthens soil mass through rooting. Likewise, water erosion, which occurs during and after precipitation, is controlled by vegetative cover through reduction of rainfall impact, runoff velocities, and runoff amounts.

Applications. Vegetative cover is used on the areas adjacent to ponds, on pond dikes and embankments, and on areas around and on completed portions of landfills.

It serves to intercept surface waters that could erode dikes and embankments. It can also stabilize surrounding slopes which are prone to slumping and/or erosion, as well as stabilize regraded areas. Vegetation is appropriate to valley-fill, side-hill, and heaped landfills and can be used both on the landfill and on the surrounding areas.

Ground covers such as grasses and legumes are appropriate for all areas. Shrubs and trees are not appropriate for drainageways, dikes, or embankments due to the possible structural damage by roots. The appropriate type of shrub or tree and the thickness of the cover soil.

Land preparation entails establishment of the required top soil depth (normally 1 to 2 ft) for the species selected, assessment of the fertility of the soil cover relative to the requirements of the plants selected, initiation of tilling or other earthwork required, and the provision of temporary erosion control measures required while a vegetative cover is established. In addition, final site contours compatible with end use plans should be established prior to seeding.

Implementation. A revegetation program consists of four steps:

- Plant selection.
- Soil preparation.
- Fertilizing.
- Seeding and mulching, if necessary.

Plants should be selected on the basis of their adaptability to local climate and soil fertility. Native species are most likely to be acclimated to the amount of rainfall and other seasonal conditions unique to the site. Particularly favorable plant characteristics are low growth spreading from rhizomes or stolons; rapid germination and development; and resistance to fire, insects, and disease. Plants that are poisonous or are likely to spread and become noxious should be avoided.

A large number of grassed and legume species are available for reclamation use. Species that find wide and frequent application are described in Tables 6-5 and 6-6. A local agronomist should be consulted for recommendation of locally adapted or newly introduced plant varieties. Trees are usually planted in the later stages of the development at the utility disposal sites. They provide long term cover and require little or no maintenance, once established.

Table 6-5

GRASSES COMMONLY USED FOR REVEGETATION

Variety	Best Seeding Time	Seed Density seeds/ft^{2}*	Important Characteristics	Areas/Conditions of Adaptation
Redtop bentgrass	Fall	14	Strong, rhizomatous roots, perennial	Wet, acid soils, warm season
Smooth bomegrass	Spring	2.9	Long-lived perennial drought resistant	Damp, cool summers,
Field bromegrass	Spring	6.4	Annual, fibrous roots, winter rapid growth	Cornbelt eastward
Kentucky bluegrass	Fall	50	Alkaline soils, rapid grower, perennial	North, humid, U.S. south to Tennessee
Tall fescue	Fall	5.5	Slow to establish, long-lived perennial, good seeder	Widely adapted, damp soils
Meadow fescue	Fall	5.3	Smaller than tall, susceptible to leaf rust	Cool to warm regions, widely adapted
Orchard grass	Spring	12	More heat tolerant but less cold resistant than smooth bomegrass or Kentucky bluegrass	Temperate U.S.
Annual ryegrass	Fall	5.6	Not winter hardy, poor dry land land grass	Moist southern U.S.
Timothy	Fall	30	Shallow roots, bunch grass	Northern U.S., cool, humid areas
Reed canarygrass	Late summer	13	Tall coarse, sod former, perennial, resists flooding and drought	Northern U.S., wet cool areas

* Number of seeds per square foot when applied at 1 lb/acre.
Source: R. J. Lutton, G. L. Regan, and L. W. Jones: Design and Construction of Covers for Solid Waste Landfills.

Table 6-6

LEGUMES COMMONLY USED FOR REVEGETATION

Variety	Best Seeding Time	Seed Density seeds/Ft^{2}*	Important Characteristics	Areas/Conditions of Adaptation
Alfalfa (many varieties)	Late summer	5.2	Good on alkaline loam, requires good management	Widely adapted
Birdsfoot trefoil	Spring	9.6	Good on infertile soils, tolerant to acid soils	Moist, temperate U.S.
Sweet clover	Spring	6.0	Good pioneer on non-acid soils	Widely adapted
Red clover	Early spring	6.3	Not drought resistant, tolerate to acid soils	Cool, moist areas
Alsike clover	Early spring	16	Similar to red clover	Cool, moist areas
Korean lespedeza	Early spring	5.2	Annual, widely adapted	Southern, U.S.
Sericea lespedza	Early spring	8.0	Perennial, tall erect plant, widely adapted	Southern, U.S.
Hairy vetch	Fall	0.5	Winter annual, survives below 0°, widely adapted	All of U.S.
Winter clover	Early fall	18	World-wide, many varieties, does well on moist, acid soils	All of U.S.
Crownvetch	Early fall	2.7	Perennial, creeping stems and rhizomes, acid tolerant	Northern U.S.

* Number of seeds per square ft when applied at 1 lb/acre.

Source: R. J. Lutton, G. L. Regan, and L. W. Jones. Design and Construction of Covers for Solid Waste Landfills. Cincinnati, Ohio: U.S. Environmental Protection Agency, August 1979. EPA 600/2-789-165.

To repare the cover soil for revegetation, an operator may need to adjust the soil pH. Depending on soil reaction and plant species selected, pH adjustment may or may not be required. Most plant species prefer pH in the range of 6.5 to 7.5. pH adjustment (e.g., liming of acid soils) is normally done during land preparation; fertilization can be done either prior to seeding or after germination.

The rate and frequency of fertilizer application and the specific nutrients added will depend on the soil, fertility, texture, and the selected plant species1. Coarse-textured soils are normally low in fertility and organic matter content, and larger quantities of fertilizers (particularly nitrogen) will be needed. In these soils, several low-rate applications per year are preferred to a single heavy application, since nutrients will tend to leach out of the soil. In fine-textured soils with relatively high fertility, organic matter content and nutrient holding capacity it may be possible to apply less fertilizer in a single application. The Agricultural Extension Service is a source of information concerning soil texting, soil pH adjustment, and nutrient requirements for various native plant species.

Seeding can be accomplished in a number of ways, including hand broadcasting, use of hand operated seeders such as cyclone seeders, or larger, mechanized seeding equipment. Hydroseeding, which permits application of seed, fertilizer and mulch in a single operation, may be advisable at some sites. It is especially useful for initial seeding with quick growing grasses. The seeding rate varies from 25 to 45 lb/ac (28 to 50 kg/ha) depending on the type of plant to be grown and its germinative ability.

On a completed landfill site, where final cover includes coarse-textured top soil, straw mulching is recommended to conserve limited moisture during the growing season. Straw is applied at a rate of approximately 1.5 ton/ac (3.4 t/ha), using a mulch spreader. The straw is incorporated into the soil by a straw crimper or other means.

On steep slopes where some form of immediate control of erosion from heavy rainfall or snow melt runoff is necessary, jute matting can be put directly on top of the seed, fertilizer, and straw mulch, and anchored to the ground with large staples. Jute matting, however, is not designed to carry large volumes of concentrated runoff. Proper grading and drainage to avoid the concentration of flow over the jute matting is therefore important.

Advantages and Disadvantages. Advantages associated with vegetative cover include:

- Permanent means of controlling erosion and runoff.
- Improved aesthetics.

Disadvantages associated with vegetative cover include:

- Periodic maintenance and revegetation.
- Increased infiltration, which is partially offset by transpiration from vegetation.

Fugitive Dust Control

Fugitive dust at utility land disposal sites generally originates either from fly ash or from exposed soil on the site or along haul roads. Fly ash dust may originate at the disposal site, or from spillate during hauling. Fugitive dust migration is more severe during dry and/or windy periods. Since many utility landfills are not compacted and covered after each period of ash placement, they are susceptible to wind erosion; disturbed, unprotected soil around ponds and landfill may also be subject to wind erosion.

The most effective method of controlling road dust is to pave the road or provide it with an all weather surface such as crushed stone or gravel. Sporadic dust problems on dirt roads can be improved by oiling or watering the road, or by applying chemical additives such as calcium chloride. The use of oil or chemical additives on roads for dust control may not be permitted in some areas due to their potential for damaging vegetation and polluting surface and groundwaters. Local and state ordinances should be reviewed prior to the use of oil or other chemicals for dust control. The techniques applied to road surfaces are also applicable to traffic-bearing areas of the disposal site.

In general, wind erosion of in-place fly ash can be controlled by proper site grading and surface cover, and prompt revegetation. In windy areas, or during windy periods, dry sites may need additional protection. Wind protection can be provided by many methods, including:

- Placement of cover.
- Use of sprayed emulsions and sealants.
- Moistening the waste surface by spraying or sprinkling it with water.
- Construction of earthen wind breaks.

- Planting of trees or brushes to serve as wind breaks.
- Suspension of waste placement during particularly windy periods.

The control of fugitive dust at land disposal sites will require an ongoing effort during the operation of the site. Complete control of dust is probably impossible during operation of a site. However, the implementation of practical considerations will minimize fugitive dust at and around a site, correct existing problems, and minimize future problems.

Equipment Requirements for Surficial Corrective Action Techniques

Many of the surficial corrective action techniques applicable to utility land disposal sites involve the excavation, hauling, placement, and compaction of natural soil materials. There is considerable overlap between the type of equipment that is commonly used at disposal sites and that required to implement many of the corrective action techniques.

The equipment types used to construct graded slopes consist of both standard and specialized vehicles. Excavation, hauling, spreading, and compaction of soil materials are the major elements of a complete grading operation. Grading vehicles include crawler dozers and loaders, rubber-tired dozers and loaders, landfill compactors, and scrapers. Due to their high flotation crawler machines are generally used for excavation and grading of waste and earth. Rubber-tired dozers cannot grade waste that is spongy and/or rough. Because of its high operating speed, a rubber-tired loader is effective when used to stockpile cover material or to load it into haul trucks. Landfill compactors are usually equipped with rubber tires sheathed in steel or hollow steel cores. Steel wheeled machines impart greater compaction than do rubber-tired or crawler machines. A steel-wheeled compactor is excellent for spreading and cmpacting on flat or level surfaces and operates fairly well on moderate slopes, but lacks traction on steep slopes. Scrapers are rubber-tired machines and should only be used for excavation, hauling, and spreading of cover material.

The earthwork capabilities of landfill equipment is summarized on Table 6-7.

SUBSURFACE CORRECTIVE ACTION TECHNIQUES

Two types of contamination may occur in the subsurface: the contamination of dry soil materials, and the contamination of both groundwater and the soil materials

Table 6-7

EARTH MATERIAL HANDLING CHARACTERISTICS OF LANDFILL EQUIPMENT

	Rating*			
Equipment	Excavating	Spreading	Compacting	Hauling
Crawler dozer	E	E	G	NA
Crawler loader	E	G	G	NA
Rubber-tired dozer	F	G	G	NA
Rubber-tired loader	F	G	G	NA
Landfill compactor	P	G	E	NA
Scraper	G	E	NA	E

* Rating: E, excellent; G, good; F, fair; P, poor; NA, not applicable.

Source: D. R. Brunner, and D. J. Keller. Sanitary Landfill Design and Operation. Washington, D.C.: U.S. Environmental Protection Agency, 1972. SW-65 ts.

through which the contaminated water flows. The potential for both types of contamination exist during the entire range of utility waste generation and management operations.

The contamination of dry soil does not necessarily pose an immediate environmental threat, depending upon the characteristics of the waste material. In most common situations arising from the spillage or leakage of utility wastes, the contaminated soil zone represents a potential groundwater or surface water pollution problem. Even slurries, sludges, and other fluid materials will usually penetrate only a short distance downward, unless infiltration or relatively large quantities of fluid are available. In this latter case, the waste constituents may penetrate the groundwater. Runoff across a contaminated soil zone or erosion in such an area can pollute surface waters. The methods of correcting a contaminated soil problem are usually straightforward (depending of course on site-specific considerations) and include:

- The excavation of the waste and/or soil materials, and their removal to a secure environment (i.e., a landfill), provided that the contaminated zone is not so extensive that such a response is not practical.
- The implementation of the types of surficial corrective action techniques previously discussed (i.e., stabilize the contaminated soil zone by protecting it from infiltration and erosion, to prevent migration of the contaminents).

Any time that both soil and groundwater are contaminated, the problem becomes much more complex. The groundwater flow system is dynamic; flow from areas of recharge to areas of discharge is continually occuring. Thus, when the groundwater becomes contaminated, the contamination will migrate. It is important to recognize whether the contamination is caused by infiltration through the waste material or actual groundwater flow through the disposal site. The creation of a groundwater mound is likely in either event but the effectiveness of surficial corrective action may differ markedly for these two cases (see Figure 6-8). The groundwater flow pattern is usually the primary factor involved in the development of a plume of leachate-contaminated groundwater. Other factors, however, may be significant. These include molecular diffusion and migration of contaminants along density or thermal gradients. Attenuation of the groundwater contaminants by cation exchange and the adsorption of contaminants by soil particles, or chemical interaction with the soil mass may occur. The effectiveness of the attenuation processes is, however, site specific and many potential contaminants are not effectively attenuated and do not exhibit pronounced attenuation.

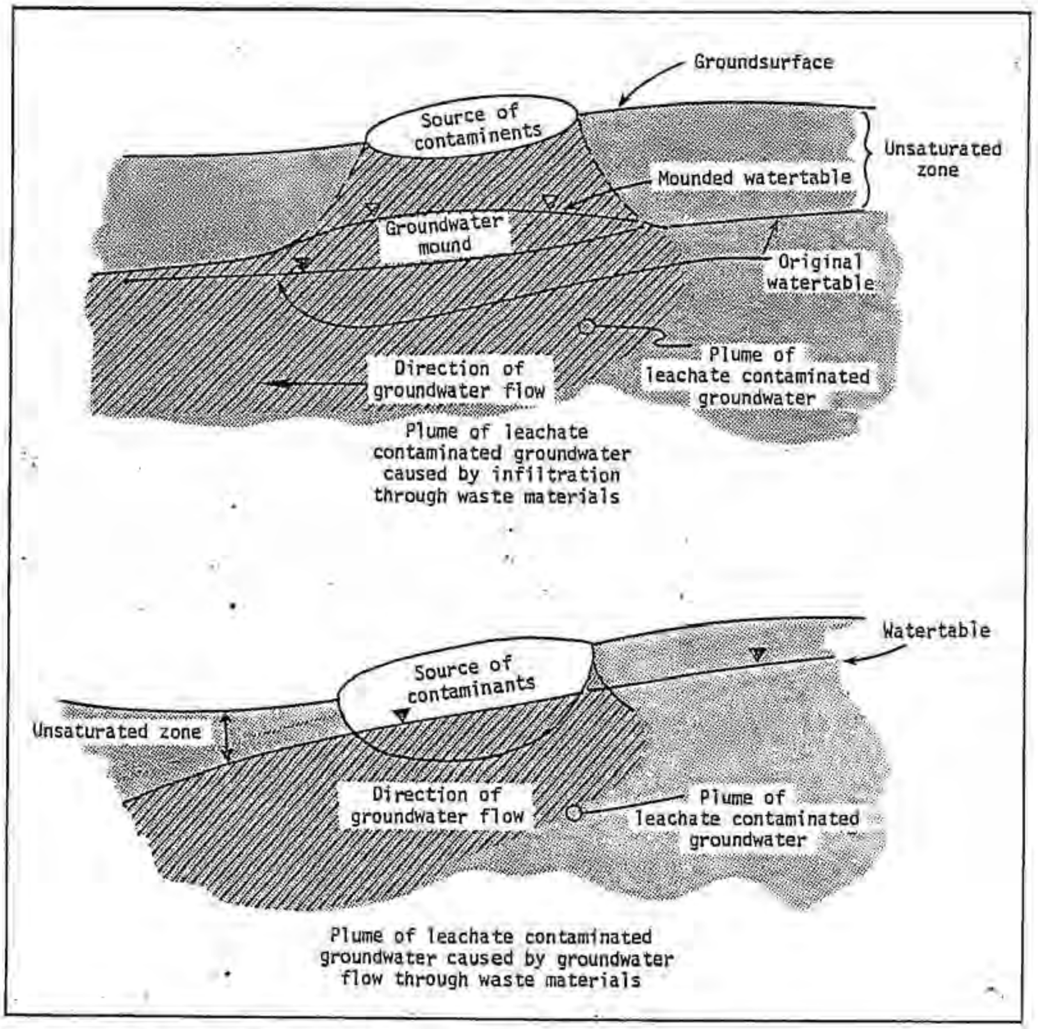

Figure 6-8. Development of contaminant plumes .

Thus, it is apparent that when the subsurface soils and the groundwater are both contaminated, a corrective action plan must involve:

- Techniques which prevent additional migration of contaminants into the groundwater.
- Techniques which isolate, remove, or minimize the impact of the contamination plume.

In most groundwater contamination cases, surficial corrective actions will be necessary regardless of the subsurface corrective action requirements because:

- The practical subsurface corrective action techniques are relatively limited in application and are only capable of providing for:

  --Isolation of the waste material from the groundwater

  --Removal of contaminated groundwater

  --Some modification of groundwater flow patterns.

- The effectiveness of subsurface corrective action is subject to considerable uncertainty due to the complexity of the subsurface environment.
- The effectiveness of the available subsurface techniques will usually be highly dependent upon the positive influence of surficial corrective action techniques in reducing infiltration, eliminating recharge and preventing the generation of additional leachate.

As listed above, the practical subsurface corrective action techniques can isolate the contaminent source, effect the removal of contaminated groundwater and modify groundwater flow patterns. These effects are achieved by modifying the subsurface to either enhance or prevent the flow of water in a particular manner. Potentially suitable techniques include:

- Gravity drains.
- Groundwater collection structures that require pumping.

  --Sumps

  --Wells

  --Vacuum wellpoint systems.

- Impervious barriers

  --Slurry trench cutoff walls

  --Grout curtains

  --Sheet piling cutoff walls.

The technical feasibility and effort required to implement any of these techniques is dependant upon site-specific conditions and problems. Often, when subsurface corrective action is necessary, it is impractical or impossible to optimize the use of these techniques because of previous site development. It is critical to carefully evaluate the water balance for a disposal site early in the planning process. A site-specific water balance or budget is a powerful planning tool, and its continual refinement is necessary throughout the design and implementation of a corrective action plan that involves the potential for subsurface corrective action. A conceptual water balance for a landfill is shown on Figure 6-9.

Gravity Drains

Drains can be used to modify groundwater flow patterns, lower the water table and intercept seepage. A properly designed drain must meet the following criteria:

- It must be pervious enough to allow seepage to enter it freely.
- It must be constructed in a manner that prevents subsurface erosion (piping) of the material being drained and subsequent clogging of the drain.
- It must drain freely to a location where the water it collects can be discharged without causing problems.

The last criterion is dependent upon site specific topographic and subsurface conditions, as well as the nature of the seepage being collected. If a drain is intercepting leachate contaminated groundwater, it may be necessary to provide treatment prior to discharging the collected water. The first two criteria, although site-specific, are satisfied by application of certain relatively standardized techniques. The permeability requirement is absolute, since a drain must be considerably more pervious than the surrounding material from which it collects seepage to serve any useful purpose.

If only small quantities of seepage are to be collected, drains comprised entirely of well graded granular material (French drains) may suffice (see Figure 6-10). However, single element drains of this nature cannot effectively handle substantial quantities of inflow or high seepage velocities, as they will rapidly become clogged.

If large quantites of seepage are anticipated, a graded filter must be constructed around a pervious conduit (see Figure 6-10). Graded filters consist of one or more zones of aggregate or granular material which become increasingly permeable (coarse) towards a central, very permeable conduit. The conduit may be a zone of very pervious aggregate, or it may be a perforated pipe. The granular materials comprising

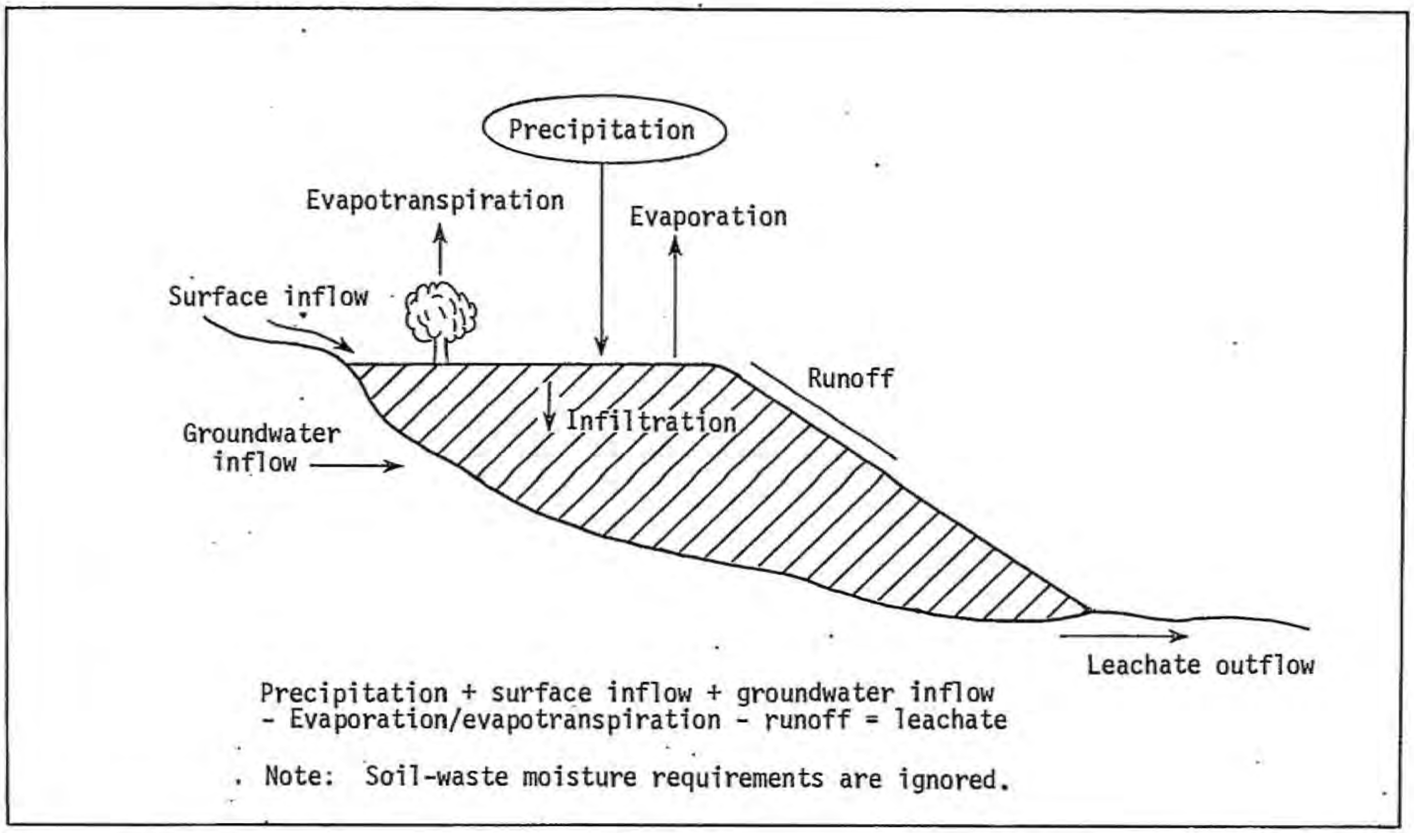

Figure 6-9. Conceptual water balance for landfill.

Source: Adapted from R.G. Knight, et al., FGD Sludge Disposal Manual, Second Edition, Palo Alto, California: Electric Power Research Institute, September 1980. CS-1515.

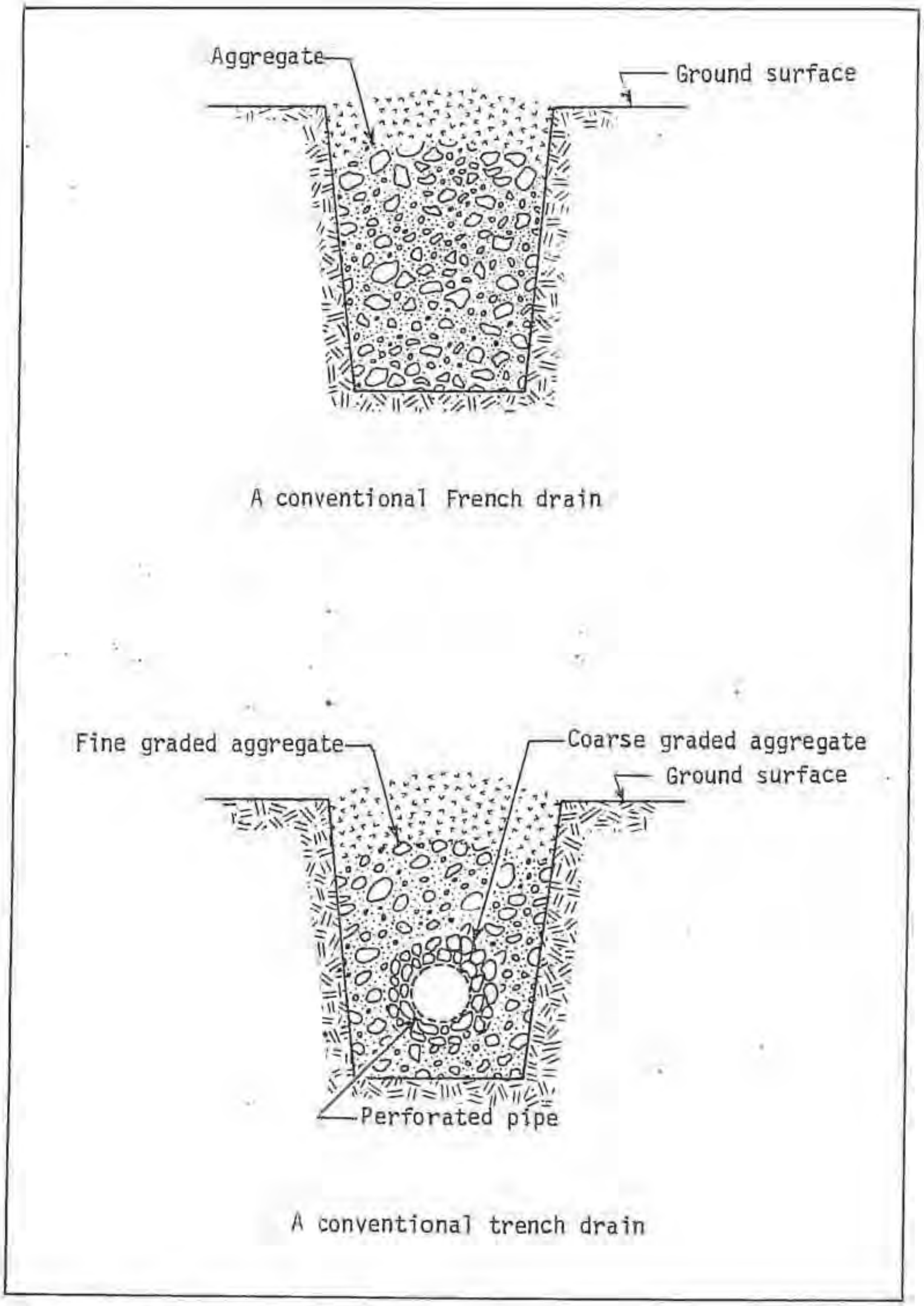

Figure 6-10. Gravity drains.

a graded filter are selected on the basis of the texture of the soil they protect, and are sized to prevent the movement of the finer filter materials into coarser as well as the movement of the coarser materials into the conduit. Graded filters consisting of several zones of aggregate are not uncommon. Synthetic filter fabrics are available and, when properly used may simplify the construction of drains by eliminating the need to construct several zones of filter soil.

Other factors that must be considered during the design of drains are the hydraulic capacity of the conduit which is a function of its size, its composition, and its slope or grade. Cleanouts, pipes extending to the surface that allow surging and flushing of the drain in the event that it becomes clogged, are normally installed at regular intervals to allow maintenance. If surface water runs across the drain trench, it may be advisable to protect the trench from undesirable infiltration of surface water.

The depth at which a drain can feasibly be constructed may be limited by equipment and construction dewatering considerations. It is necessary to excavate a trench the full length and depth of the proposed drain. Hence, it may be a distinct advantage to schedule drain construction in accordance with seasonal water table fluctuations, to reduce the effort associated with construction dewatering.

Relatively shallow drain trenches can be excavated with trenchers or backhoes. Trench stability can be maintained with trench boxes and/or suitable benching or sloping of the sides of the excavation. Deeper trenches can be excavated with draglines and clamshells. These trenches require more elaborate support systems or substantially wider excavations to allow for sloping sides. Trench dewatering can be a simple operation, or it may be a relatively complex endeavor requiring sophisticated equipment. Construction dewatering may be a significant factor in determining the feasibility of constructing drains substantially below the water table.

The potential for using gravity drains as a corrective action measure is strongly influenced by the specific site topography and groundwater flow patterns in the area. However, upgradient and downgradient drains are both common. Lateral drains can be used to advantage at some sites, and drains are often employed to collect leachate both beneath and immediately downgradient of disposal sites. The effective locations and depths of drains must be determined on a site-specific basis.

Although they are a powerful technique for controlling seepage, their application as a corrective action technique is limited by the following considerations:

- The lateral effect of a gravity drain on groundwater level decreases rapidly with distance from the drain; thus to cause a substantial change in water table elevation over a large area, closely spaced or impractically deep drains may be required.
- The excavation of trenches substantially below the water table may be difficult and require sophisticated equipment.
- Previous site development may limit the areas where drains can be installed.
- Excavation support or side sloping requirements for deep trench excavations limit the practical depth to which drains can be installed.

Gravity drains are most effective for collecting shallow seepage, and are generally used most advantageously during corrective action for the following applications:

- The collection of leachate contaminated groundwater beneath and in the immediate vicinity of disposal sites.
- The interception of groundwater upgradient from disposal sites.
- The redistribution of groundwater and groundwater recharge to effect changes in the groundwater flow patterns and levels.

Groundwater Collection Structures that Require Pumping

Groundwater depth and flow patterns can be significantly altered by groundwater pumping. This is due primarily to the substantial hydraulic gradient differential that it can create. Groundwater pumping techniques which are potentially useful for corrective action at utility disposal sites include:

- Sumping gravity drains.
- Well extraction and/or injection.
- Vacuum well point systems.

Sumps. Sumps are openings in the ground from which water is pumped. For corrective action, their primary utility is as an outlet for gravity drains when space or grade limitations preclude surface discharge. Alternatively, sumps can be used to dewater excavations. A permanent installation normally consists of a watertight drop manhole or wetwell to receive and store discharge from gravity drains for intermittent or continuous pumping. The type of pump used would be dependant up the lift and discharge requirements as determined by the sump's location relative to the discharge destination.

Wells. Basically, wells are deep openings in the earth from which water can be extracted by pumping. Wells can be effective in creating substantial, temporary changes in groundwater levels and flow patterns. They can be used effectively for several purposes pertinent to corrective action, including:

- Temporary reversal of hydraulic gradients.
- Dewatering (groundwater lowering) for construction or other purposes.
- Collection of leachate contaminated groundwater for treatment.

Wells can be designed to function effectively in most subsurface materials, except those of very low permeability. Wells can be driven or drilled, and equipment for their installation is generally available locally.

In consolidated materials, the well opening may not require any support to prevent its collapse; in unconsolidated materials, casing will be required for support. Water entering a well under the influence of pumping is moving at a high velocity relative to most groundwater flow situations. Thus, in unconsolidated or poorly consolidated materials, it is necessary to both support and protect the well without restricting inflow. This problem is also common to gravity drains and in practice is handled in a similar fashion. The portion of the well that water enters is supported by a perforated pipe or screen. The screen may be surrounded by a graded filter comprised of aggregate, or its openings may be sized to control subsurface erosion. In the latter case, the openings should be large enough to permit some of the surrounding subsurface material to enter the well. Prior to actual use of the well, it is "developed," the material surrounding it is intentionally eroded and a natural graded filter is thus created. Wells provided with an aggregate filter are called "gravel packs" and may also require development. A typical gravel pack well is shown on Figure 6-11. It is important to properly develop wells to protect the pumping system from being damaged by sand entering the well and to improve their hydraulic characteristics. Many types of pumps can be used in wells, including: submersible pumps, jet pumps, and turbines driven by shafts extending from a motor located above the ground.

The depth of a well is limited primarily by the subsurface materials. Generally they can be constructed to fully penetrate the groundwater bearing zone. The hydraulic characteristics of a well are controlled by the wells depth and diameter, and by the properties of the subsurface, particularly permeability, uniformity, and saturated thickness. "Drawdown" refers to the change in water level elevation

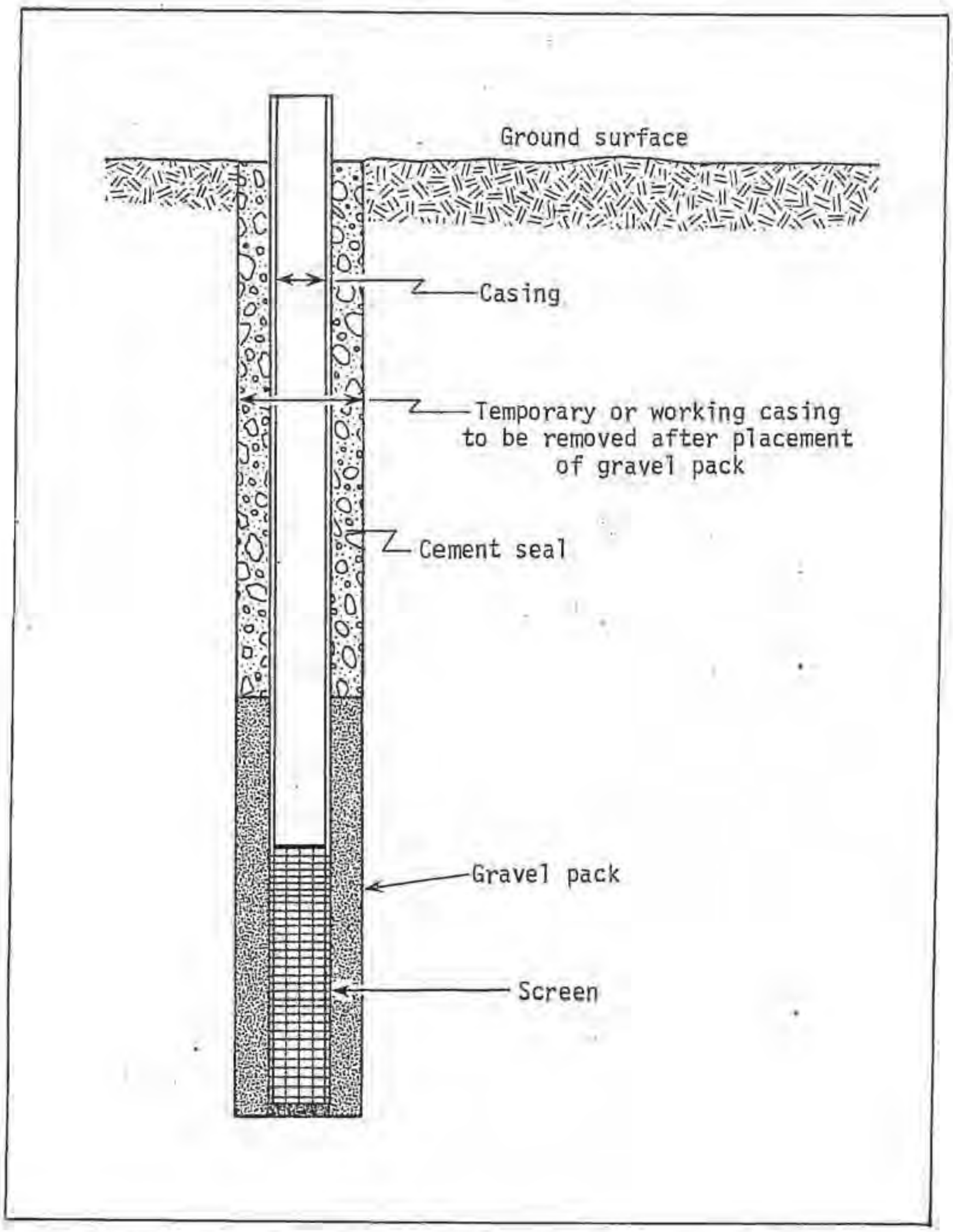

Figure 6-11. Schematic portrayal of typical gravel pack well.

caused by the pumping of a well. The "cone of influence" (or "cone of depression") refers to that area around a well where drawdown occurs.

Under ideal conditions (i.e., a uniform subsurface), the cone of influence will be circular in plan view and cone shaped in a vertical section. The effect of well pumping on water table and confined aquifers is shown on Figure 6-12. The cone of influence will continue to enlarge as long as the well is pumped. The magnitude of drawdown at the well is dependent on well depth and the pumping system, and can easily be manipulated. The cone of influence, however, is dependent upon pumping rate, duration of pumping, and the characteristics of the subsurface environment, particularly permeability. Seldom will a cone of influence actually be circular in the plan view; usually it will be oval, elongated, or irregular in shape due to distortions caused by variations in the subsurface conditions (see Figure 6-13). The magnitude and extent of a cone of drawdown is a function of permeability, if all other factors are considered constant (see Figure 6-14).

Pervious materials will, in general, exhibit an extensive, flat cone of influence in response to pumping of a well; while less pervious materials will exhibit a deeper, steeper, less extensive cone of influence.

The normal practices utilized for production well design are not necessarily applicable to corrective action situations. Proper design criteria for corrective action wells must be determined on a site-specific basis. The influence of several wells acting in unison can be used to substantially modify groundwater flow pattern and levels. The proper spacing must be determined on a site-specific basis.

Well technology not only allows groundwater level and flow pattern manipulation by groundwater table depression; it can be used to raise groundwater levels for the same purpose. When groundwater is injected into the groundwater system, a "mound" of water is created around the well. This mound of water around an injection well is called the "cone of impression." Groundwater "mounding" can be used to create subsurface hydraulic barriers and reverse flow patterns.

Vacuum Extraction. A vacuum system consists of a number of relatively shallow, small diameter wells connected by a common manifold, or headerline, to a vacuum pump. Small wells of this nature are usually called "well points" and are installed by being driven, inserted into drilled holes, or jetted into place. The major limitation of a vacuum system is its maximum lift capacity; theoretically slightly more

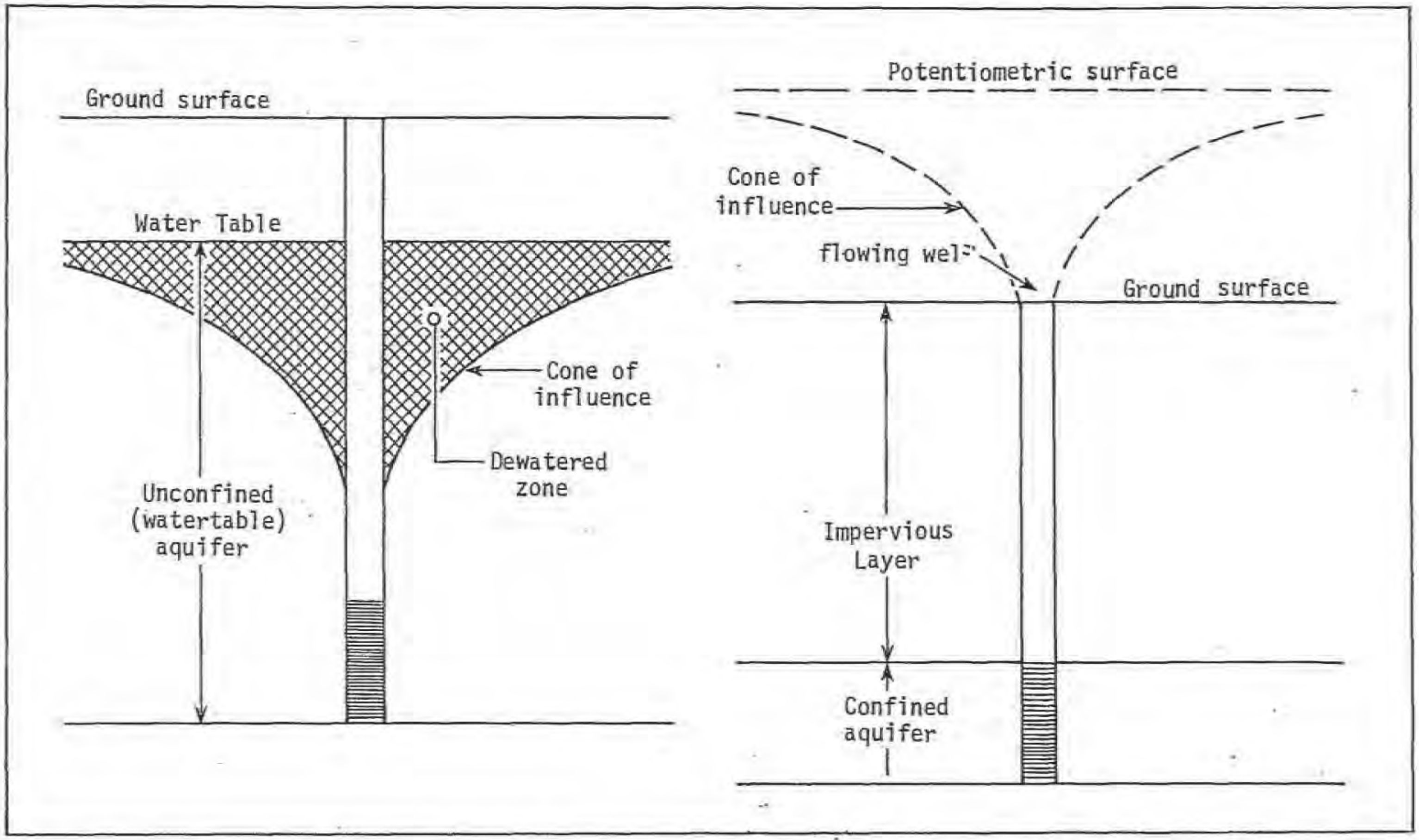

Figure 6-12. Comparison of the effect of wells on confined and unconfined aquifers (note: the potentiometric surface need not extend above the ground surface, only above the bottom of the impervious layer).

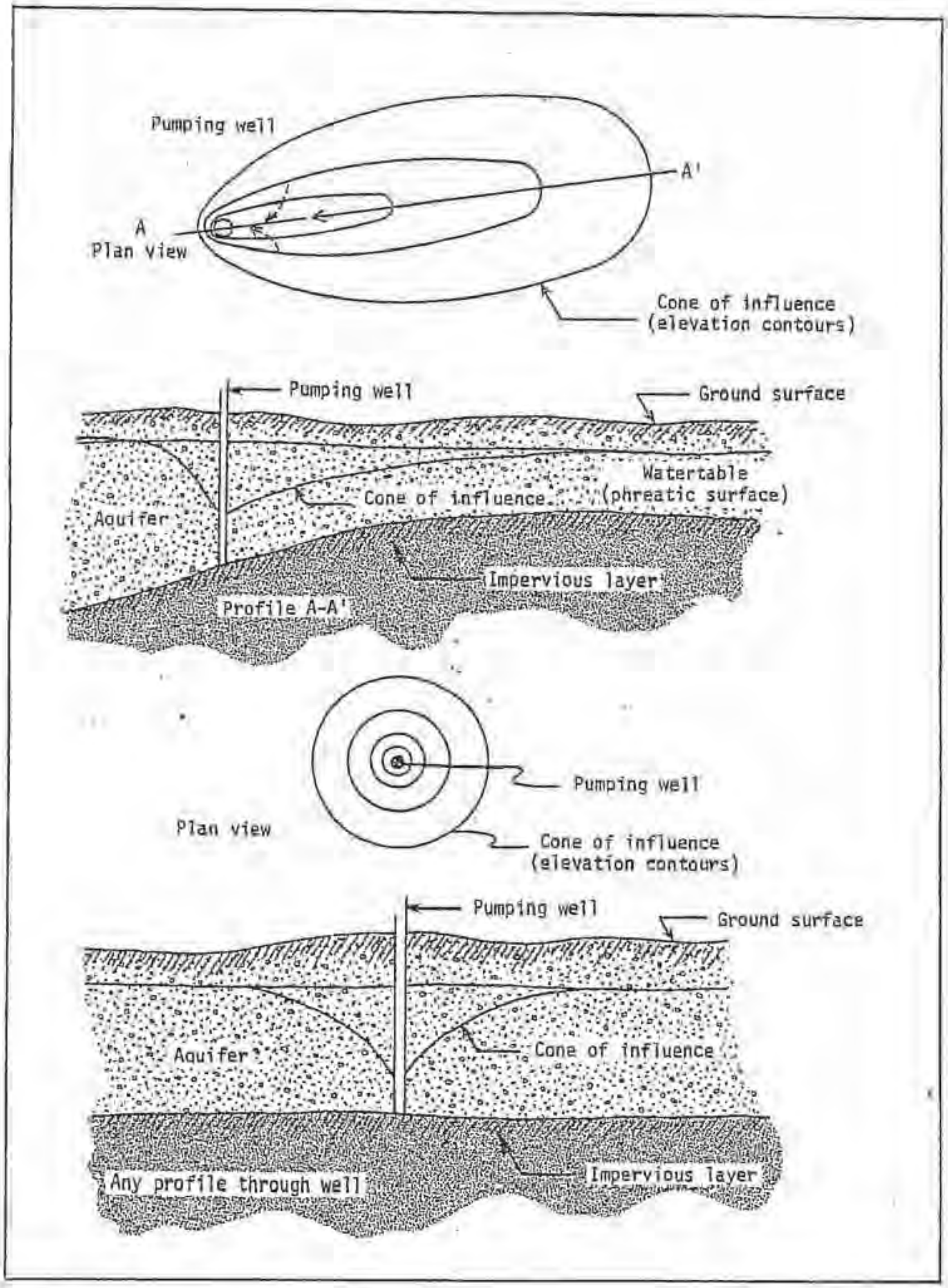

Figure 6-13. Comparison of cone of influence in a water table aquifer of variable thickness to the cone of influence in a uniform water table aquifer.

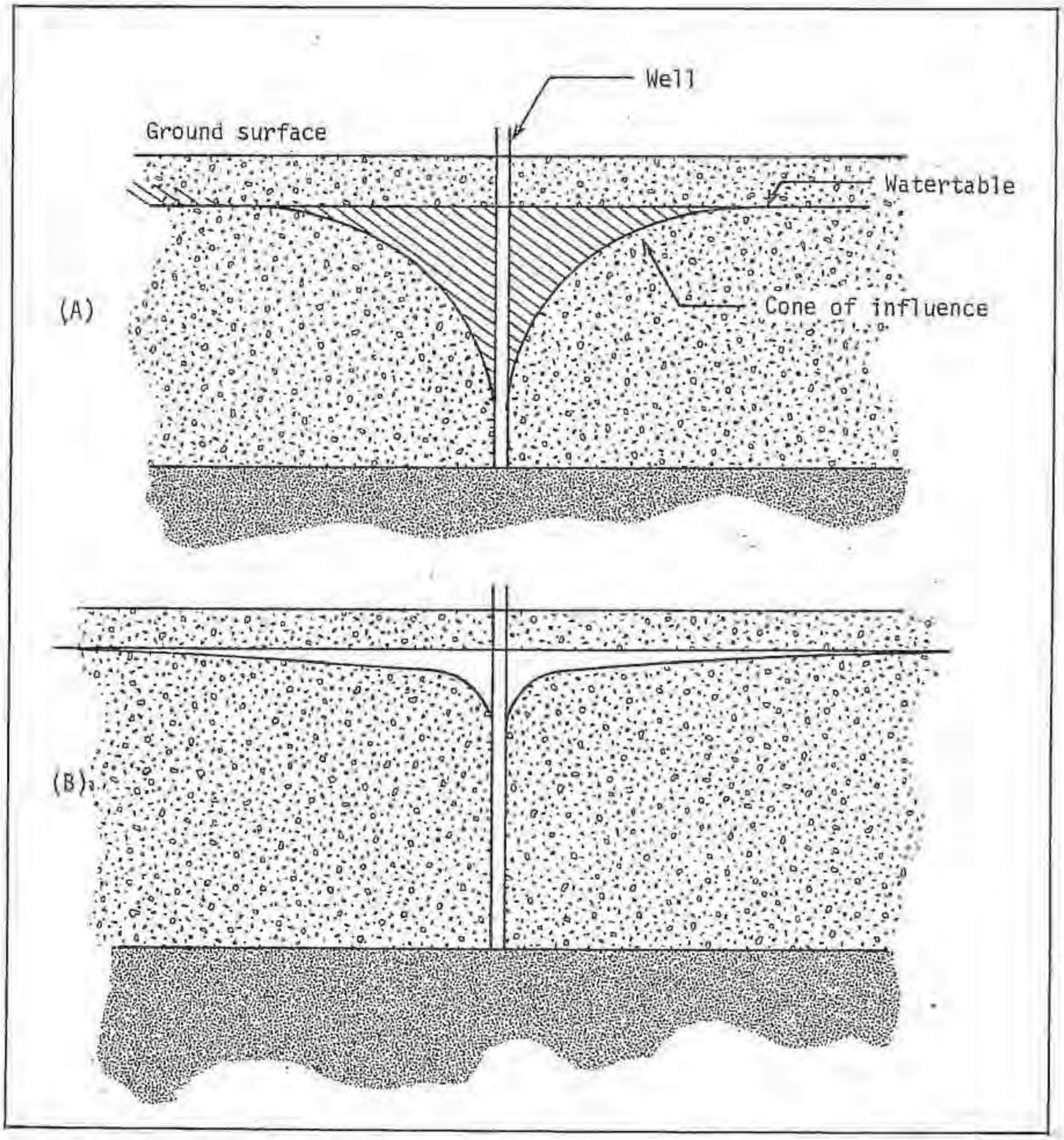

Figure 6-14. Changes in the cone of influence (draw down and radius) caused by permeability differential; permeability of aquifer A is 10 times permeability of aquifer B. (Source: Groundwater and Wells. St. Paul, Minnesota: Johnson Division, Universal Oil Products Co., 1974, p. 100).

than 30 ft, it is somewhat less. The design basis for a well point system is essentially the same as for wells.

Although vacuum well point systems can be installed by some well drillers or test boring firms, a number of speciality contractors are available throughout the United States for the installation of extensive or complicated systems. A wide range of commercially available well points are available for different subsurface conditions and applications.

The uses of vacuum well point systems for corrective action are similar to those of wells. They are particularly useful in shallow surficial aquifers and in areas where large quantities of water must be collected in relatively restricted areas. They are often used for dewatering excavations or where the effective radius of influence of larger wells would require close spacing or many installations.

Summary. Subsurface groundwater control drains and pumped systems are a powerful means of effecting changes in groundwater levels and flow patterns. With adequate subsurface information, normally derived from subsurface investigations and pump testing, they can be designed to accomodate a wide variety of situations. Further, their effects on the groundwater system are reasonably controllable and predictable. Groundwater gradients and levels can be altered by pumping water out of or injecting water into the subsurface environment.

The use of groundwater pumping techniques as a corrective action must be carefully cosidered because:

- The installation of dewatering or injection equipment is relatively costly.
- Pumps and piping systems must be maintained on a regular basis.
- Power requirements for pumping can be substantial.
- Once water is removed from the ground it must be disposed of properly and, if contaminated by leachate, treatment prior to disposal may be necessary.
- Large scale dewatering can affect the stability of nearby structures.
- Substantial changes in the groundwater level and flow patterns may adversely affect vegetation, springs and stream flow, and potentially water supplies.
- The long term management of groundwater pumping systems will involve continued professional review and monitoring.

Pumping techniques for corrective action are most feasible as temporary or interim measures. Appropriate uses include:

- The extraction of leachate plumes for treatment.
- The temporary dewatering of areas for construction purposes.
- The temporaty modification of groundwater levels to permit other corrective action techniques to be implemented.

Impervious Barriers.

Impervious barriers are used to isolate portions of the subsurface environment from the groundwater flow system. they include:

- Grout curtain briers.
- Slurry trench cutoff wells.
- Sheet piling cutoff walls.

The installation of grout curtains is accomplished by the injection of materials into the subsurface to reduce its permeability. Grout materials include:

- Portland cement.
- Bentonite.
- Chemical grouts of widely varying compositions and properties.

Cement grouts are strong, and can be designed to resist chemical deterioration in many cases. Generally, cement grouts are more economical than chemical grouts although their useful range of application may be more limited. the mix ratio of cement to water controls the viscosity of the grout. Admixtures and fillers, such as bentonite, chemicals to hasten or delay setting, and materials to reduce shrinkage of the grout as it sets, can be used to vary the properties of the grout.

Chemical grouts consist of a mixture of solution of chemicals (e.g., sodium silicates and acrylamides) that, subsequent to their injection, react to form a precipitate or gel. Although chemical grouts are more flexible in their application than cement grouts, they are usually more costly on a unit basis. their viscosities are lower than those of cements and their set times are more controllable. They are injected as both one- and two-part solutions. Two-part solutions are mixed as they are injected; one-part solutions are premixed. Their resistance to dessication damage and potential for contaminating the groundwater vary. Some mixtures are not suitable for use near water supplies. Grout curtain design is a sophisticated process requiring substantial subsurface information, considerable expertise, and probably grout injection testing at the site. Grout placement is difficult to predict and control, thus experienced operators and post injection testing are necessary.

The grout materials, and the properties and uniformity of the subsurface are critical factors in grout curtain installation. These factors determine:

- Grouting feasibility and procedures.
- Location, spacing, and arrangement of injection holes.
- Testing and regrouting requirements.

The installation of a slurry trench cutoff wall is a particularly simple method of constructing an impervious barrier, and applicable to a variety of subsurface conditions. Basically, a slurry trench is a narrow excavation filled with a mixture of bentonite slurry and the material excavated from the trench. The bentonite slurry is added to the trench as the trench is excavated and provides support to the trench walls; elaborate support for the excavation is, therefore, not necessary. Additionally, the trench can be kept very narrow, relative to conventional trench excavation requirements. Thus, excavation depth, is not as significant a factor as it is with drain installations. Excavation below the water table presents no unusual problems and dewatering is not required. Compaction of soil/bentonite slurry is not necessary, but thorough mixing of the bentonite and soil is required. Backhoes, clamshells, and draglines are all suitable for slurry trench construction.

The bentonite and fine soil particles fill the voids between the larger particles and cake the sides of the trench, forming a highly impervious barrier. Slurry trenches are succeptible to damage from dessication. Subsurface meterials requirements are minimal, but the soil mixed with the slurry should contain appreciable quantities of fine soil particles. Fine grained soil can be imported if not available on site.

Impervious cutoff walls comprised of sheet piling are used for many purposes. Sheet piling, comprised of concrete with groutable joints or steel with interlocking joints, may be useful for corrective action at utility disposal sites. The use of sheet piling as a temporary impervious barrier is relatively common, as its use for supporting excavations. Sheet piling can be driven in many soil types, but it cannot be driven through soil with numerous cobbles or boulders with the expectation that it will remain undamaged. Under the best of circumstances, it is difficult to confirm the integrity of a sheet piling barrier. As a corrective action technique, the use of sheet piling may serve for shallow groundwater barriers, or if only partial isolation of a site is necessary.

The applicability of impervious barriers is, to a large degree, dependent upon the site's subsurface conditions. Such structures are truly effective, in the long term, only when they fully penetrate the aquifer and encounter an impervious substratum. to provide a three-demensional barrier. It is possible to install a horizontal grout curtain to prevent vertical seepage, if the subsoils are groutable and this level of effort is warranted.

The applicability of the three impervious barrier techniques to a corrective action program varies considerably. Generally, slurry trenches are considered the most useful, followed closely by grout curtains. The use of sheeting is probably quite limited in corrective action applications. A properly planned and constructed impermeable barrier can effectively isolate a land disposal site from the groundwater flow system. However, impermeable barriers that only partially isolate a site are of questionable value in a corrective action program. Groundwater flow is significant but not the sole factor to be considered in the subsurface transport of contaminants. Molecular diffusion, thermal convection, density differentials and other factors cause the movement of contaminants in groundwater. At relatively low seepage velocities, these other factors may dominate groundwater contaminant transport.

Finally, if a site is fully isolated from the groundwater system, the act of isolation will cause a concentration or buildup of leachate within the isolated zone. If water continues to penetrate the disposal site, the barriers may be overtopped. Thus, effective surficial corrective actions and proper management of the disposal site is critical if impervious barriers are employed as part of a corrective action plan.

SELECTION OF A CORRECTIVE ACTION PLAN

As discussed earlier, corrective action techniques range from straightforward construction practices to complex procedures requiring specialized equipment and considerable expertise. The effects of many of these techniques are interrelated, potentially duplicative and are dependant upon site specific conditions.

There is no standard procedure for assessing the suitability of these techniques on a site-specific basis. The selection process can, however, be approached in a logical, organized fashion. The initial steps involve assessment of the existing situation and delineation of the available alternatives. One alternative always exists: to close the existing site and develop a new one. One of the first comparisons to be made therefore, is that between the costs and benefits of continued site use, and the costs and benefits of developing and operating a new site. Once the economic comparison has been made, social and political factors must be considered. This first comparison will determine a baseline level of effort warranted to provide corrective action for continued use of a site. The ultimate site closure requirements must be a factor in this analysis; they will apply to either option, but may vary considerably depending on whether or not corrective action is implemented.

Once the initial decision has been made to design and implement corrective action rather than develop a new site, a plan must be selected which meets the site requirements and fits, at least initially, within the established level of effort for corrective action. At each step of selecting and designing a corrective action plan, the choice to close the existing site and develop a new one always remains an option.

It will be useful early in the selection process to assemble and carefully review the available information about the site to help identify existing and potential environmental problems, and to locate significant data gaps that may exist. Such information may include:

- Construction records for the disposal facility and/or power plant.
- Subsurface information.
- Technical reports/design plans of the disposal facility.
- Monitoring records.
- Period of use, quantity of wastes.
- Site plans, particularly predevelopment topographic maps.
- Characteristics of the waste material.
- Published geologic, pedologic, and hydrologic information.

Another factor which should be assessed early in the planning of a correction action plan, is whether or not groundwater contamination or its potential exists at a site. Groundwater monitoring is the only way to make such a determination. However, review of available information about a site is a valuable means of gaining insight into its existing and potential problems.

Assuming that groundwater contamination is not a present or potential problem, the development of a corrective action plan begins with a straightforward evaluation of the feasibility of each of the possible surficial corrective action techniques described earlier. A team of professional civil and soils engineers and hydrologists can then readily develop a site-specific corrective action plan to address, as warranted:

- Site grading requirements:
  - --Surface water controls.
  - --Erosion controls.
  - --Run-on.
  - --Siltation.
  - --Surface water contamination.
  - --Surface water infiltration.
- Fugitive dust control.
- Modification of site operational requirements.
- Development of a landfill cover plan.
- Development of a site closure plan.

If the groundwater is contaminated or the potential for groundwater contamination cannot be dismissed (based on groundwater monitoring results), then a different approach is required. First, the presence, extent, and severity of the groundwater problem must be assessed through the installation of a groundwater monitoring system, or by upgrading the existing system. If no problem is found to exist, the use of only surficial techniques is appropriate.

Groundwater contamination can result from:

- The actual flow of groundwater through waste material.
- The flow of surficial infiltration and waste supernate downward through the unsaturated zone to the groundwater.
- The development of a groundwater mound beneath the site that extends upward, into the waste material, due to high localized infiltration/recharge.

In the two latter cases, the implementation of an appropriate surficial corrective action plan will reduce and eventually eliminate the source of groundwater contamination. In the first case, the severity of the problem will determine the effectiveness of surficial corrective action techniques. If their implementation can cause an adequate and permanent reduction in groundwater levels in the vicinity of the site, the source of the problem will eventually be eliminated. If surficial techniques are inadequate, then the implementation of subsurface techniques in addition to surficial techniques will be necessary to isolate the pollution source. In all three cases, the plume of leachate-contaminated groundwater will continue to exist after the contaminant source has been eliminated.

The necessity of either removing or isolating contaminated groundwater is determined by the severity and extent of the problem. The subsurface corrective action techniques described earlier are considerably more effective in isolating the contamination source or removiang relatively localized contaminant plumes than in correcting a widespread problem.

Surficial techniques will always comprise an important aspect of corrective action plans, because:

- Their effects are considerably more reliable and verifiable than subsurface techniques.
- Their implementation will usually be less costly than subsurface techniques.
- They stress prevention, not mitigation.
- The effective implementation of subsurface corrective action techniques is almost always dependant upon the effectiveness of conjunctive surficial corrective action.

Subsurface techniques, particularly properly located and designed drains, sumps, and cutoff walls, can be very effective in preventing groundwater contamination and collection and/or isolating leachate. However, their application as corrective actions may be limited since the effective application of drains and cutoff walls is dependent upon their proper location (a function of the site's subsurface conditions); they may be difficult to install at the necessary locations at a developed site.

Groundwater pumping can be used as a corrective action on a temporary basis and to collect or divert contaminated groundwater; however, its use as a corrective action rather than a remedial action is very limited.

In conclusion, it is imperative to fully evaluate the options available for corrective action at a particular site, to fully recognize the benefits that corrective action can provide, and to determine if indeed such action is warranted. Common sense, good professional judgment, and carefully executed investigations and testing are all critical in constructing an effective approach to such a potentially complex problem.

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Section 7

CONVERSION OF WET TO DRY DISPOSAL SYSTEMS

There is a trend toward dry disposal systems of utility wastes for both regulatory and economic reasons. Regulatory agencies point to the problem of constant hydraulic head in ponds driving leachate into the underlying soils and groundwater. Utilities see a substantial reduction in land costs associated with dry disposal of these wastes. Conversion to dry disposal can therefore be considered upgrading of a site.

Conversion from wet to dry disposal constitutes two separate concepts: treatment of wastes already ponded to produce a material for landfilling, and subsequent conversion of the waste generation process to one which will generate a dry material. While the former concept involves landfill modification and the latter a process modification, both concepts involve many of the same treatment and conversion steps. As such, they are both presented in this section to avoid redundancy.

PROCESS CONVERSIONS FOR DRY WASTE GENERATION

Conversion of a waste slurry/sludge, at the point of its generation, to a waste that can be disposed of by conventional dry techniques, can be accomplished in several ways, depending on the type of waste and the nature of the generation process (scrubber versus electrostatic precipitator, etc.). Most conversions will involve the addition of some steps for solids concentration or treatment at the end of the existing process. This additional processing will generate a product which may be suitable for sale and/or reuse, an option which is discussed in detail in Section 10.

An inventory of the most applicable alternatives for in-plant conversion from wet to dry disposal is presented in Table 7-1. A summary of advantages and disadvantages of each process is also presented. Details of conveyance, transportation, and storage procedures associated with these alternatives are presented in Section 10 of this report.

Table 7-1

PROCESSES FOR CONVERSION OF WET WASTE TO DRY WASTE: ADVANTAGES AND DISADVANTAGES

Process	Advantages	Disadvantages
(1) Primary Dewatering	In combination with secondary dewatering, provides less expensive ways to dewater. Thickener underflow, as a feed to secondary dewatering, may be better suited to mechanical dewatering equipment than FGD slurry.* Lower capital and O&M cost than secondary dewatering.	Primary dewatering underflow contains only 15 to 30% solids. Thickener/clarifiers usually must be close to scrubbers. Results in wet disposal methods. Generally requires leachate control. Fly ash slurry settles extremely slowly. Large area required for ash settling ponds. Higher transportation costs than for Case 2. Higher disposal costs than for Case 2.
(2) Secondary (Mechanical) Dewatering	End product contains 55-65% solids. Lower transportation costs than for wet sludges. Lower disposal costs than for Case 1. Resulting solids can be landfilled by conventional dry techniques. Does not require special concern for climatic factors.	Increased power requirements. Increased maintenance requirements. Transportation costs may offset dewatering costs. Usually must be close to scrubbers. Redundant equipment usually needed. More sensitive to waste variability than drying beds.
(3) Drying Beds	When land is readily available, this method presents the lowest capital cost. Small amount of operator attention and skill is required. Low energy consumption. for Less sensitive to waste variability	Lack of rational engineering design approach allowing sound engineering economic analysis. Requires more land than mechanical dewatering. Must be carefully designed to account climatic effects.

Table 7-1 (continued)

Process	Advantages	Disadvantages
	than secondary dewatering. Can be used not only for dewaterings, but also for waste drying to solids content higher than 80%, thus allowing dry disposal.	May be more visible to the general public than mechanical dewatering. Waste removal usually labor-intensive.
(4) Forced Oxidation	Increased settling and dewatering properties. End product contains 80% solids. End product has low COD. Enhanced structural properties for waste disposal. Lower transportation costs than for Case 2. Lower land requirements than for Case 2. Lower land acquisition costs than for Case 2. Lower disposal costs than for Case 2. End product has commercial value.	High TDS potential in leachate and runoff Lack of experience in United States. Increased power requirements. Increased maintenance requirmenent.
(5) Fly Ash Blending	Materials on site. Dry fly ash can be utilized for sludge processing. Dry fly ash can be used for dewatering bottom ash by blending. End product is dry. Requires less equipment than fixation (Case 6). Requires less manpower than fixation (Case 6). Enhanced waste structural properties over Case 2. Fairly inexpensive.	Leaching characteristics variable.

Table 7-1 (continued)

Process	Advantages	Disadvantages
(6) Fixation	End product is dry (solid). Structural properties of wastes greatly enhanced. Processes are formulated to contain contaminants. Solidified wastes are nontoxic. Leaching greatly reduced. End products have commercial value. Lower disposal costs than for Case 2. End products are easy to handle.	Only proprietary processes available. Expensive†. More personnel and equipment needed than for Cases 1 through 5. Higher maintenance requirements than for Cases 1 through 5.

* FGD slurry: 5-15% solids.
† Disposal costs for processing where leachate is a problem may offset costs of fixation.

In the discussion that follows, the appropriate unit processes for conversion of FGD sludge and wet ashes to dry products are presented. Conversion costs are presented in Section 11. Note that these processes begin at the current point of wet waste generation, and do not apply to modification of the existing generation system (e.g., conversion of wet FGD to spray drying, etc.).

FGD Sludge

The typical solids content of FGD sludge directly from the scrubber ranges from 5 to 15%. To facilitate dry disposal of these wastes, a much higher solids content must be achieved. There are five possible in-plant scenarios for converting wet disposal of FGD sludges to a dry material (Figure 7-1):

- Primary/secondary dewatering.
- Drying beds.
- Forced oxidation.
- Blending.
- Fixation.

Primary/Secondary Dewatering. The suitability of sludges to be dewatered is a function of size, distribution, and crystalline structure of the sludge particles. In sulfite-rich sludges, the microstructure is comprised of small platelets and platelet fragments, which tend to slow the settling rate. Upon settling, greater amounts of liquid are trapped in these sludges due to their particle structure. However, sludges rich in sulfate can usually achieve a higher solids content than sulfite-rich sludges.

In this alternative, scrubber sludge is thickened to an average of about 15 to 30% solids, and then mechanically dewatered to about 65% solids for a limestone FGD system, or to 55% for a lime or dual-alkali system (1). Filtrate is returned to the FGD system, and the filter cake is transported to a landfill or placed in storage without additional treatment (Figure 7-2) (2).

Primary dewatering usually occurs in a clarifier or thickener. The clarifier is a large sedimentation vessel designed to remove all settleable suspended matter. Flocculant addition coupled with gentle stirring helps to improve the efficiency of this settling process. Weirs and flow wells provide proper flow distribution at the inlet and outlet of the clarifier. Bottom rakes continuously move solids to the sludge hopper.

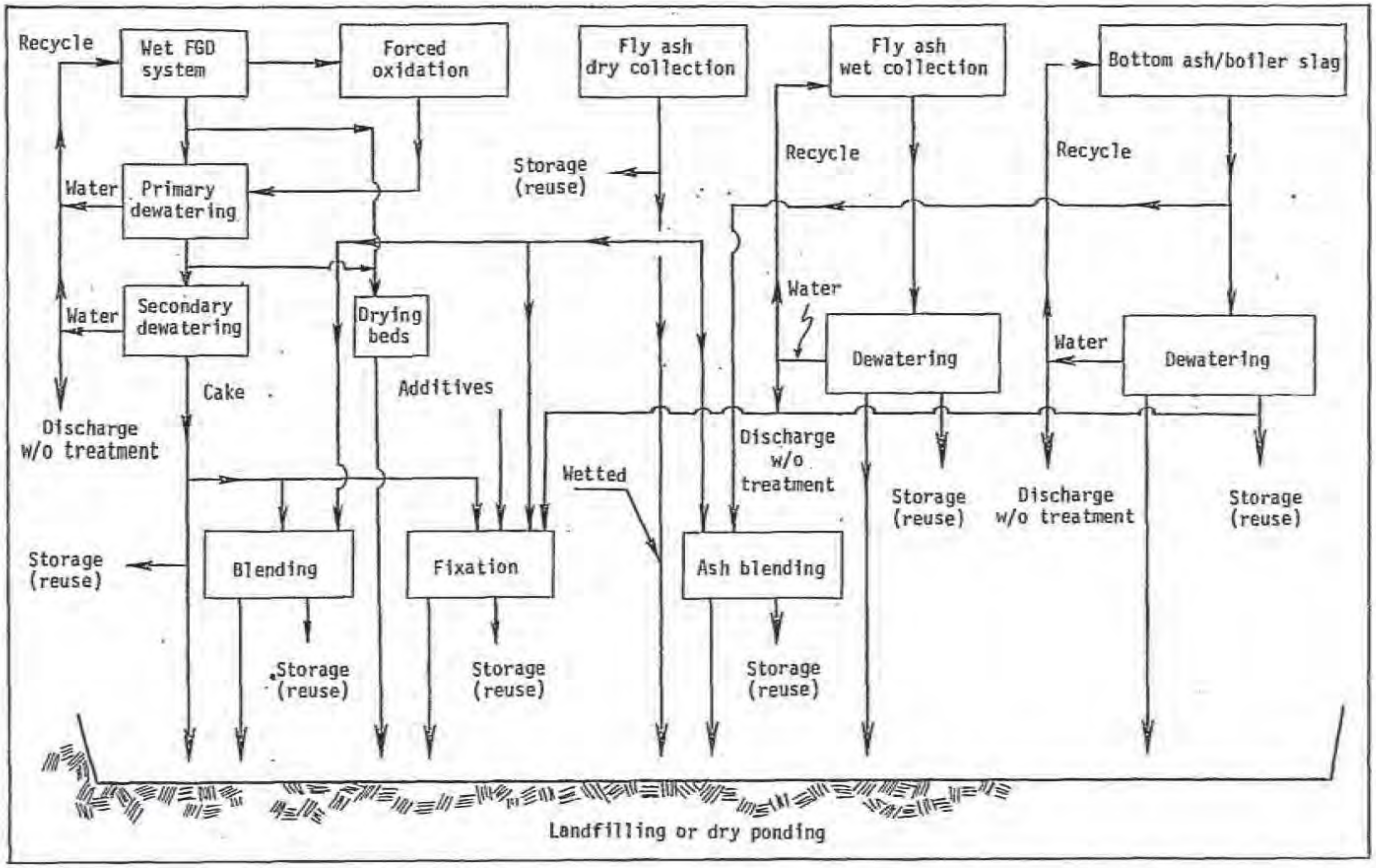

Figure 7-1. Alternatives for in-plant conversion of wet to dry disposal of FGD sludges and ashes.

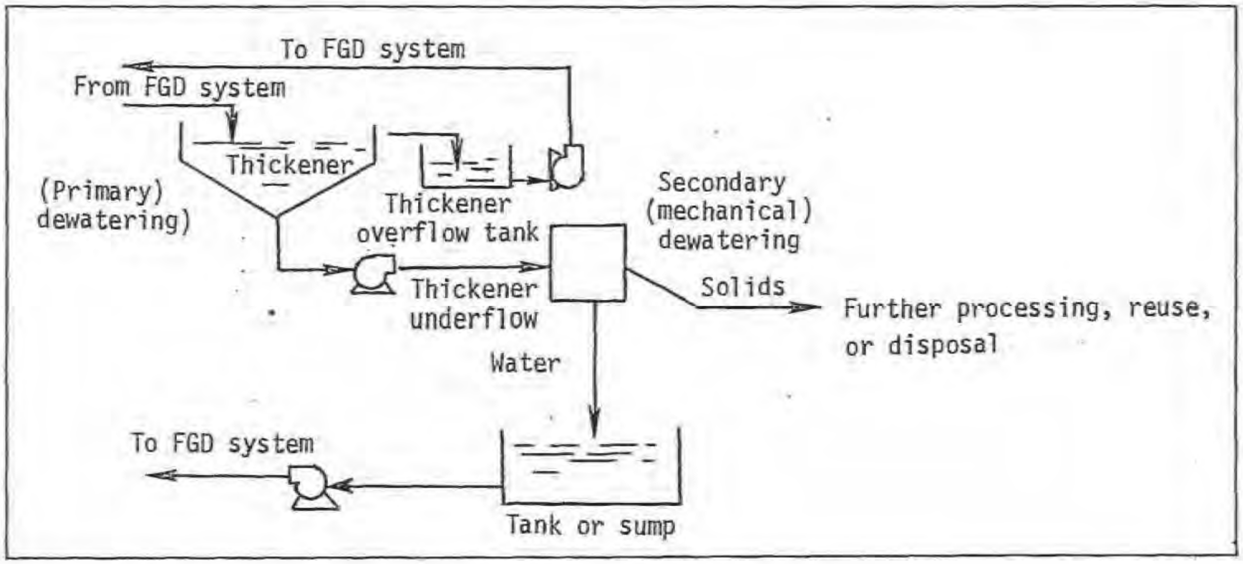

Figure 7-2. Primary/secondary dewatering of FGD sludges.

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A thickener is similar to a clarifier except that mechanical compaction takes place by the effect of gravity alone. The thickener is usually designed for heavier duty operation than a clarifier. The thickener is a rugged, high-torque machine in which clarity of the overflow is not a major consideration. The rake is usually of heavy-duty construction to withstand the density of thickening sludge as it increases.

A hydroclone (or liquid cyclone) can replace the thickener/clarifier as the primary dewatering device. In a hydroclone, solids and liquids are separated by a combination of centrifugal force and liquid shear in a free-vortex centrifugal separator. The energy of the liquid pumped into the cyclone is first converted to velocity energy at the inlet, and then to rotational energy as it moves down through the cyclone. A natural vortex action is created, moving heavier particles to the outside and lighter ones toward the center. The heavier solids are discharged from the orifice at the cyclone tip.

Secondary or mechanical dewatering in the FGD sludge treatment process can be accomplished by various methods. Detailed descriptions of secondary dewatering methods are given in the EPA Manual for Sludge Processing and Disposal (3).

A common method of secondary dewatering is vacuum filtration. Process efficiency is directly dependent on sludge characteristics. Sludge variables directly affecting filter performance include concentration and nature of solids, viscosity temperature, and compressor strength. Operating variables include vacuum strength, drum speed, filter media, drum submergence, and fluid agitation. There are five types of vacuum filters that may be applicable to dewatering sludges from lime/limestone FGD processes: drum, disk, horizontal, belt, and pan. The rotary drum and rotary disk are the two types that are commonly used.

A bulk of solids is retained as a cake, while most of the water and a small percentage of solids passes through the filter. This cake is vacuum-dried, and is mechanically separated from the filter media.

Another method of secondary dewatering is centrifugation. Centrifuges applicable to the dewatering of scrubber sludges are of two types: the countercurrent in which solids are discharged at the slurry inlet end of the bowl, and the concurrent in which solids discharge from the end opposite the slurry inlet. These centrifuges differ markedly in rpm, physical size, and centrifugal force. There is very limited utility experience with centrifuges to either substantiate or refute manufacturer's claims. In the conversion process, the engineer should evaluate and compare both types for his specific application.

Dewatering facilities should be located as close as possible to the scrubber facility. This eliminates the need for lengthy large-diameter piping required to transport scrubber bleed to the dewatering facility and the subsequent return of the liquid fraction that is removed.

In limestone FGD systems (Figure 7-3) (4), slurry that leaves the absorber is directed to the reaction/recycle tank where precipitation of calcium sulfite and calcium sulfate occurs. These precipitated solids are then carried by a bleed stream to a thickener where FGD solids, residual fly ash, and unreacted limestone settle out. Thickener overflow should be recycled back to the FGD system; the underflow is to be pumped to a secondary dewatering system.

For dual-alkali FGD systems (Figure 7-4) (4), the liquid stream that has reacted with the sulfur dioxide in the absorber enters a reaction tank. A portion of the reaction tank liquor is recycled back to the absorber, and the balance is pumped to a regeneration tank, where lime reacts with the liquor to regenerate the scrubbing liquor. Insoluble calcium sulfite crystals precipitate in the regeneration tank, and are removed in a thickener. The clarified and regenerated scrubbing liquor should be recycled back to the absorber via the reaction tank. Thickener underflow should be pumped to a mechanical dewatering apparatus, such as a rotary vacuum filter, where washing is performed to recover sodium salts in the waste products. In both cases the resulting filter cake is then transported either to further processing, to storage, or to waste disposal.

Dewatering facilities may be installed individually, in parallel, or in series, depending upon the desired degree of treatment. Sizing of mechanical equipment should allow for sufficient storage and surge capacity to permit flexible operation. Sufficient equipment capacity should be designed to ensure full-time operation during planned or unscheduled downtime due to process or equipment failure. This usually entails utilizing oversized equipment, providing redundant equipment, or installing bypass emergency storage facilities. Detailed information is found in the EPRI report on sludge dewatering for FGD products (5).

Drying Beds. Drying beds are the most widely used method for municipal sludge dewatering in the United States. Detailed descriptions of this technology are given in the U.S. EPA Technology Transfer Process Design Manuals for Sludge Treatment and

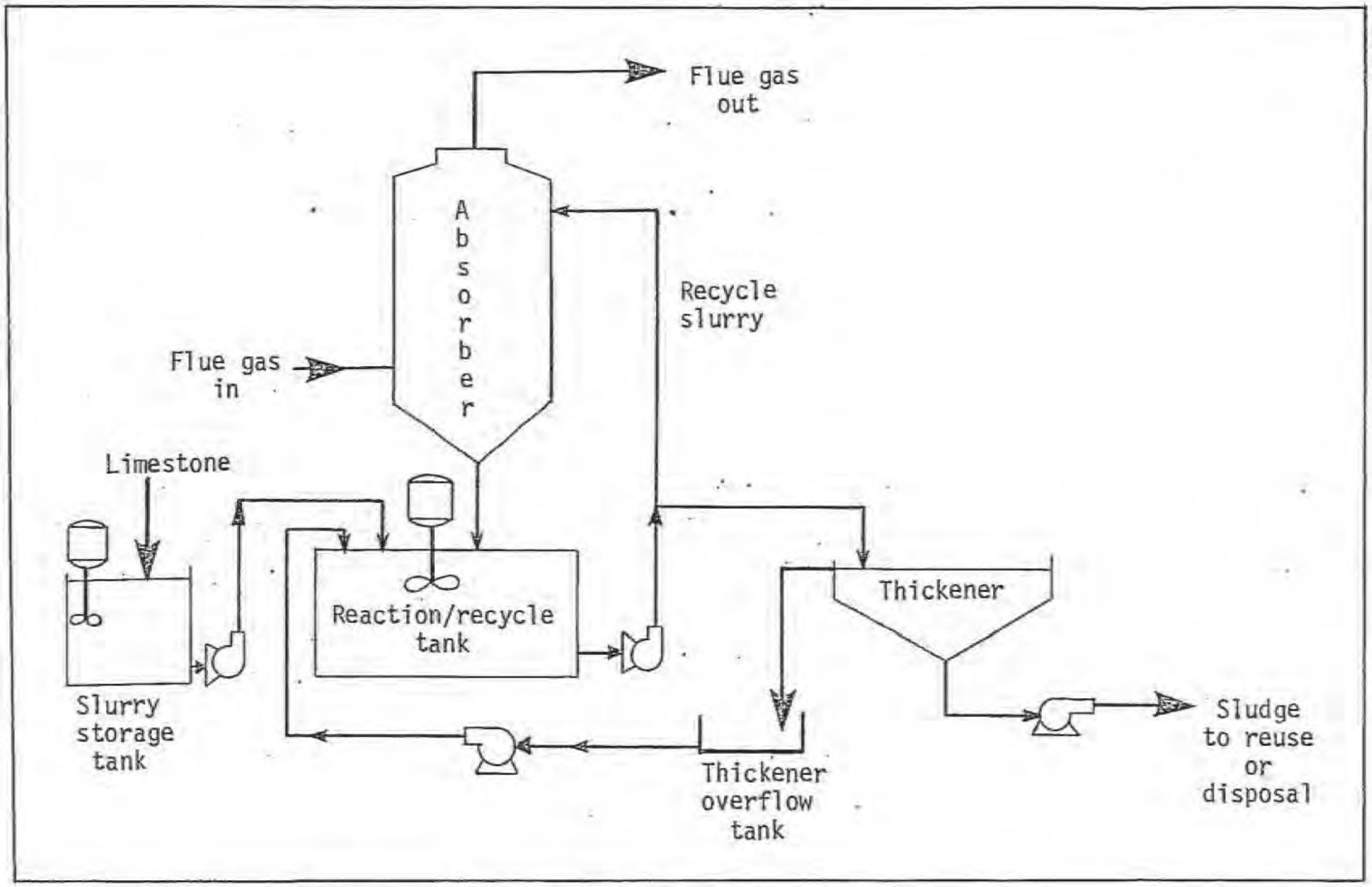

Figure 7-3. Limestone FGD system with primary dewatering.

Source: Adapted from <u>Combustion</u>, January 1980, pp. 21-27.

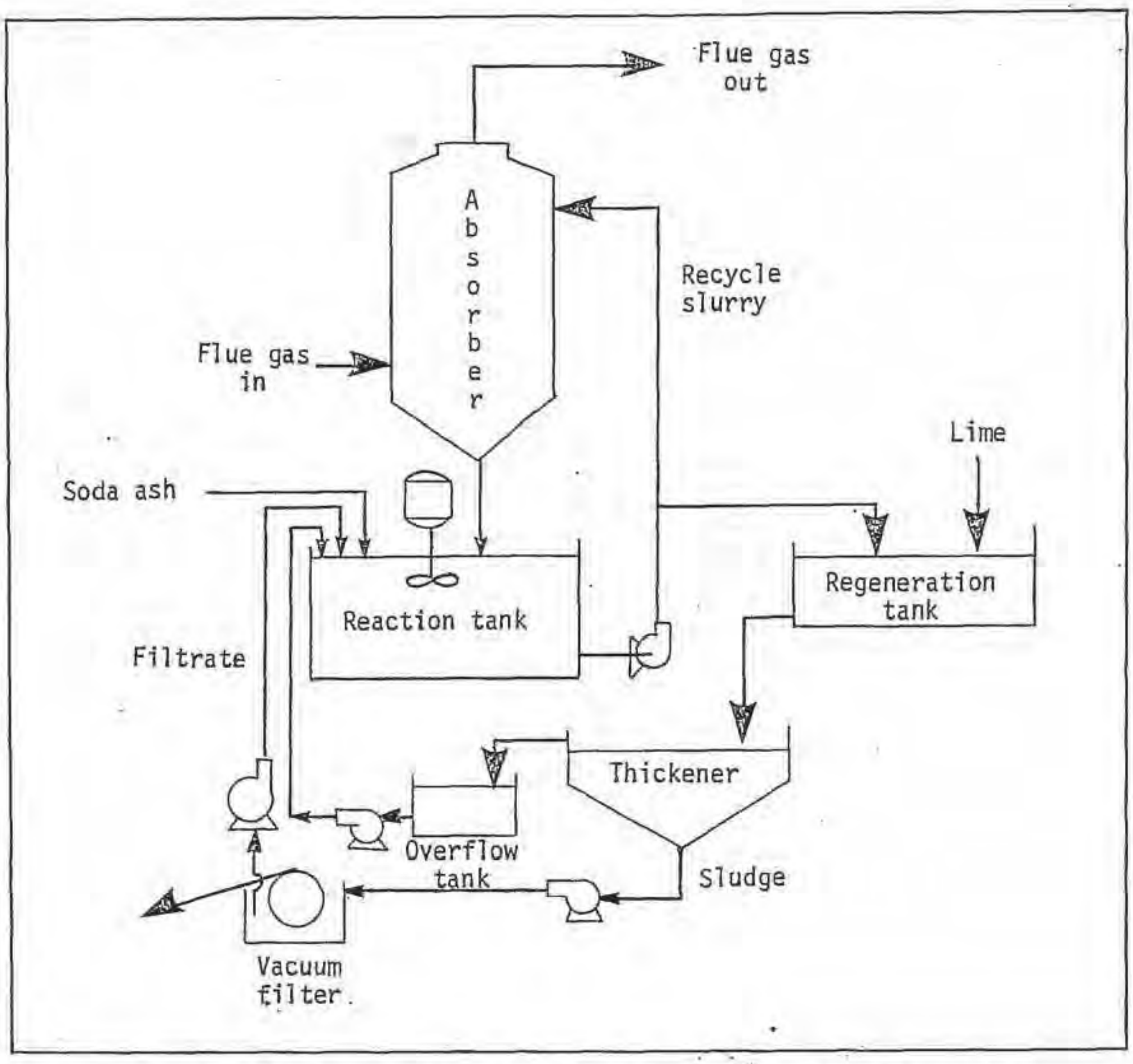

Figure 7-4. Double alkali FGD system with primary/secondary dewatering.

Source: Adapted from Combustion, January 1980, pp. 21-27.

Disposal (3) and Municipal Sludge Landfills (6). It is important to note that drying beds can be used not only to dewater wastes, but also to dry them to a solids concentration of more than 80%. However, due to the possibility of low permeability and drainability of these wastes, periodic decanting and/or discing or turning of the drying material may be advantageous. Although the use of drying beds might be expected in smaller plants and in warmer sunny regions, they can also be used in large facilities in northern climates (3, 4). Whenever there is the possibility of long periods of rain, snow, or cold weather, consideration should be given to employing covers for the drying beds.

Drying beds generally consist of a 1- to 3-ft (0.3- to 1-m) high retaining wall enclosing a porous drainage media. This drainage media may be comprised of various sandwiched layers of sand and gravel, combinations of sand and gravel with cement strips, slotted metal media, or a permanent porous media. Ancillary equipment includes waste feed pipelines and flow meters; filtrate drainage and recirculation lines; mechanical waste removal equipment; and a cover or enclosure.

Both manual labor and mechanical systems can be employed to remove dried waste from drying beds. With the manual labor type of removal, a 50 to 60% solids concentration is required. With mechanical waste removal systems, solids concentrations between 40 and 50% can be handled.

There are several types of drying beds: conventional, paved, wedge-wire, and vacuum-assisted. Each of these configurations is described below. Only the conventional and paved types have found widespread acceptance in industrial/municipal applications.

Conventional sand drying beds are the oldest, most commonly used type of drying beds. Current U.S. practice is to make drying beds rectangular, 15 to 60 ft (4.5 to 18 m) wide, and 50 to 150 ft (15 to 47 m) long with vertical side walls. Usually 4 to 9 in (10 to 23 cm) of sand is placed over 8 to 18 in (20 to 46 cm) of graded gravel or stone. The sand usually has the effective diameter of 0.012 to 0.05 in (0.3 to 1.2 mm), and a uniformity coefficient less than 5.0. Gravel is normally graded from 0.125 to 1 in (0.3 to 2.5 cm) in effective diameter. Underdrain piping is normally of vitrified clay or asbestos-cement, but plastic pipes are also acceptable. The pipes should be at least 4 in (10 cm) in diameter, should be spaced 8 to 20 ft (2.4 to 6 m) apart, and should have a minimum slope of 1%. Figure 7-5 shows a typical sand drying bed construction. Sand drying beds can be built with or without provision for mechanical waste removal, and with or without cover.

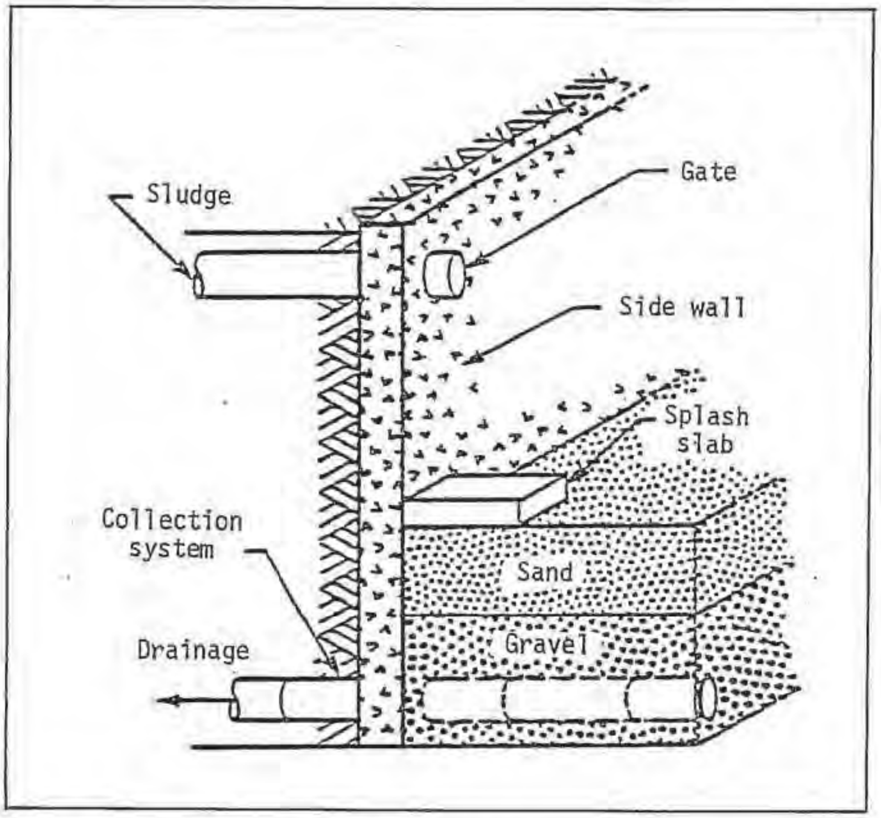

Figure 7-5. Typical sand drying bed construction.

Source: Process Design Manual for Sludge Treatment and Disposal. EPA 625/1-79-011, September, 1979.

Paved drying beds are normally rectangular, 20 to 50 ft (6 to 15 m) wide, by 70 to 150 ft (21 to 46 m) long, with vertical side walls. Current practice is to use either a concrete or asphalt lining. Normally, the lining rests on an 8- to 12-in (20- to 30-cm) built-up sand or gravel base. The lining should have a minimum 1.5% slope to the drainage area. Drainage is conveyed by a pipe at least 4 in (10 cm) in diameter. An unpaved area, 2 to 3 ft (0.6 to 1 m) wide, is placed along either side or down the middle for drainage. Typical paved drying bed construction is shown in Figure 7-6. Paved drying beds can be built with or without a roof. For a given amount of waste, paved drying beds require more area than sand beds. Their main advantages are reduced bed maintenance and the possibility of using front-end loaders for waste removal.

Operational procedures common to all types of drying beds include:

- Applying 8 to 12 in (20 to 30 cm) of waste onto the drying bed surface.
- When the bed is filled to the desired level, the waste is permitted to dry to the desired final solids concentration. This concentration can vary from 50 to 80%, depending on the type of waste, processing rate needed, degree of dryness required for lifting, etc.
- Removing the dewatered waste either mechanically or manually.
- Disposing of the dewatered waste by landfilling.
- Repeating the cycle.

A typical wedge-wire drying bed consists of a shallow rectangular watertight basin fitted with a false floor of wedge-wire panels (see Figure 7-7). These panels have slotted openings of 0.01 in (0.25 mm). The false floor is made watertight with caulking where the panels abut the walls. An outlet valve is located beneath the false floor to control the rate of drainage.

In a wedge-wire drying bed, waste slurry is introduced onto a horizontal open-drainage media in a way that yields a clean filtrate and provides a reasonable drainage rate. The procedure used for dewatering waste involves the pumping of water or pond supernatant into the wedge-wire unit until a depth of approximately 1 in (2.5 cm) over the wedge-wire septum is attained. This water serves as a cushion which permits the added waste to float without causing upward or downward pressure across the wedge-wire surface. The water further prevents compression or other disturbance of the colloidal particles. After the bed is filled with waste, the initially separate water layer and the drainage water are allowed to percolate at a controlled rate through the outlet valve. After the free water has been drained,

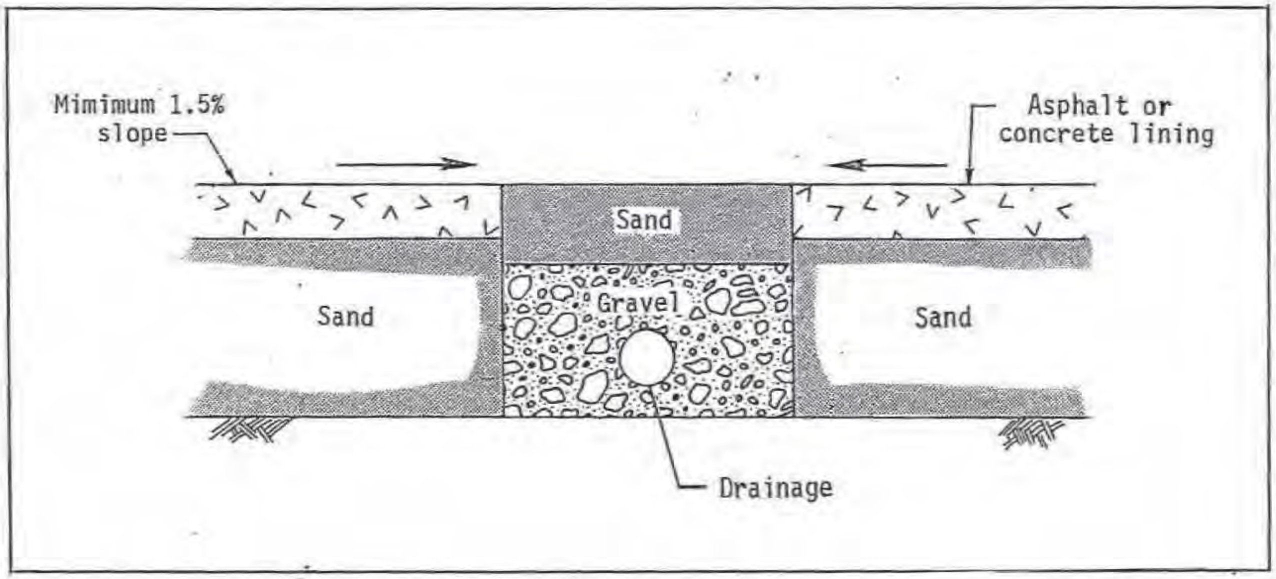

Figure 7-6. Typical paved drying bed construction.

Source: Process Design Manual for Sludge Treatment and Disposal. EPA 625/1-79-011, September, 1979.

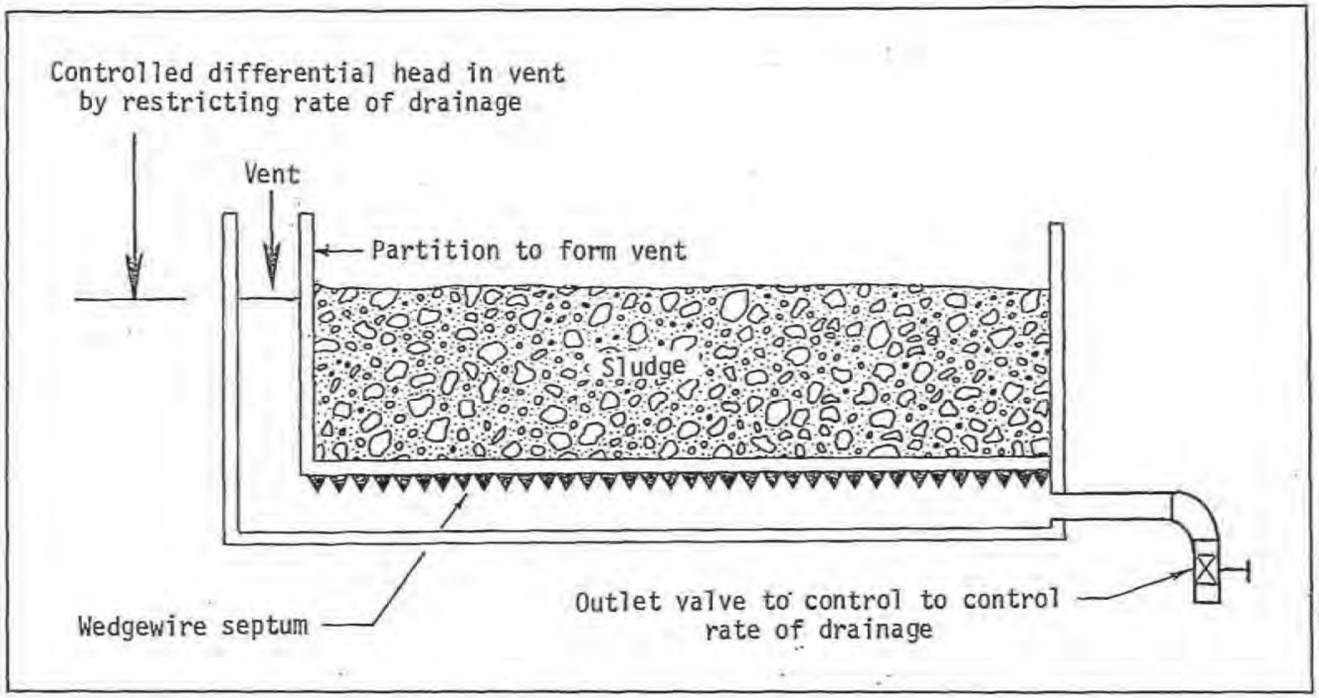

Figure 7-7. Cross section of a wedge-wire drying bed.

Source: <u>Process Design Manual for Sludge Treatment and Disposal</u>. EPA 625/1-79-011, September, 1979.

the waste further concentrates by drainage and evaporation until it is removed for disposal.

The above procedure assures no clogging of the media, and thus a constant and rapid drainage. Compared to conventional sand beds, the throughput rate for wedge-wire drying beds is higher, wastes which are difficult to dewater can be dried, and the removal of dewatered wastes is easier.

Vacuum-assisted drying beds consist of the following principal components: a bottom ground slab of reinforced concrete; a layer of stabilized aggregate several inches thick which provides support for the rigid multimedia filter top, and also serves as the vacuum chamber; and a rigid multimedia filter top placed on the aggregate support. Waste is then applied to the surface of this media.

The operating sequence for vacuum-assisted drying beds is as follows:

- Waste is introduced onto the filter surface by gravity flow to a depth of approximately 12 to 18 in (30 to 46 cm).
- Filtrate drains through the multimedia filter, and is either pumped back to the plant or discharged to the environment.
- As soon as the entire surface of the multimedia filter is covered with waste, the vacuum system is started and maintained at 1 to 10 in (2.54 to 25.4 cm) of mercury.

Forced Oxidation. Forced oxidation is a processing step usually incorporated as part of the scrubber cycle. The purpose is to oxidize the sulfite species to sulfate (gypsum) by the addition of air either to the bulk of the scrubbing equipment or to a bleed stream from the recycle loop (Figure 7-8). The degree of oxidation increases with a decreasing pH; the oxidation rate is proportional to the bisulfite concentration in solution. Air for the oxidation process is usually supplied by compressors.

This oxidized form of the waste stream (i.e., gypsum) settles faster than the sulfite form. Test results have shown an increase of 500 to 800% in the settling rates of oxidized slurry as compared to mixed slurries. These results indicated the possibility of using considerably smaller thickeners. Subsequent mechanical dewatering of oxidized sludges, resulted in an average cake solids content of 80 to 85%, thus indicating the formation of a sludge with excellent qualities for reuse or dry disposal. The reduced volume of this final product, in turn, implies a decrease in transport costs, land requirements, and disposal costs. The above tests were per-

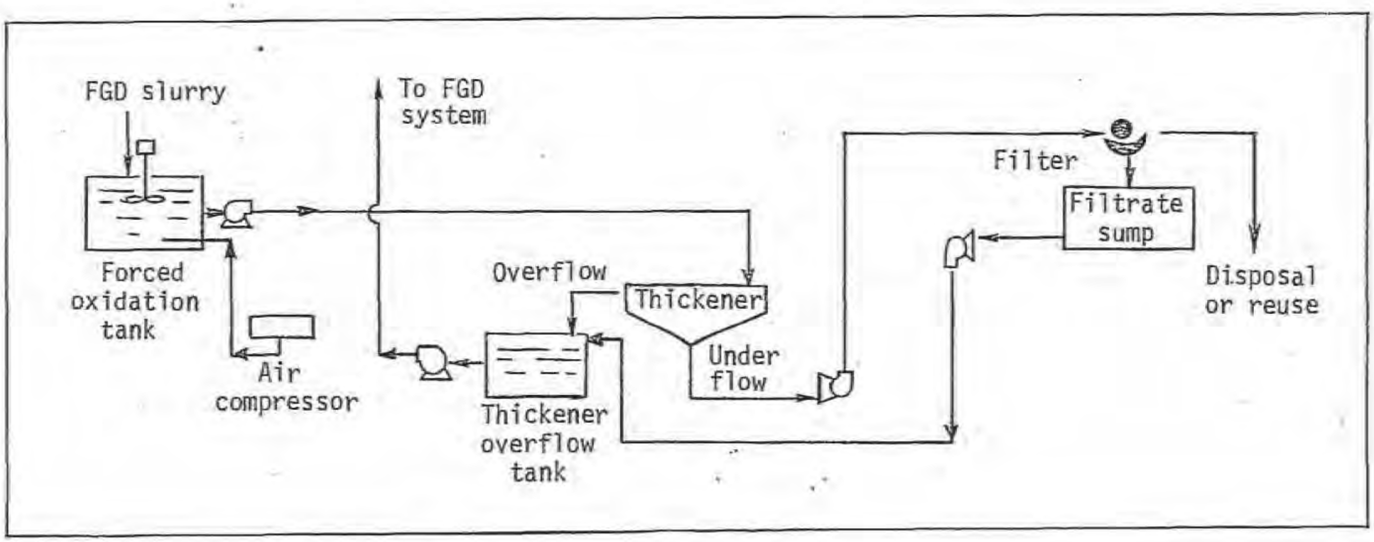

Figure 7-8. Forced Oxidation

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formed on prototype process ecuipment; adaptation to commercial scrubbing equipment appeared feasible based on the results.

The primary disadvantage of a forced oxidation system appears to be the lack of experience with the process in the United States. There is only one full-scale operational plant in the United States located at the Sherburne County power plant (Northern States Power Company). Forced oxidation for other power plants is in the planning stages.

Furthermore, high total dissolved solids (TDS) in leachate or runoff from gypsum disposal areas may pose an environmental problem. Good design and management efforts should alleviate most of these problems. The usefulness of gypsum as a building material or as a structurally stable waste may outweigh its disadvantages. Use of utility by-products is discussed in Section 10.

Blending. Blending is a treatment designed to stabilize sludge by reducing moisture content, and to improve sludge handling characteristics by the addition of adsorbents such as dry fly ash or soil. The most common practice is to blend with fly ash, since it eliminates the need for outside materials.

Blending incorporates one of the easiest and most economical methods of converting wet disposal systems to dry ones. Blending with fly ash physically stabilizes the FGD sludge by mixing it with the ash in a pug mill or muller (Figure 7-9). The powdery ash agglomerates the sludge particles, forming a nonthixotropic, nonplastic material with improved physical and engineering properties over the sludge.

As mentioned earlier, without blending, only 55 to 65% solids content can be achieved through conventional primary dewatering followed by secondary dewatering. Fly ash blending results in an increase in solids content to approximately 75%. Many utilities have developed their own blending formulas.

Fixation. Fixation is defined as a treatment which involves cementitious-type reactions brought about by the addition of lime or other active alkaline material. Fixation thus provides a predictable improvement in the physicochemical and handling characteristics of the sludge. These processes are formulated to contain contaminants, and no attempt is made to remove any hazardous/toxic materials from the sludge.

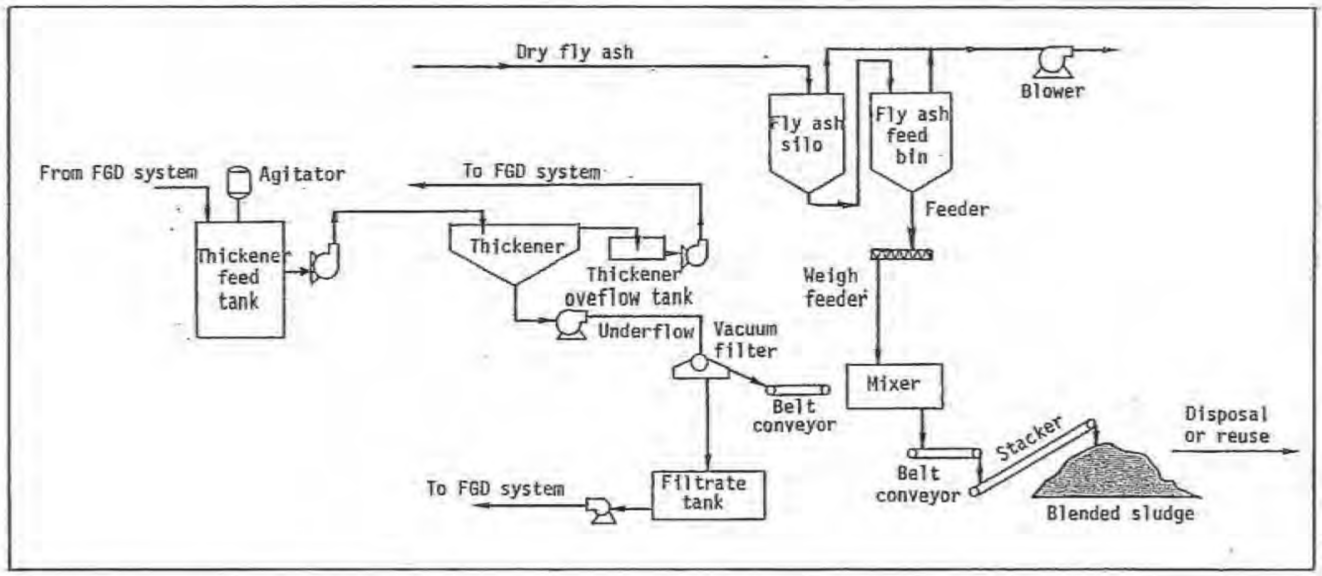

Figure 7-9. Stabilization of FGD sludges by fly ash blending.

Source: Adapted from Ansari, A.H., and J.E. Oven, Pollution Engineering, May 1980, pp. 66-72.

Numerous fixation processes are available (Table 7-2). However, only two such processes will be discussed: the IUCS and Dravo Lime Company processes, both of which have shown full-scale applications in treating FGD sludges.

The IUCS system (Figure 7-10) uses lime and fly ash in its fixation process (7, 8). The cured product is known as Poz-o-Tec. In this system, vacuum-filtered sludge is mixed with fly ash and lime in a pug mill. Dry fly ash is added in proportions between 50 and 100% of dry sludge weight; lime is added at the rate of 3 to 4%. The mixture is controlled to maximize compaction properties. Pozzolanic reactions within the lime-fly ash mixture result in significant increases in load-bearing strength, permeability, compressibility, and bulk strength, as compared to untreated sludges. Although dry fly ash is most often used as a pozzolan, wet fly ash can be substituted; if no fly ash is available, other pozzolanic materials can be used at a higher cost.

Mechanical compaction of Poz-o-Tec is required to obtain maximum strength and minimum permeability. When disturbed, the compacted material will decrease in density but will not reslurry, unlike untreated sludges.

The IUCS fixation system is very compatible with calcium-based or calcium-regenerated dual-alkali sludge. It is not particularly sensitive to pH, sulfate/sulfite ratio, or solids content; however, these parameters can have adverse effects on the process. After mixing, Poz-o-Tec can be stored without adversely affecting the curing process. Only at temperatures below 40°F will the curing process stop.

Disposal of the treated sludge is accomplished by landfilling. However, in addition to landfill disposal, Poz-o-Tec can be used for structural or construction material such as road bases, artificial reefs, landfill or reservoir linings, and concrete aggregate (see Section 10 on utility wastes reuse for more detail). IUCS has experimented with these applications, and is capable of modifying the process to fit each application.

The Dravo Lime Company has patented a fixation process called Synearth (Figure 7-11), which involves the addition of a proprietary material named Calcilox, a cementitious powder derived from basic glassy blast furnace slag (7, 8). Hydrated lime or fly ash is required to adjust the pH to 10.5. Calcilox is added at a rate of 5 to 10% of sludge solids.

Table 7-2

FIXATION PROCESSES: THEIR CHARACTERISTICS AND APPLICATIONS

Vendor	Fixation Process	Wastes Treated	Wastes Excluded from Treatment	Physical/Engineering Properties of Final Product	Past/Present Applications
Dravo Lime Co.	Additives: Hydrated lime or fly ash. Process: Pozzolanic	Calcium-based FGD wastes; coal preparation wastes; uranium mill tailings.	Sludges containing organics; sewage wastes.	Leaching: 10^{-6}-10^{-8}cm/sec LBC*: $5.5x10^3$ g/cm^2	Bruce Mansfield Power Station; Phillips Power Station; Pleasants Station; American Electric Power Mines.
IU Conversion Systems, Inc. (IUCS)	Additives: Fly ash and lime. Process: Pozzolanic	FGD sludges; electroplating wastes; steel mill wastes; chemical process wastes.	Various organic wastes.	Leaching: 10^{-6}-10^{-8}cm/sec LBC: $3.3x10^3$ g/cm^2 UCS†: $2.7x10^4$ g/cm^2	11 power plants in the U.S.A.; large battery manufacturer.
Chemfix, Inc.	Additives: Cement or silicates. Process: Cementitious	FGD sludges; wastes from various other industries.	Certain organics; toxic anions; undesirable non-toxic compounds.	Leaching: 10^{-5}-10^{-6}cm/sec UCS: $3.8x10^3$ g/cm^2	Tests at TVA Shawnee facility; automotive metal finishing wastes; sewage sludges; oil refinery wastes; organic chemical plant wastes.
Environmental Technology Corporation	Additives: Lime and other. Process: Chemical binding and encapsulation	Commercially used only for hydroxide sludges.	Further laboratory testing required.	Leaching: 10^{-6}cm/sec Typical strength: 97.6 g/cm^2	No FGD experience.
Ontario Liquid Waste Disposal Limited	Additives: Silicates. Process: Formulation of stable silicates similar to geologic materials	Virtually all inorganic wastes; mine tailings; sewage sludges.	Various organic wastes.	Leaching: <1 mg/l heavy metals. UCS: $2.1x10^5$ g/cu^2	Liquid wastes; the product used as a cover material for sanitary landfill.

Table 7-2 (continued)

Vendor	Fixation Process	Wastes Treated	Wastes Excluded from Treatment	Physical/Engineering Properties of Final Product	Post/Present Applications
Sludge Fixation Technology, Inc.	Additives: Cementitious material. Process: Terra Crete process with $CaSO_3$ or $CaSO_4$	Designed for sulfite/sulfate-based sludges.	Not specified.	Leaching: 10^{-6} cm/sec UCS: 976-5856 g/cm^2	The process tested only under laboratory conditions.
Stabatrol Corporation	Additives: Cementitious material. Process: Terra-Tite	Most industrial wastes	Not specified.	Leaching: 10^{-7} cm/sec UCS: 5.5×10^3 g/cm^2	Heavy metal sludges; contaminated soil.
Stablex Corporation	Additives: Silicate-based materials. Process: Formation of silicates; final product resembles "synthetic rocks"	Organic wastes; heavy metal wastes; aqueous wastes containing miscible organics.	Organics not miscible with water; aqueous wastes containing small concentration of toxic materials.	Leaching: 10 times less than for concrete. UCS: Similar to UCS of grouts used for filling voids in soil stabilization.	3 plants in United Kingdom; sludges from POTW's with large industrial input.
TJK, Inc.	Additives: Cement-based materials and special additives for stabilizing toxic material. Process: Cementitious	Muds with high water content; sludges from POTW's and industrial facilities.	Sludges with >20% fats and oils; sludges with paint wastes.	UCS: $5\text{-}10 \times 10^5$ g/cm^2	Toxic substances containment; 17 projects with deposits under water; 7 projects with industrial discharges.
Werner and Pfleiderer Corporation	Additives: Asphalt-solidifying agent. Process: Incorporation with bitumen or plastic matrix.	Radioactive wastes.	Sludges with strong oxidizers; borates; smelling salts.	Leaching: 10 times less than for concrete.	Full-scale radwaste encapsulation units in France and West Germany.

* LBC = Load Bearing Capacity

† UCS = Unconfined Compressive Strength

Conversion Units: 1 g/cm^2 = 0.014 lb/in^2
1 cm/sec = 0.033 ft/sec
1 mg/l = 6.24×10^{-5} lb/ft^3

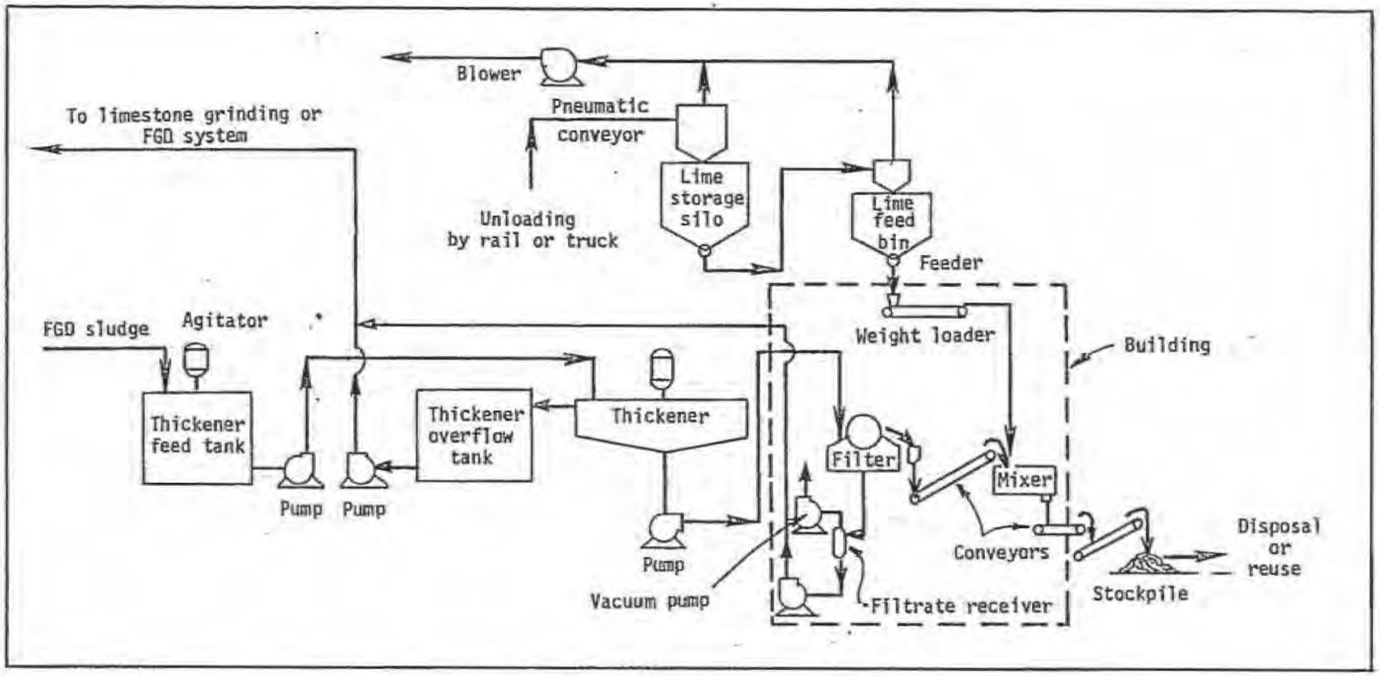

Figure 7-10. IUCS fixation system for FGD sludge.

Source: Adapted from Power, 123, No. 3, September 1978, pp. 35-47.

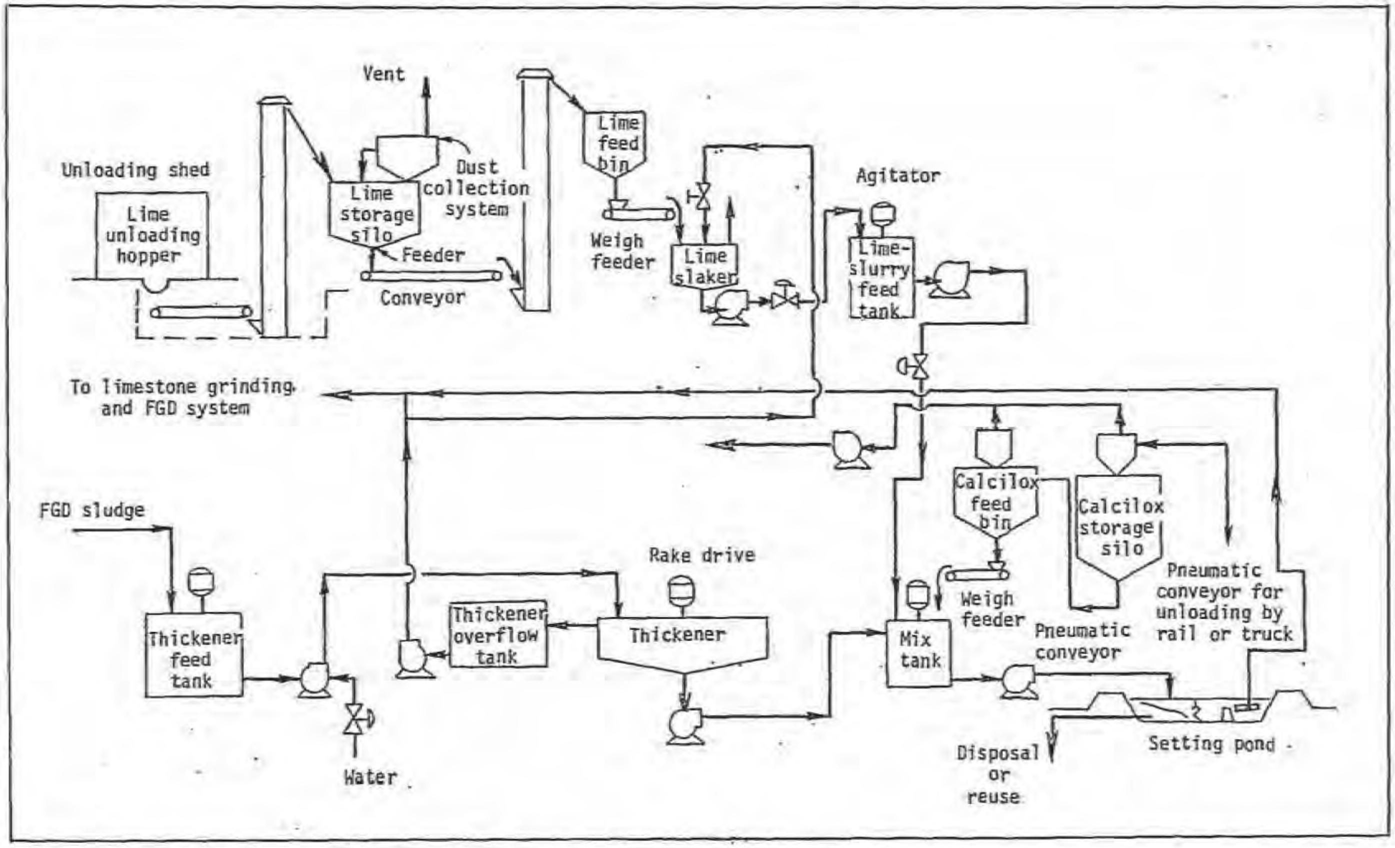

Figure 7-11. Dravo Lime Company fixation process for FGD sludge.

Source: Adapted from Power, 123, No. 3, September 1978, pp. 35-47.

Three distinct variations for treatment/disposal are possible using the Calcilox stabilizing agents:

- Permanent ponding.
- Interim ponding.
- Mechanical dewatering with direct landfilling.

In ultimate disposal by ponding, the treated sludge mixture is pumped to a pond, which provides a means for both complete curing and disposal. Ponding in this case is intended as a permanent method of disposal.

In areas where vast land requirements are expensive or unavailable, interim ponding may be the preferred alternative. The treated sludge mixture is pumped to an interim (holding) pond where it is completely cured in 30 days. After this curing period, the fixed sludge is excavated and transported to a landfill. To allow for continuous operation, a series of ponds are sequentially filled, cured, and excavated. With Dravo's interim ponding option, curing time is critical, as it determines the capacity of the interim curing ponds.

In situations where interim ponding is not an option, direct landfilling can be utilized. Dry fly ash is mixed with Calcilox and partially dewatered sludge, and transported directly to the landfill. The material requires an initial curing period of 5 to 6 days prior to spreading and compaction. As is the case with Poz-o-Tec, the final product after fixation with Calcilox can also be used as structural or construction material (see Section 10).

Fly Ash/Bottom Ash

As shown in Figure 7-1, there are two general in-plant modifications for drying ash:

- Dewatering.
- Dry fly ash-bottom ash blending.

In both alternatives, bottom ash is collected by wet methods, while fly ash can be collected by either dry or wet methods. Dewatered ashes can either be transported to disposal areas (landfills or dry impoundments) or stored for future use. In landfilling, bottom ash is either placed along with fly ash or reused for drainage blankets or filters.

Since the compacted ash is capable of supporting moderate foundation loads, the dry disposal sites can be compacted after closure, and subsequently developed for homes, parks, golf courses, and industrial sites.

Dewatering. Three basic alternatives are available for dewatering fly ash and bottom ash slurries:

- Primary dewatering.
- Secondary dewatering.
- Drying beds.

Primary dewatering of ashes involves gravity separation systems such as dewatering bins, settling ponds, or settling basins, while secondary (mechanical) dewatering is accomplished by methods such as filtration and centrifugation. Drying beds, as mentioned earlier in this section, can be used to accomplish both dewatering and drying.

The following is a description of primary dewatering of ash slurries by dewatering bins and settling ponds or basins. Descriptions of secondary dewatering systems and drying beds were presented earlier in this section under the dewatering methods for FGD sludges.

In the case of dewatering by dewatering bins (Figure 7-12), ashes from water slurries are settled, and water is removed through decanting and dewatering elements, so that relatively dry ash can either be delivered to the disposal site or stored for future use. Overflow from the ash hoppers and dewatering bins is collected in a shallow settling tank (usually of a diameter substantially greater than the dewatering bins) for the removal of fine particles (9). The water is finally drained to a storage tank for reuse in ash collecting and conveying systems, to which it is returned by pumps. Makeup water from an outside source must be provided to the system to restore the water lost through ash discharge from the dewatering bins. Makeup is usually added to the storage tank. Particulates accumulated in the settling and storage tanks are continuously returned at a low rate to a dewatering bin to prevent sludge buildup.

Ash is pumped into a bin over a bar screen which permits the finer material to drop directly into the center; the coarser particles are diverted toward the sides of the bin, forming a filter to trap fines before they can reach the decanting elements.

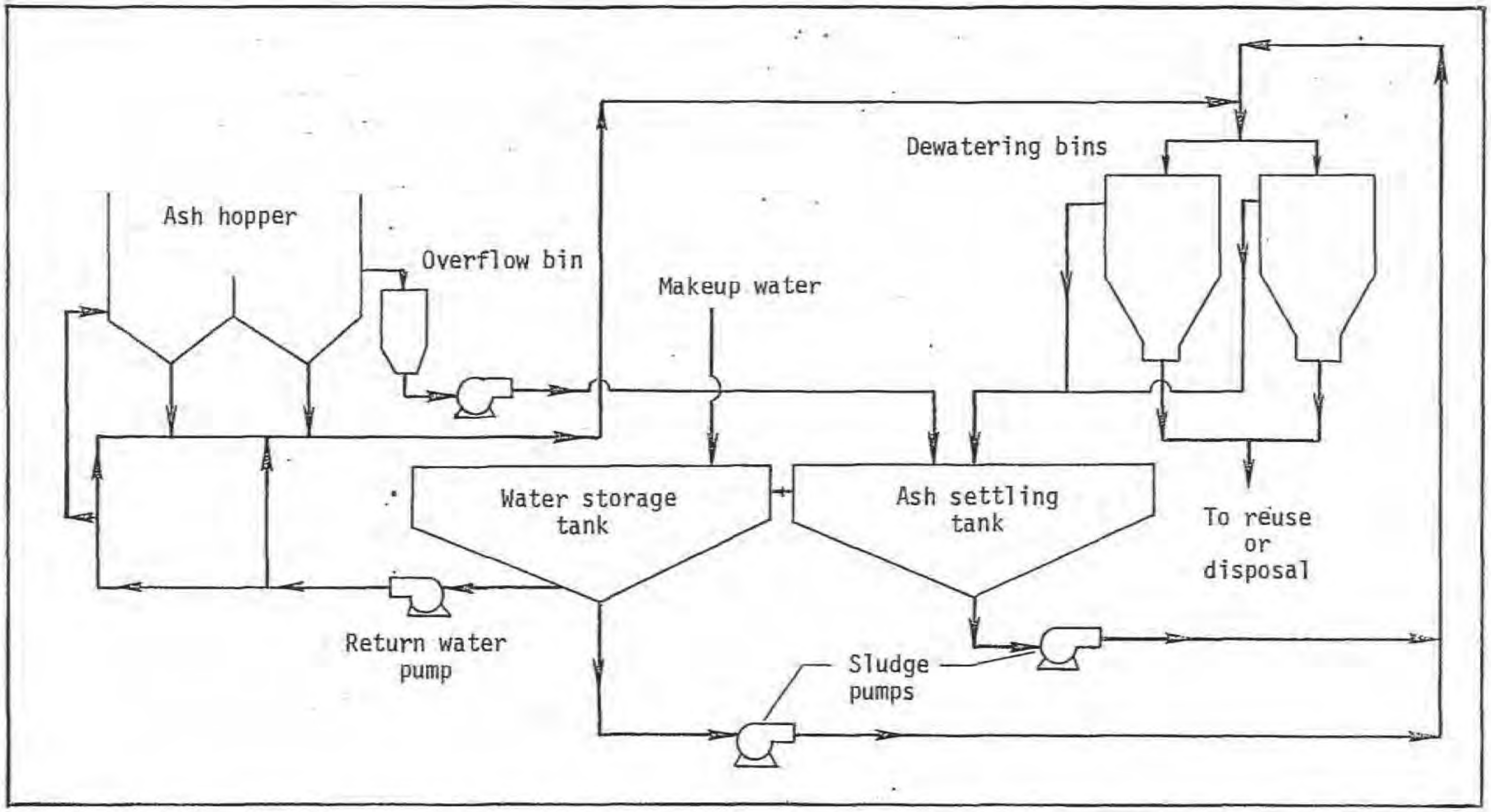

Figure 7-12. Dewatering of ashes by dewatering bins (with water recycle). (Source: Adapted from A Primer on Ash Handling Systems, 1976, pp. 1-31).

When the bin is filled to the top, excess water overflows a serrated weir, around the bin periphery, into a trough from which it flows by gravity through a drainpipe to waste or to a settling system for recycling. An important element in any dewatering bin is an underflow baffle, concentric with the outer shell. All material entering the bin must pass under this baffle before reaching the overflow weirs. The baffle also prevents the turbulence caused by the incoming conveying system discharge from reaching the weirs, so that flow over the weirs is as steady and undisturbed as possible.

For more effective operation, two dewatering bins are normally required: after filling the first bin to its rated capacity, flow must be diverted to a second bin where the filling procedure is continued. The first bin is then allowed to stand undisturbed until ash has settled (usually about 1 hour) leaving relatively clear water above the ash, which is then drained off. The total dewatering process time will vary depending on the quality of the ash and the degree of dewatering desired. Normally, about 8 hours are sufficient to obtain a product satisfactory for removal in trucks or railroad cars. Ash is discharged through the bottom by means of a hydraulically operated gate.

Dewatering bin capacities are generally determined by the longest period during which it may not be possible to unload the bins. This is usually considered to be a weekend of 64 hours. (Ash hoppers are usually designed to provide 12-hour retention time.) Where ash is known or anticipated to have cementing properties, it may be well to consider using a number of small bins and a procedure of frequent unloading to prevent ash from setting up with consequent removal difficulties.

In the case of dewatering by settling ponds or basins, fly ash and bottom ash slurries are pumped into separate ponds or basins (Figure 7-13). To be effective, these settling systems must cover a considerable area, since retention time is the only means by which ash can be settled and separated from the conveying water. Where space permits, volume in a settling basin should be provided for 1 day's retention of the ash conveying water (9). For effective operations, either alternate ponds or two-compartment settling basins should be provided so that one side may be cleaned while the other is receiving ash (9). Overflow from such ponds or basins will flow to sewers or to clarifiers depending on regulations. In most localities, discharge of untreated overflow is no longer permitted.

Ash removed from the dewatering basins can either be hauled to a disposal site or stored for subsequent utilization. Depending on regulations, supernatant from these

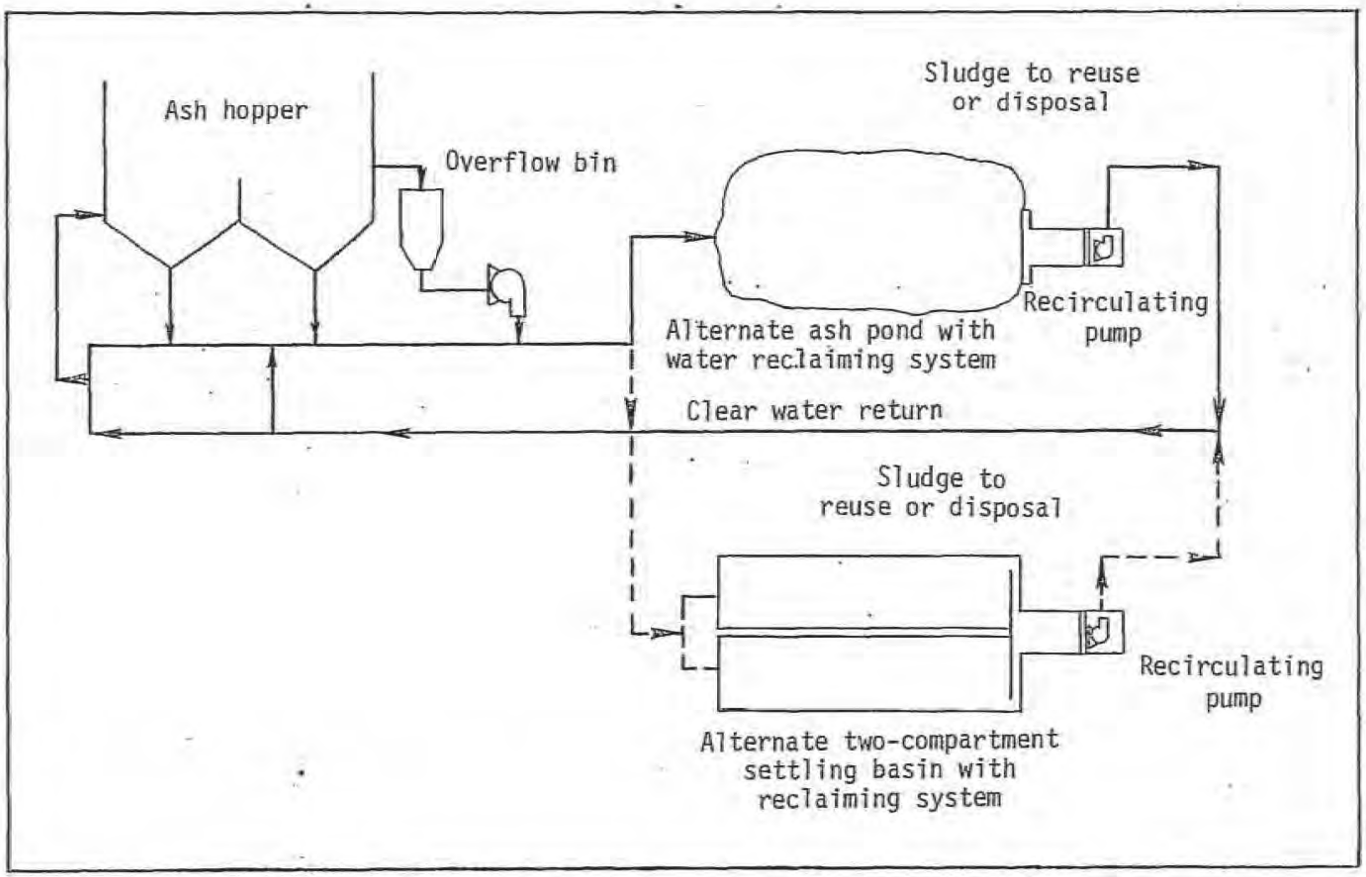

Figure 7-13. Dewatering of ashes by ponds or settling basins (with water recycle). (Source: Adapted from A Primer on Ash Handling Systems, 1976, pp. 1-31).

ponds can be returned to the plant for the ash conveying system, or discharged directly to sewers after treatment by clarifiers.

Dry Fly Ash-Bottom Ash Blending. In this option, fly ash, collected by dry methods, is blended with wet bottom ash. This technique helps to dewater and stabilize the wet bottom ash. The resulting admixture can either be transported to a landfill (where it is spread and compacted with conventinal earth-moving equipment) or stored for reuse.

Criteria Governing Selection of In-Plant Wet-to-Dry Conversion System

In order to select a proper conversion system and to arrive at correct sizing of all components of the chosen system, the following parameters need to be considered:

- Characteristics of materials to be handled.
- Quantities to be handled.
- Process rate.
- Physical arrangement of the existing system.
- Capital costs.
- Operating costs.
- Maintenance requirements.
- Land requirements.
- Land availability.
- Climate.
- Geological conditions.
- Hydrologic conditions.

For example, to derive correct sizes of system components and to establish conveyance rates, it is necessary to consider such information as the type of coal burned, percentage of sulfur and ash in coal, distribution of ash between bottom ash and fly ash, chemical composition of ashes, SO_2 content in flue gases, reagent used for wet scrubbing, stoichiometric ratio, SO_2 removal efficiency, waste density, waste particle size distribution, waste concentration and waste chemical characteristics.

Furthermore, site-specific parameters, such as climate and hydrogeologic conditions, have to be evaluated. For example, climatic areas of high precipitation may favor the use of fixation over forced oxidation or fly ash blending due to the leaching characteristics of the disposed materials. On the other hand, fixation would likely not be used in areas of little rainfall. In areas where high percolation rates exist, conversion schemes with the least amount of leaching tendencies should be considered. Furthermore, in areas where groundwater is very deep, leaching characteristics might not be of great importance in selecting a dry conversion process.

Concurrent with site-specific parameters, the prediction of waste disposal volumes per each conversion process needs to be considered for the life of the plant. Capital, operating and maintenance, and overall costs should be developed to represent a levelized base for each conversion scheme.

Finally, decisions on conversion from wet to dry disposal systems must also consider the existing regulatory frameworks. However, such decisions have to be made on a case-by-case basis, thus providing the utilities with the needed flexibility to conform to all applicable federal, state, and local requirements.

CONVERSION OF WET DISPOSAL SITES TO DRY DISPOSAL SITES

Several general approaches are possible for converting disposal ponds to landfills. All of these approaches involve pond draining and subsequent land disposal of the remaining solids.

The characteristics of the ponded wastes will dictate the landfill method to be used. Ponded sludges/ashes can be either (1) dewatered and/or dried to a solids concentration of ≥60%, and landfilled or permanently ponded by conventional dry disposal techniques; or (2) dewatered (if needed) to a solids content of ≥30% and disposed of by special landfilling methods. Conventional methods are described in the EPRI FGD Sludge Disposal Manual and the Coal Ash Disposal Manual (1, 10). The design of specialized sludge landfills is addressed later in this section, along with applicable dewatering methods.

Dewatered ponded wastes can also be treated with a blending/fixation agent prior to final disposal. Although most of the available blending/ fixation systems are integrated into plant design, it may be possible to use a portable treatment system at the disposal site itself. A detailed discussion on available blending/fixation systems was given earlier in this section.

Pond Draining

As mentioned above, all of the alternatives considered for the conversion of wet disposal sites to dry ones require draining of the sludge/ ash ponds, and removal of the solids by excavation for subsequent dewatering and/or land disposal. Liquids from dewatering can either be returned to the FGD system without treatment, or discharged to a nearby surface water body, an evaporation pond, or a local wastewater treatment plant. Depending on the climate, quality of the removed water, ground and surface water quality and proximity, distance to the local wastewater treatment plant, and environmental regulations, the removed liquid can either be treated prior to discharge or discharged without treatment.

The removal of water from utility waste ponds to effect their conversion to dry disposal sites is best accomplished by gravity drainage into one or more sumps or well-like structures, located in the topographically low portions of the site. The dewatering structures will most likely require pumps for removal of collected water. The design of the dewatering structures should be based on:

- Permeability and drainage characteristics of the waste material.
- Texture of the waste material.
- Depth of the waste material.
- Volume of water that must be removed.

The design considerations of wells and gravity drains are discussed in Section 6 of this manual. The major differences between conventional dewatering of natural soil material and utility wastes are as follows:

- The waste materials will likely exhibit dramatic reductions in permeability and porosity as they are dewatered, due to consolidation of the waste mass in response to hydraulic stress caused by pumping.
- The waste materials are loosely placed, and hence are highly susceptible to subsurface erosion and piping.

Thus, the pump system must be capable of dealing with highly variable quantities of seepage. Automatic pump controls will likely be warranted to allow intermittent pumping as dewatering progresses. Additionally, the graded filter, gravel pack, and/or screen must be effective in preventing the migration of fine waste particles into the dewatering structure.

Normally such dewatering structures are relatively large in diameter to provide (1) access for maintenance; (2) storage for accumulated seepage between pumping periods; and (3) a large surface area in contact with the refuse to reduce the seepage velocity of water entering the structure. Furthermore, the openings of the screen(s) or the texture of the filter surrounding the dewatering structures should be relatively fine to prevent uncontrolled migration of solid waste particles into it. However, even under the most favorable circumstances, it will probably be necessary to filter the water entering a landfill dewatering sump prior to its discharge in order to remove suspended waste particles.

Dewatering structures should be designed in accordance with site-specific characteristics and requirements. The construction materials should reflect the duration of the dewatering requirement. In some instances, it may be necessary to dewater utility ponds on a regular basis due to the accumulation of water from precipitation and dust control spraying. If this is the case, the dewatering structure should be constructed of materials resistant to the chemical environment of the disposal site. If long-term use of such dewatering structures is necessary, regular maintenance will probably be required to ensure satisfactory operation.

Dewatering of Ponded Utility Wastes

The following two methods are applicable to dewatering of ponded sludges and ashes following supernatant removal:

- Secondary dewatering.
- Drying beds.

Secondary dewatering unit processes and their advantages and disadvantages were described earlier in this section. To accomplish secondary dewatering, the ponded sludges/ashes can be passed either through the existing in-plant mechanical dewatering device, or through rented equipment located in the vicinity of the disposal site. The resulting cake, generally containing 55 to 65% solids, is transported to the landfill site and disposed of by conventional dry disposal techniques.

If directed back to the plant, ponded wastes need to be introduced to the system at a point upstream of the mechanical dewatering step, but beyond the oxidation step, if used (see Figure 7-2). Such routing will usually require longer pumping distances, since in-plant mechanical dewatering devices are usually located close to scrubbers. In addition, provisions will be required for temporary pipelines. An oversized dewatering device needs to be incorporated into the waste handling step to accommodate the existing waste stream and any additional flows from the wet disposal sites. However, if sludge generation varies sufficiently over the year, the additional flow from the disposal site can be dewatered during off-peak months. In such cases, there may be no need for oversized equipment.

The application of this alternative requires that the waste have a solids content and viscosity that allow it to be pumped. Diluting the settled solids with supernatant may thus be required in some cases. Detailed information on the available sludge pumps can be found in the U.S. EPA Process Design Manual for Sludge Treatment and Disposal (3).

Specialized Landfilling of Ponded Utility Wastes

Conventional ash and FGD sludge landfill technology is most appropriate for material which has been mechanically dewatered, dried, and/or stabilized. When removing settled solids from a pond during site relocation, it is possible to dispose of these solids without elaborate dewatering or treatment, using special landfilling techniques. These "sludge-only landfilling" techniques, developed originally for municipal sewage sludge disposal, include the following:

- Trench fill:
  - --Narrow trench.
  - --Wide trench.
- Area fill:
  - --Area fill mound.
  - --Area fill layer.
  - --Diked containment.

Not all utility wastes are suitable for sludge-only landfills. For these methods, the solids concentration should be 30% or more. Wastes having a solids content below 30% usually will not support cover material. Although soil may be added to a low-solids waste as a bulking agent to effectively increase the solids concentration, soil bulking operations are generally not cost-effective for wastes with a solids content of less than 30%.

General descriptions of these landfilling methods, including waste and site requirements and design criteria, are presented below. Table 7-3 provides information on these considerations as well as on equipment requirements for each landfilling method. A detailed discussion of sludge-only landfill designs and ancillary facilities which may be required in association with the landfill site can be found in the U.S. EPA process design manuals for sludge treatment and disposal (3) and for municipal sludge landfills (6).

Table 7-3

LANDFILLING OF PONDED UTILITY WASTES: WASTE CHARACTERISTICS, SITE CONDITIONS, AND DESIGN CRITERIA

Method	Waste Solids Content	Trench Width	Bulking Required	Bulking Agent	Bulking Ratio[*]	Cover Thickness Interim	Cover Thickness Final	Imported Soil Required	Waste Application Rate (In Actual Fill Areas)	Equipment	Hydrogeology	Ground Slope
Narrow trench	30-40%[#] 40-60%[#]	2-3 ft 3-10 ft	No No	---- ----	----	---- ----	2-3 ft 3-4 ft	No	1,200-5,600 yd^3/acre	Backhoe with loader, excavator, trenching machine	Deep groundwater and bedrock	<20%
Wide trench	40-60%[#] ≥60%[**]	10-50 ft 10-50 ft	No No	---- ----	----	----	3-4 ft 3-4 ft	No	3,200-14,500 yd^3/acre	Track loader, dragline, scraper, track dozer	Deep groundwater and bedrock	<10%
Area-fill mound	>40%[**]	----	Yes	Soil	0.5-2 soil: 1 waste	2-3 ft	2-3 ft	Yes	3,000-14,000 yd^3/acre	Track loader, backhoe with loader, track dozer	Shallow groundwater or bedrock	Suitable for steep terrain as long as level area is prepared for mounding
Area-fill layer	≥30%[**]	----	Yes	Soil	0.25-2 soil: 1 waste	0.5-1 ft	2-4 ft	Yes	2,000-9,000 yd^3/acre	Track dozer, grader, track loader	Shallow groundwater or bedrock	Suitable for medium slopes, but level ground preferred
Diked containment	40-60%[#] ≥60%[**]	---- ----	No[†] No[†]	Soil Soil	0.25-0.5 soil: 1 waste	1-2 ft 1-2 ft	3-4 ft 3-4 ft	Yes	4,800-15,000 yd^3/acre	Dragline, track dozer, scraper	Shallow groundwater or bedrock	Suitable for steep terrain as long as a level area is prepared inside dikes

Source: Adapted from Reference Three.

[*] Volume basis unless otherwise noted.

[†] Sometimes bulking is required.

[#] Land-based equipment.

[**] Sludge-based equipment.

Conversion Units:

1 ft = 0.305 m

1 yd^3/acre = 1.89 m^3/ha

Trench Fill. For sludge-only trenches, subsurface excavation is required so that waste can be placed entirely below the original ground surface. Trench applications require that groundwater and bedrock be sufficiently deep so as to allow excavation and still maintain sufficient buffer soils between the bottom of the waste deposits and the top of the groundwater or bedrock.

In trench applications, soil is used only for final cover, not as a waste bulking agent. The soil excavated during trench construction provides quantities sufficient for cover applications. Accordingly, soil importation will not be required in trench applications.

Two submethods have been identified under trench fill applications: narrow trench, and wide trench. The depth and length of both narrow and wide trenches are variable and dependent upon a number of factors. Trench depth is a function of depth to groundwater and bedrock, side wall stability, and equipment limitations. Trench length, which is virtually unlimited, is dependent upon property boundaries and other site conditions. Both narrow and wide trenches should be oriented parallel to one another to minimize intertrench areas. Distances between trenches should only be large enough to provide side wall stability as well as adequate space for soil stockpiles, operating equipment, and haul vehicles.

Narrow trenches have a width of less than 10 ft (3 m). Waste is usually disposed of in a single application, and a single layer of cover soil is applied on top of this waste. Narrow trenches are usually excavated by equipment based on solid ground adjacent to the trench; the equipment does not enter the excavation. Accordingly, backhoes, excavators, and trenching machines are particularly useful in narrow trench operations. Usually, excavated material is immediately applied as cover over an adjacent waste-filled trench. However, it is occasionally stockpiled alongside the trench from which it was excavated for subsequent application as cover over that trench. Cover material is then applied by equipment which is also based on solid ground outside the trench. Narrow trench operation is shown graphically in Figure 7-14.

A wide trench has a width of greater than 10 ft (3 m). Wide trenches are usually excavated by equipment operating inside the trench (see Figure 7-15). Accordingly, track loaders, draglines, scrapers, and track dozers are particularly useful in wide trench operations. Excavated material is usually stockpiled on solid ground adjacent to the trench from which it was excavated for subsequent application as cover

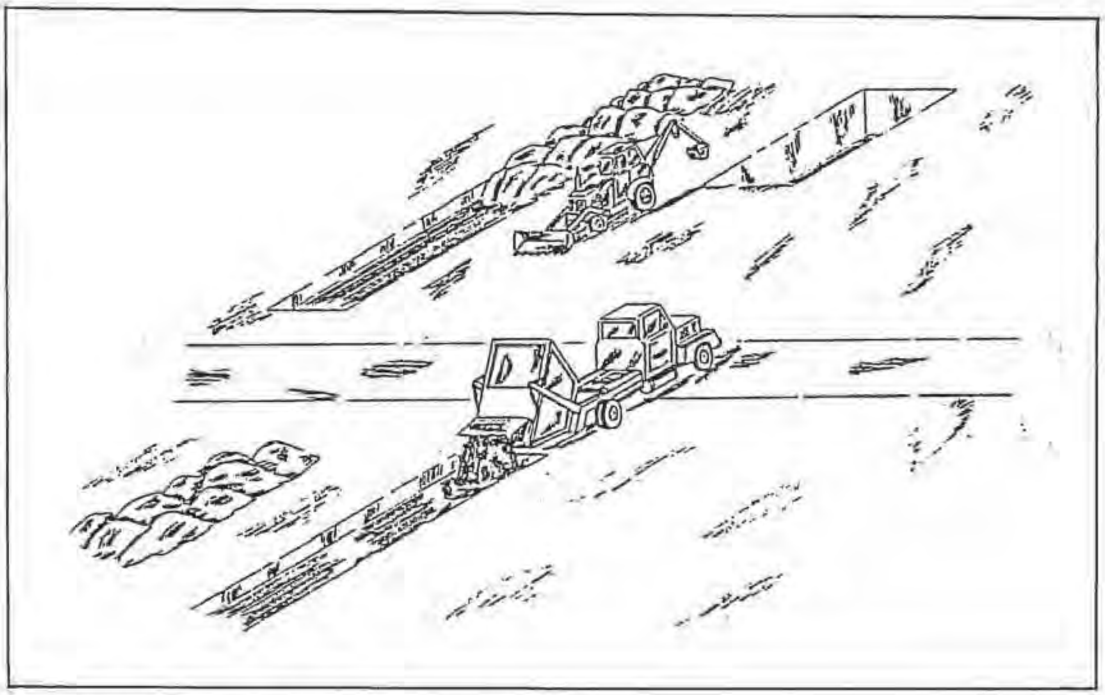

Figure 7-14. Narrow Trench Operation

Source: Process Design Manual for Municipal Sludge Landfills, EPA - 625/1-78-010, SW-705, October 1978.

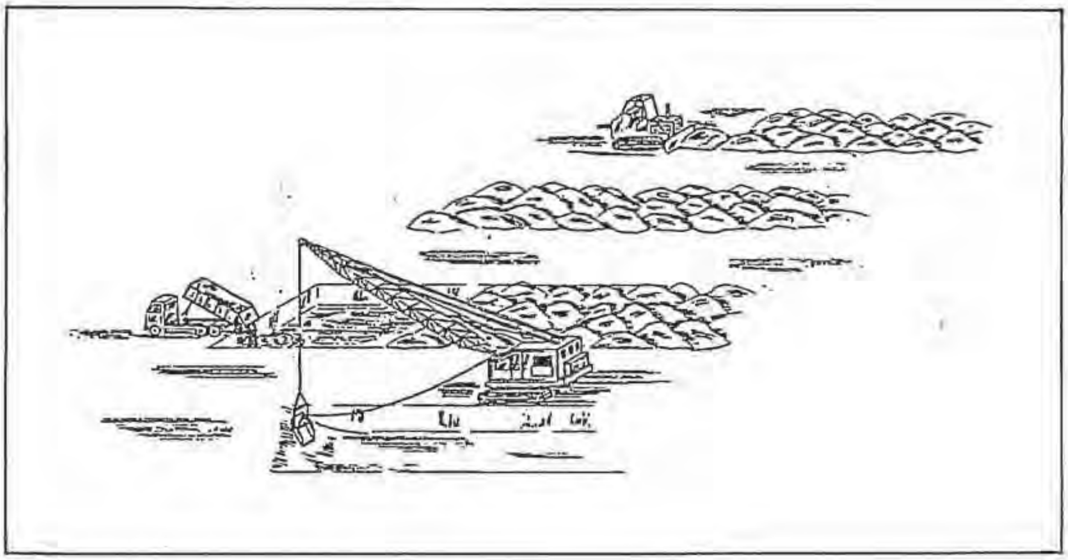

Figure 7-15. Wide Trench Operation

Source: Process Design Manual for Municipal Sludge Landfills, EPA - 625/1-78-010, SW-705, October 1978.

over that trench. However, occasionally it is immediately applied as cover over an adjacent waste-filled trench.

Cover material may be applied to wide trenches in either of two ways. If its solid content ranges from 40 to 60%, the waste in the trench is incapable of supporting equipment. Therefore, cover should be applied in a 3- to 4-ft (0.9- to 1.2-m) thickness by equipment based on solid, undisturbed ground adjacent to the trench. In this way, a wide trench may be only slightly more than 10 ft (3 m) wide (using a front-end loader to apply cover) or up to 50 ft (15 m) wide (using a dragline to apply cover). Alternatively, if its solids content is 60% or more, covered waste in the trench is capable of supporting special equipment. Track dozers are the most useful equipment in this application.

Area Fill. For sludge-only area fills, waste is usually placed above the original ground surface. Because excavation is not required and waste is not placed below the surface, area fill applications are particularly useful in areas with shallow groundwater or bedrock. The solids content of waste is not necessarily a limiting factor. However, because side wall containment (available in a trench) is lacking and equipment must be supported by the waste in most area fills, waste stability and bearing capacity must be relatively good. To achieve these qualities, soil is usually mixed with the waste as a bulking agent. Since excavation is generally not performed in the landfilling area, and since shallow groundwater or bedrock may prevail, the large quantities of soil required must usually be either hauled from other on-site locations or imported from off site.

Because of the likely proximity of groundwater or bedrock to the ground surface, the installation of a liner will often be required at area fills. Because filling proceeds above the ground surface, liners can be more readily installed at area fill operations than at trench operations. With or without liners, surface runoff of moisture from the waste and contaminated rainwater should be expected in greater quantities at area fills, and appropriate surface drainage control facilities should be considered.

In area fills, the landfilling area usually consists of several consecutive lifts or applications of waste/soil mixture and cover soil. As with any landfill, cover should be applied as necessary to provide stability for additional lifts.

Three submethods have been identified under area fill applications: area fill mound (Figure 7-16), area fill layer (Figure 7-17), and diked containment (Figure 7-18).

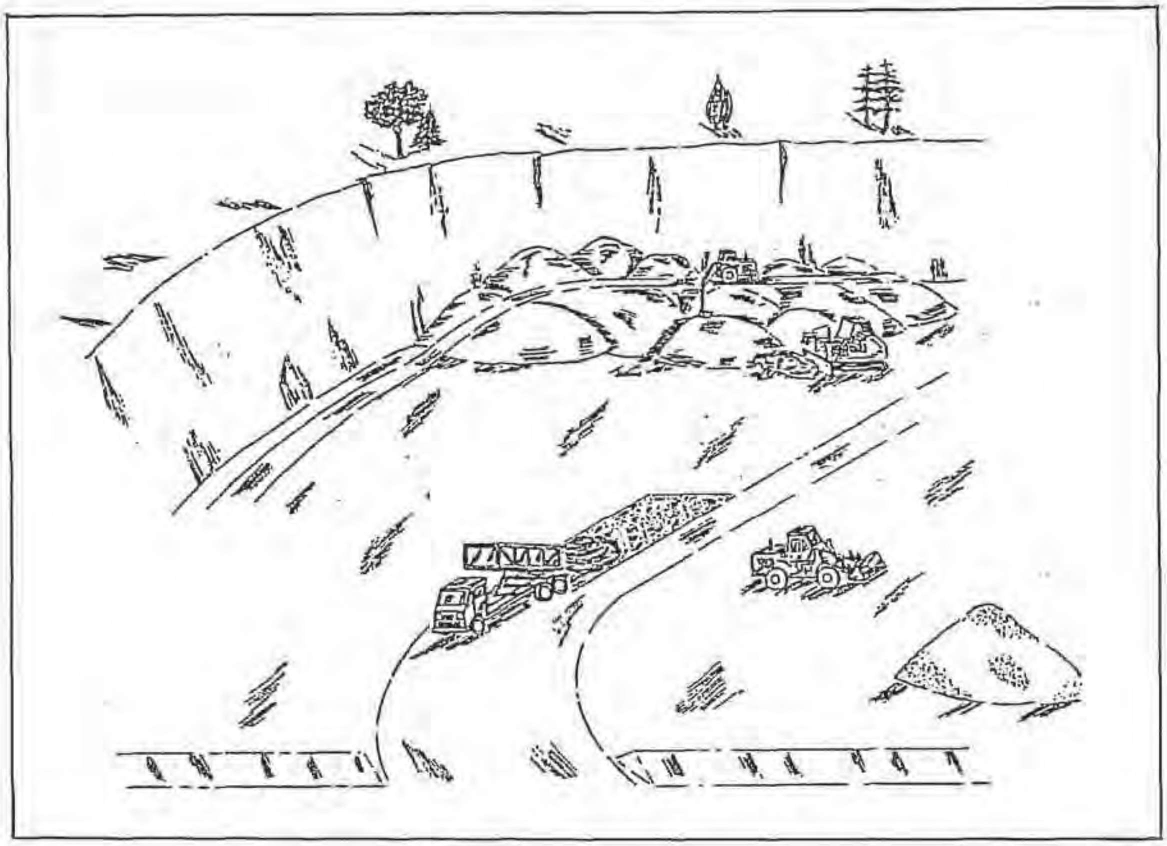

Figure 7-16. Area-Fill Mound Operation

Source: Process Design Manual for Municipal Sludge Landfills, EPA - 625/1-78-010, SW-705, October 1978.

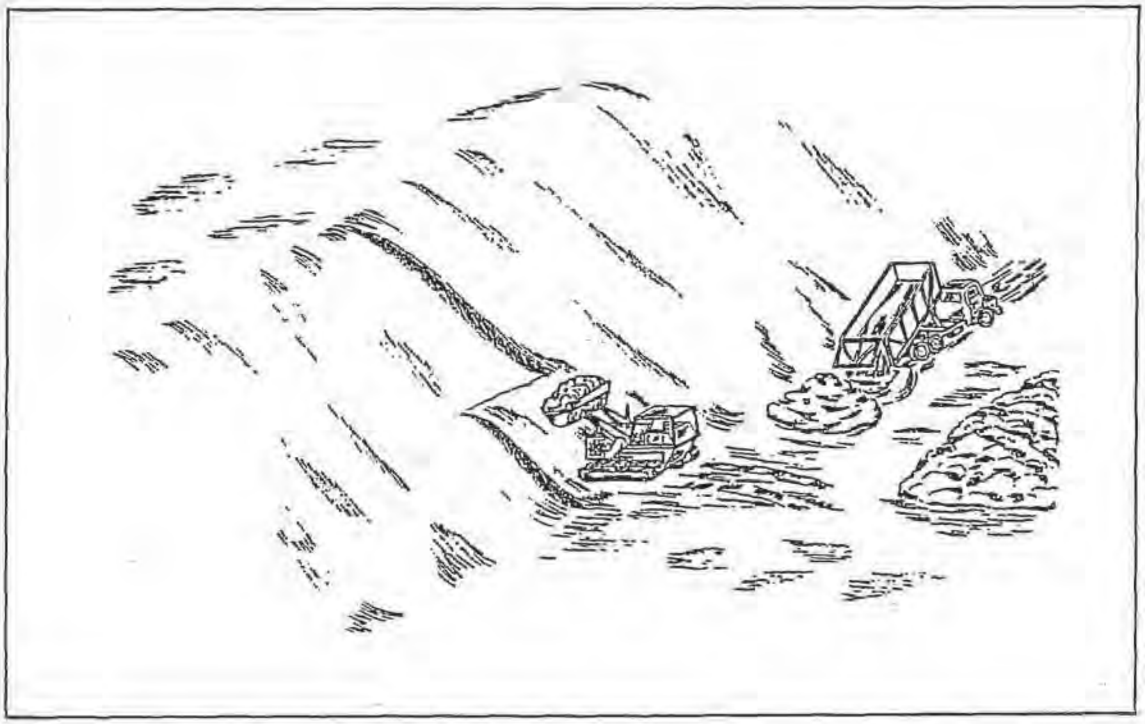

Figure 7-17. Area-Fill Layer Operation

Source: Process Design Manual for Municipal Sludge Landfills, EPA - 625/1-78-010, SW-705, October 1978.

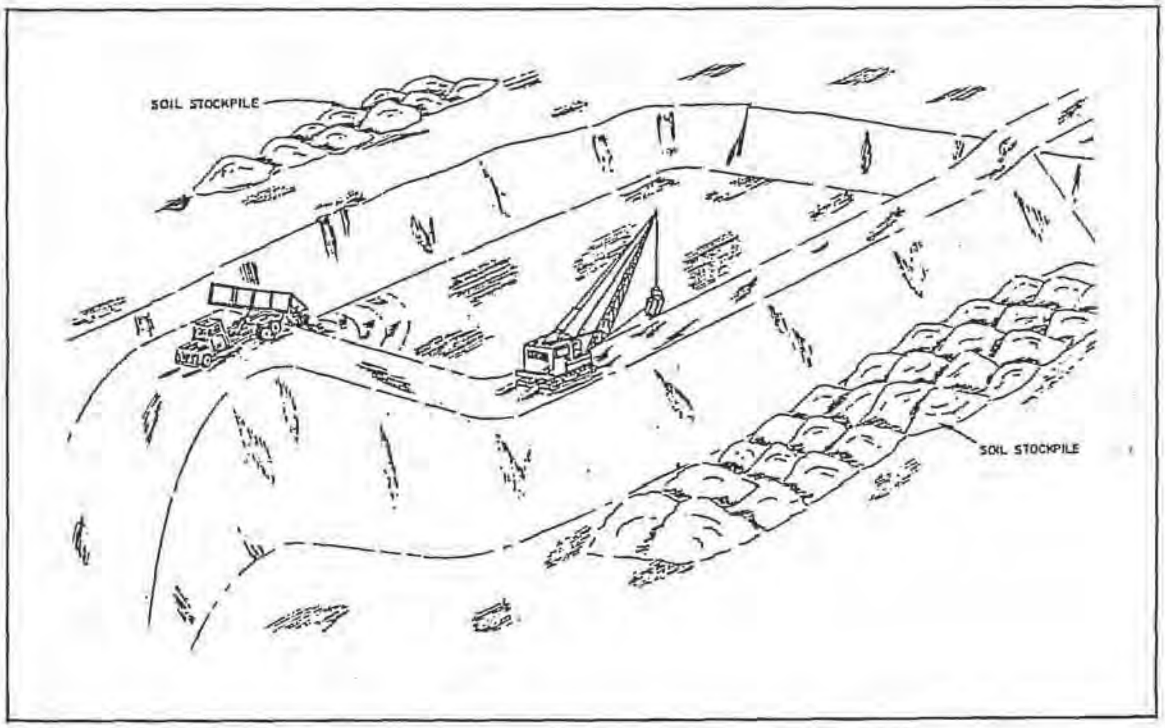

Figure 7-18. Diked Containment Operation

Source: Process Design Manual for Municipal Sludge Landfills, EPA - 625/1-78-010, SW-705, October 1978.

In area fill mound applications, it is recommended that the solids content of waste received at the site be no lower than 40%. Waste is mixed with soil (1 part waste to 0.5 to 2 parts soil) to produce a mixture with more stability and greater bearing capacity. The exact ratio employed will depend on the solids content of the waste as received, and the need for mound stability and bearing capacity (as dictated by the number of lifts and equipment weight).

The waste/soil mixing process is usually performed at one location, and the mixture is hauled to the filling area. At the filling area, the waste/soil mixture is stacked into mounds approximately 6 ft (1.8 m) high. Cover material is then applied on top of these mounds in a 2- to 3-ft (0.6- to 0.9-m) thick application. This cover thickness may need to be increased if additional mounds are applied on top of the first lift. Because equipment may pass over the waste during mixing, mounding, and cover operations, lightweight equipment with swamp pad tracks is generally recommended for area fill mound operations. However, heavier wheeled equipment may be more appropriate in transporting bulking material to and from soil stockpiles.

Area fill mound operations are usually conducted on level ground to prevent mounds from flowing downhill. However, if a steeply sloping site is selected, a level mounding area can be prepared into the slope and a side wall created for containment of mounds on one side.

In area fill layer applications, waste received at the site may contain as low as 30% solids. Waste is mixed with a soil bulking agent to produce a mixture with more stability and greater bearing capacity. Typical bulking ratios range from 0.25 to 2 parts soil for each part waste. As with area fill mounds, the ratio will depend on the solids content of the waste, and the need for layer stability and bearing capacity (as dictated by the number of layers and the equipment weight).

This mixing process may occur either at a separate waste dumping and mixing area or in the filling area. After mixing the waste with soil, the mixture is spread evenly in layers from 0.5 to 3 ft (0.15 to 0.9 m) thick. This layering usually continues for a number of applications. Interim cover between consecutive layers may be applied in 0.5- to 1-ft (0.15- to 0.3-m) thick applications. Final cover should be from 2 to 4 ft (0.6 to 1.2 m) thick.

As with mounding operations, equipment will pass over waste during mixing, layering, and cover operations. Accordingly, lightweight equipment with swamp pad tracks is generally recommended for area fill layer operations. However, heavier wheeled equipment may be appropriate for hauling soil. Slopes in layering areas should be relatively flat to prevent the waste from flowing downhill. However, if the waste solids content is high and/or sufficient bulking soil is used, this sliding effect can be prevented and layering can be performed on mildly sloping terrain.

In diked containment applications, waste is placed entirely above the original ground surface. Dikes are constructed on level ground around all four sides of a containment area. Alternatively, the containment area may be placed at the toe of a hill so that the steep slope can be utilized for containment on one or two sides. Dikes would then be constructed around the remaining sides.

Access is provided to the top of the dikes so that haul vehicles can dump waste directly into the containment area. Interim cover may be applied at certain points during the filling, and final cover should be applied when filling is discontinued.

The solids content of waste received at diked containments should be a minimum of 40%. For wastes with a solids content between 40 and 60%, cover material should be applied by equipment based on solid ground above the dikes. Thicknesses should be 1 to 2 ft (0.3 to 0.6 m) for interim cover, and 3 to 4 ft (0.9 to 1.2 m) for final cover.

For wastes with a solids content of 60% and above, cover material should be applied by equipment which pushes and spreads cover soil into place as it proceeds out over the waste. For this situation, a track dozer is the best equipment for cover application.

Usually, diked containment operations are conducted without the addition of soil bulking agents. Occasionally, however, soil bulking is added. Under these circumstances, soil may be added to increase the solids content and to allow the operations as described above.

Landfill Selection Criteria. The advantages and disadvantages of specialized landfilling methods which are suitable for the conversion of utility wet disposal sites to dry sites are identified in Table 7-4.

In practice, the selection of a landfilling method is an integral part of the site selection process, since the acceptability of a given site is contingent on the landfilling method to be employed. Likewise, the acceptability of a given landfilling method is dependent upon the site where it is to be employed. In turn, the

Table 7-4

SPECIALIZED LANDFILLING METHODS SUITABLE FOR CONVERSION OF WET DISPOSAL SITES: ADVANTAGES AND DISADVANTAGES

Method	Advantages	Disadvantages
Trench Fill	Lower surface runoff than in area fill methods. Liners are less often required than for area fill. Surface drainage control facilities less often required than for area fills. Does not require importing soil. Does not require bulking with soils.	Requires deep groundwater or bedrock areas.
--Narrow Trench	Ability to handle waste with relatively low solids content.	Relatively land-intensive compared to wide trench. Lower application rates than for other methods. Liners are impractical to install.
--Wide Trench	Less land-intensive than narrow trench. Liners can be installed easier than in narrow trench. Excavation may proceed closer to bedrock or groundwater in wide trenches with liners than in narrow trenches without liners.	Need for a higher solids waste than narrow trenches. Wastes with 64% solids do not spread out evenly when applied above the trench side wall. Need for flatter terrain than for narrow trenches.

Table 7-4 (continued)

Method	Advantages	Disadvantages
Area-Fill	Useful in areas with shallow groundwater or bedrock. Waste solids content not necessarily limited. Liners can be installed easier than at trench operations.	Large quantities of soil for bulking are required. Liners are often required. Higher surface runoff than in trench operations. Surface drainage control facilities may be required.
--Mound	Good land utilization.	Constant need to push and stack slumping mounds. Higher manpower and equipment requirements than in other methods.
--Layer	Completed fill areas are relatively stable. Maintenance requirements lower than for area fill mounds. Manpower and equipment requirements lower than for area fill mounds.	Poor land utilization compared to other area fill methods.
--Diked Containment	Individual diked containments are are relatively large. Efficient land use.	Higher leaching than in other methods. Liners and other leachate controls may be required. Higher capital cost than other methods due to the construction of dikes.

acceptability of both the landfilling method and the site is contingent on the characteristics of the waste received. Consequently, a thorough investigation of waste characteristics should be performed first, with investigations of sites and landfilling methods to follow.

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Section 8

SITE CLOSURE PROCEDURES

Closure and post-closure monitoring of a retired utility waste disposal site is considered to be the last phase of waste management at the site. Acceptable closure practice should as a minimum be:

- Technologically sound with respect to protection of local water resources.
- In compliance with regulatory requirements.
- Compatible with the projected end use of the site.

In this section, the following aspects of site closure are discussed:

- Current site closure practices and their deficiencies.
- Recommended site closure procedures.
- Elements of a formal site closure plan.

The specific engineering elements of site closure are reviewed in general terms here. Detailed engineering guidelines are often included by reference to other sections of this report, as well as to EPRI's FGD sludge and coal ash disposal manuals.

CURRENT SITE CLOSURE PRACTICES AND THEIR DEFICIENCIES

The most common closure practices employed for retired utility waste disposal sites are (1) covering with soil followed by revegetation; (2) pond draining and backfilling with soil; and (3) pond abandonment.

Covering followed by revegetation is the most common method of closing a utility waste landfill. Federal regulations require a minimum 2 ft (61 cm) of cover soil for sanitary landfills, although EPRI's FGD Sludge Disposal Manual (CS-1515) (1) suggests that 6 in. (15 cm) is generally sufficient to revegetate most FGD waste landfills (1). Soil cover of a completed landfill is either taken from topsoil stockpiled during site excavation or by "borrowing" from an on-site pit (1, 2). Imported soil specifically chosen for final cover of the fill has also been occasionally used. Once soil cover is in place, it is graded and contoured to divert runoff and to minimize infiltration and erosion (1-3). These practices are described in detail in Section 6.

Revegetation is established on a completed landfill to provide an aesthetically pleasing appearance and to stabilize slopes against erosion which can lead to blowing ash and silting of streams (4). Plant species commonly chosen for revegetation include grasses, clovers, and herbs (4, 5). Research has also been conducted on other species, including beets, legumes, trees, and bushes (5-7).

Pond draining followed by soil backfill calls for the discharge of supernatant water from an ash or sludge pond to a nearby surface water body. After the free water is drained out, the site is covered with an inert material, graded, and revegetated. An NPDES permit is required for discharge.

Pond abandonment is common in areas where land development is not pronounced, and where site reclamation is not economically justified. Site "abandonment," despite its negative connotation, can be an environmentally acceptable method of site closure if it is compatible with local hydrology and land use. The buffer area around the pond can be landscaped and revegetated, and the site fenced to limit public access. A good example of the site closure of a pond is the CAPCO Bruce Mansfield plant, which is planned for use as a recreation area following closure. Pond abandonment is also common in areas where evaporation exceeds precipitation, such as the southwest; in these areas, ponds are allowed to dry without direct discharge to surface waters.

Not all sites are being closed in accordance with the prevailing regulations or sound waste disposal engineering practice. Common deficiencies in current site closure practices include the following:

- Lack of provision to minimize surface water infiltration due to highly permeable or otherwise inadequate soil cover.
- Lack of provision for leachate and waste washout control.
- Lack of post-closure maintenance and monitoring.

Deficiencies associated with pond abandonment are of greatest concern, because they favor leachate generation. This is particularly a problem with untreated FGD sludges which are generally more permeable and soluble than other utility wastes (8). Because ponds by design maintain a hydraulic head of standing water above the settled waste, there is little that can be done to eliminate leachate generation and migration. The addition of finely divided materials (e.g., clay or fly ash) or sealing chemicals can help retard leachate generation but generally will not prevent it. For this reason, ponding has fallen into disfavor with EPA as a permanent method of waste disposal.

Stabilized FGD sludges, while generating a leachate of comparable quality to raw FGD sludges, are considerably less permeable, and thus produce lower mass emissions than raw sludges (9). Alkaline fly ash releases relatively fewer metal contaminants and possesses self-sealing capabilities (10, 11); acid fly ashes are much more readily leachable (4). Bottom ash is essentially inert (4).

SITE CLOSURE PLANNING AND IMPLEMENTATION

Separate closure procedures are recommended for landfills and for ash/ FGD sludge ponds. Procedures for closing a landfill, when either a distinct segment or an entire site has been filled to capacity, include the following steps:

- Cover the fill with topsoil and compact the cover.
- Install surface liner (surface sealing) prior to applying final cover if adequate soil cover material is not available.
- Grade the soil-covered area; depressions and cracks should be filled using on-site or borrowed soil.
- Revegetate the area with appropriate plant species (optional, depending on the projected end use of the finished site).
- Outline a timetable to ensure that the following features are inspected at regular intervals:

  --Settlement, cover soil integrity, and need for regrading.

  --Vegetation.

  --Sediment and erosion controls.

  --Leachate control.

  --Monitoring.

For ash/sludge ponds, the proper site closure steps are as follows:

- Drain supernatant water out to sewers leading to a nearby wastewater treatment plant (if available and acceptable) or to a surface water body such as a creek, river, or lake following appropriate treatment. An approved NPDES permit is required for the latter discharge. In cases where an existing pond poses a direct hazard to potable ground or surface water, the waste must be excavated/pumped out and reburied at an approved landfill (see Section 7).
- Backfill the pond with inert material, such as stockpiled soil.

- Install a surface liner (surface sealing) if soil cover is inadequate to minimize rainwater infiltration.

- Grade, revegetate, and set a maintenance/monitoring timetable as outlined in closing procedures for ash landfill.

These recommended site closure procedures call for the use of several specific techniques, which are described in more detail in the following pages. Each closure element is discussed in terms of design considerations, material and equipment requirements, and installation techniques. When some details of a given closure element (or the element itself) have already been presented in a related section of this manual, they are given by reference only.

Final Cover and Grading

Final soil cover (along with daily and interim cover) is a legal requirement in most states. Appropriate final cover will comply with requirements of air, surface, and groundwater protection concerning dust, erosion, and leachate contamination. Functions of the final soil cover will include infiltration and leachate generation control, vegetation support, support of vehicular traffic, erosion resistance, and dust control. Techniques for final cover of a completed landfill are described in Section 6. The total thickness of the cover, as specified under current federal standards, is 6 in. (15 cm) of clay and 18 in. (45 cm) of other material.

Proper grading of final cover at utility waste disposal sites is essential. The selection and maintenance of suitable surface grade serves the following purposes:

- Reduces ponding, which minimizes the infiltration of surface water.

- Reduces the rate of leaching of waste contaminants.

- Reduces soil erosion and helps establish and maintain vegetative cover.

The end use of the site has an influence on the design criteria for grading. Completed landfills have been used for light construction (particularly parking areas and industrial parks), and recreational areas. Minimal slopes are suggested for sites used for recreational purposes.

Finished landfill surfaces require drainage protection in the form of benches, interceptors, and planting. To prevent erosion, benches should be constructed on side slopes at intervals not to exceed 25 ft (7.6 m) measured vertically. Ideally, where the property line is far enough from the toe of the fill, benches should be at least 8 to 10 ft (2.4 to 3.1 m) wide (most construction equipment is 8 ft, or 2.4 m, wide or wider) and be provided with paved terrace drains. Filled slopes higher than 50 ft (15.2 m) measured vertically should be provided with horizontal benches with a minimum width of 15 ft (4.6 m). Interceptor drains should be constructed at the top of the fills, and paved drains should be provided to carry runoff down the slopes. Terrace drainage should be provided to carry runoff down the slopes, and should not contribute to erosion. Velocities should not be less than 4 ft/sec (122 cm/sec) nor greater than 8 ft/sec (244 cm/sec) (12). For detailed information on grading and surface control techniques, the reader is referred to Section 6.

Revegetation

Establishment of vegetation on a completed landfill site can help to prevent or minimize the contamination of surface and groundwater. An appropriate revegetation design will perform the following functions:

- Minimize infiltration by enhancing evapotranspiration.
- Minimize water and wind erosion of cover materials through the stabilizing effect of the plant root system.
- Discourage surface runoff by using the water retention capability of cover vegetation.
- Enhance the final appearance and use of the completed site by providing buffers and visual screens.

Factors influencing selection of plant species and revegetation procedures are discussed in Section 6.

Pond Draining and Backfilling

The first step in closing a utility waste disposal pond involves pumping out supernatant water prior to earth backfill. The reader is referred to Section 7 for a detailed discussion of pond draining.

Earth backfilling of an excavated landfill or drained pond is a special form of final cover; the thickness of soil cover is the only real difference. Soil selection criteria are essentially the same as for final cover. Factors dictating the thickness of earth fill include:

- Depth of depression (i.e., drained pond or re-excavated landfill).
- General topography of the area.
- Expected end use of the site.

For earth backfill considerations, the reader is referred to Section 6.

Surface Sealing

Surface sealing is achieved by installing a liner on the surface of a completed disposal site. The technique has recently been applied to the control of surface water infiltration into the site and eventual prevention of groundwater contamination. Surface sealing is utilized before final cover is placed. In areas experiencing high annual rainfall or where impermeable soil cover is not available, this method of leachate control is sometimes warranted, and has actually been used at several chemical waste disposal sites. Since no definite design criteria specify liner materials to be utilized, cost is a major influence. In addition, the projected use of the completed site has a bearing on the type of liner material to be utilized. Liner installation guidelines are presented in Section 9.

It should be stressed that although this control method alleviates the problem of surface water seepage into the site, thus reducing the production of leachate within the site, groundwater contamination may still result from groundwater movement through the waste from underneath the site. Procedures to impede the movement of groundwater through the fill are discussed in Section 6.

The projected end use of the site and the high cost of liners are the major considerations in the selection of surface liners. Some liner materials are more prone to puncture under stress. Thus, if heavy traffic is anticipated on the completed site, these materials should be avoided.

The list of materials proposed for use as disposal site surface liners include conventional paving asphalt, hot sprayed asphalt, asphalt-sealed fabric, polyethylene (PE), polyvinyl chloride (PVC), butyl rubber, hypalon, ethylene propylene diene monomer (EPDM), chlorinated polyethylene (CPE), compacted clay, and mixtures of native soil with either bentonite, or cement (13). All of these materials have been used to line the bottoms of landfills and impoundments, providing an impervious layer for protection of the groundwater table. These materials could also be applied as surface liners to prevent rainwater infiltration into the disposed waste.

For the proper installation of surface liners, the landfill surface upon which the liner will be placed must be smooth and compacted. In many cases, soil should be applied to a minimum depth of 6 in. (15 cm) before the liner is installed (13). This provides a layer of protection between the waste cell and the liner material, and prevents punctures and chemical decomposition. A minimum of 6 in. (15 cm) of soil cover should be provided for revegetation and protection of the liner (13). This cover should be free of sharp objects and jagged rocks. In addition to these practices, proper grading should be provided to avoid any ponding above the liner which might hinder growth of vegetation. Temporary stabilization techniques should be provided along with vegetation to protect against erosion of the soil cover. Routine maintenance of the liner should include field inspection and puncture repair.

Post-Closure Maintenance and Monitoring

The purposes of post-closure maintenance and monitoring of groundwater are to preserve site integrity, to prevent exposure or escape of disposed ash, and to minimize subsurface contamination. The degree of post-closure maintenance/monitoring required at ash disposal sites is largely dependent upon the post-closure use of the site, and the associated federal/state regulations.

As was discussed in Section 3, the post-closure plan for a given site (i.e., type of maintenance/monitoring, and length of time for post-closure care) is determined on a case-by-case basis under federal regulations for nonhazardous waste disposal. Post-closure care normally consists of routine maintenance and groundwater monitoring. Some states require several years of post-closure care, including water quality monitoring. Other states do not address post-closure maintenance in their regulatory requirements. It is advisable to remain current on developing regulations in such states.

For routine site maintenance, visual inspection and monitoring should be performed on a regular basis, preferably once every 3 months. The following items should be checked for their condition/activity:

- Surface Cover:

  --Cracking, erosion, or stagnant water on the site surface.

  --Signs of excessive resettlement.

  --Signs of puncture on surface liner (e.g., presence of deep rooted plant species).

  --Site use by off-road vehicles, such as motorcycles, which can cause unwanted loss of erosion protection.

- Vegetation:

  --Esthetically pleasing appearance of vegetation, if visible to the public.

- Erosion and Sediment Control Structures (e.g., interceptor ditches, diversion ditches):

  --Structural integrity.

  --Accumulated sediment (should be removed in order to ensure the functioning of these structures at design levels).

It is advantageous to develop an inspection checklist which addresses all appropriate items listed above and their current condition. The checklist will ensure a complete inspection, and signal the need for prompt and appropriate attention to a recognized problem. An example post-closure inspection checklist is shown in Table 8-1.

Post-closure groundwater monitoring is mandatory in some states, and may be required by the U.S. EPA (see Section 3). Its objective is to prove that the site has been properly closed, and that closure poses no threat to the underlying groundwater.

Post-closure groundwater monitoring is expensive, particularly if new or additional monitoring wells are needed. The design of a long-term post-closure monitoring system is based on the following considerations:

- The presence of an existing monitoring well system at the site.
- The potential for groundwater contamination (even if all original design measures have been followed).
- Federal/state regulatory agency requirements governing monitoring activity in the post-closure plan.

When establishing a groundwater monitoring system, the following steps are taken:

- Well location selection.
- Well installation.
- Water sample collection.
- Water sample analysis.
- Data interpretation.

Highlights of these steps are presented below. For a detail discussion, the user is referred to the EPRI Coal Ash Disposal Manual (CS-2049) (14).

Well location selection applies only to sites without an existing monitoring well system, unless the system is considered inadequate. Knowledge of the direction of groundwater flow is crucial for selecting a well location. A typical monitoring network could consist of one upgradient well and three downgradient well points (14). The downgradient wells should be located as close to the disposal area as possible to provide an "early warning" if leakage occurs.

Monitoring wells should be installed in such a manner that any leachate plume generated by the disposal site will be intercepted. Leachate migration into groundwater

Table 8-1

POST-CLOSURE SITE INSPECTION CHECKLIST
Sheet 1 of __
Date ______________

Subject Needed	Items to Inspect	Previous Status*				Current Status				Comments/Action
		OK	$1^{\dagger}$	$2^{\#}$	3^{**}	OK	$1^{\dagger}$	$2^{\#}$	3^{**}	
Soil Cover-Surface Liner	Cracking Ponded water Erosion Excessive settlement Puncture									
Vegetation	Density Appearance									
Surface Water-Erosion Control	Excessive erosion Excessive sedimentation Structural integrity									
Sediment Control Structures	Structural integrity Sediment accumulation									Cleaning needed Y N

Monitoring Wells Damaged Y N# Last Sampling Date ____________# Sampled This Inspection Y N

* Show results of previous inspection for comparison.
† A checkmark indicates a potential problem and a need to monitor the situation carefully.
\# A checkmark indicates a need for future maintenance.
** A checkmark indicates a need for immediate action.

Note: Attach sketches and descriptions of any current status notations other than "OK".

Table 8-1 (continued)

Attachments:

1. Groundwater Monitoring Data Sheet Y N
2. ______________________________
3. ______________________________
4. ______________________________

Inspector ______________________________ Approved ______________________________ tends to enter as a plume(1, 14). Downgradient wells should be drilled to various depths to ensure plume interception. Casing for monitoring wells should be made of PVC rather than steel to avoid contamination of samples. Collection of representative samples from a groundwater monitoring well is critical. Practically, the well must be flushed before a sample is taken. When a well is installed in permeable soils, a flushing volume ranges from two to more than five well casing volumes. A well in low-permeable soil should be pumped dry, and the incoming water collected for analysis.

Prior to obtaining any samples, the parameters of interest must be identified. These parameters may be dictated by regulatory requirements. Advanced knowledge on monitoring parameters is needed for the selection of sample size and preservation method. Well water samples can then be taken by baling, pumping, or by use of a bubbler sampler (14).

In terms of sampling frequency, it is recommended that samples be taken on a quarterly basis. However, regulatory requirements or site conditions may dictate a different sampling schedule. When the monitoring program is required by federal/state regulatory agencies, it is more likely that the water samples will have to be analyzed by a state-approved chemical laboratory.

Analytical data from on-site and downgradient water samples should be compared with those of upgradient water samples (i.e., background water data) and with groundwater quality standards (see Appendix B) (15). In particular, a distinction should be made between water quality changes due to seasonal variation and changes caused by contaminants originating from disposed wastes.

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Section 9

LINER SELECTION AND INSTALLATION

Waste disposal sites may be lined with materials which impede the movement of leachate away from a site. Liners have conventionally been used to restrict seepage from lagoons, ponds, canals, reservoirs, and landfills. However, many traditional lining materials, such as concrete, asphalt, metal, and clayey soils, have not proven entirely satisfactory for waste containment. Some of these materials are vulnerable to fracture, permeation, or corrosion, while others are too costly for large projects. As a result, the use of polymeric materials to restrict leakage has increased.

The use of surface impoundments and landfills to store and dispose of FGD sludge, fly ash, and bottom ash is common practice in the utility industry. With more stringent requirements for groundwater pollution control, many existing facilities will need to be upgraded, and new facilities will be designed so that leakage of contaminants or leachate from the disposal facilities can be prevented. In situ soils may not meet the governing regulatory requirements for subsurface protection. Thus, high-integrity materials having low permeability will find increased application in the utility and other industries. A utility engineer confronted with the prospect of lining a waste disposal site must therefore be aware of the available lining materials, their applicability to the particular site and waste, and the drawbacks to specific liner applications.

The number of power plants which have lined landfills or ponds is not currently known. A partial list of lined utility waste disposal facilities is presented in Appendix C. The performance of these liners has not been evaluated by these facilities. The success or failure of a particular liner material will depend on the characteristics of the waste (or waste mixture), design specifications, construction techniques, and operation of the facility.

While there is extensive experience in the utility industry with the installation of liners, there is little knowledge of long-term waste/ liner interactions and the associated leak potential. EPRI has contracted for some major research (RP-1457) in the field of liner/utility waste compatibility. Preliminary results should become available in 1982.

Although the use of liners is an obvious option in complying with regulatory standards, there are some fundamental questions to be answered when considering lining a disposal site. These questions pertain to (1) the comparative economic advantages of different liner systems, (2) regulatory requirements and acceptance, (3) liner material selection and design risks, and (4) contractor selection and guarantees.

In this section, various types of lining materials will be described, followed by guidelines for their selection, design, and installation.

TYPES AND CHARACTERISTICS OF LINERS

Many different types of lining materials are commercially available for land disposal facilities. These include clays, admixes, polymeric membranes, spray-on materials, chemical absorbants, etc. (1 - 6). Many of these materials have been used to contain water and potentially polluting fluids. Each of these generic types has advantages and disadvantages associated with its characteristics, environmental factors, and the wastes contained. Table 9-1 lists some commonly used lining materials; their characteristics are discussed below.

Clays

Natural clayey soils have been used to contain a variety of industrial wastes, including utility solid wastes. The use of clayey soils as liners is normally based on their quality (i.e., clay content, low permeability, swelling, etc.), availability, and depth of deposit. The permeability of clayey soils can be as low as 10^{-9} cm/sec if properly compacted.

The best known form of clay for lining and sealing is bentonite, a sodium-montmorillonite possessing a high degree of swelling, impermeability and high attenuating capacity for cations and heavy metals (7). Treated bentonite clays are also available (6, 8). To produce these, the bentonite is either chemically treated or polymerized so that the final product inhibits contact between the contaminants in water and the bentonite itself. These types of "encapsulated" bentonites are claimed to be highly resistant to organic and inorganic contaminants alike (8).

Transportation is a major cost element if clay is to be imported from other areas. Since large deposits of bentonite are not widespread, many indigenous clays have been used to line disposal facilities.

Table 9-1

LIST OF COMMONLY USED LINING MATERIALS

- Clays
  - Clayey soils
  - Bentonite
- Polymeric Membranes
  - Chlorosulfonated polyethylene (CSPE)
  - Polyvinyl chloride (PVC)
  - Ethylene propylene rubber (EPDM)
  - Butyl rubber
  - Chlorinated polyethylene (CPE)
  - Neoprene (chloroprene rubber)
  - High-density polyethylene (HDPE)
- Admixes
  - Asphalts (hydraulic asphalt concrete, asphalt panels, sprayed-on asphalt membranes)
  - Soil cements
  - Stabilized FGD sludge

Clay liners are plastic and can deform with earth settlement and movement. Problems can arise when these movements exceed the plastic limit of the clay, causing a break in the clay and allowing the release of contaminants. Clay liners must be kept wet at all times to prevent drying and subsequent shrinkage and cracking.

In one case where soil bentonite (saline seal) and compacted clays were each exposed to various industrial wastes, including caustic petroleum sludge, acidic steel pickling wastes, and electroplating sludges, liner deterioration was observed (4). In many of these examples, the level of ionic salts present was sufficient to reduce the swelling index of bentonite and impair its effectiveness as a liner. These two liner materials, however, were resistant to oily refinery sludge, rubber and plastic wastes, toxic pesticide formulations, and toxic pharmaceutical wastes (4).

The general advantages and disadvantages of clay liners are summarized below:

Lining Material	Advantages	Disadvantages
Compacted native clayey soils	• No need for imported material. • Low cost. • Low permeability. • Wide applicability.	• Permeability can vary depending on compaction. • Very difficult to detect leaks. • Must be kept moist at all times; prone to develop cracks if dried out. • Little resistance against weathering and many chemicals. • Resistance to waste contaminants questionable.
Bentonite	• High swelling to fill voids. • Reatively low cost in comparison to other liners. • Relatively long service life. • High cation exchange capacity. • Easy to install.	• Must be imported in many cases • Must be covered above water line. • Can lose its low permeability through collapse of structure due to high ion concentration in the waste.

Admixes

Admixes or admixed liners have been used in the impoundment of water. All of them are hard-surface materials which are constructed in place. There is little information on the use and performance of admixes as liners at waste disposal facilities.

Asphalt. Asphalt liners are normally used for erosion control above the normal water level. However, several types of asphalt liners have been used at sanitary landfills (2). Asphalt materials have been shown to be resistant to acids, bases, and inorganic salts; they are susceptible to organic solvents and chemicals, particularly hydrocarbons (9).

There are five types of asphalt liners: hydraulic asphalt concrete, asphalt panels, hot-sprayed membrane, rubber-modified asphalt, and emulsion sprayed on a geotextile or fabric.

Hydraulic asphalt concretes are controlled hot mixtures of asphalt cement and high quality aggregate, compacted into a uniform dense mass. When compacted properly, these materials have a permeability in the range of 10^{-7} to 10^{-9} cm/sec. They are stable on side slopes, resisting slip and creep, and retain enough flexibility to conform to slight deformations of the subgrade.

Prefabricated asphalt panels have been used as liners for water reservoirs. The panels are rugged and flexible; when properly installed and seamed, they form a relatively smooth watertight seal exhibiting the resistance characteristics of asphalt concrete described above. Some problems occur with aging in hot dry climates, causing panels to become somewhat brittle and shrink.

Sprayed-on asphaltic membranes are usually prepared by spraying hot asphalt on a prepared soil surface. The finished membrane is about 0.25 in. (0.64 cm) thick, formed by two or more passes of the spray device; sections are overlapped by 1 to 2 ft (30 to 60 cm). These membranes retain their tough flexible qualities indefinitely when properly covered and protected from mechanical damage (9). The addition of 3 to 5% rubber improves the properties of the asphalt by inducing greater resistance to flow, increased elasticity and toughness, decreased brittleness at low temperatures, and greater resistance to aging (10).

Rubber modified asphalt membranes are formed by applying one coat on horizontal surfaces or two coats on vertical surfaces. The membrane is about 50 mil (12.5 mm) thick and has good UV stability and low temperature ductility, eliminating the need for a soil cover in most cases (11).

Emulsions of asphalt in water can be sprayed at ambient temperatures onto a supporting geotextile or fabric to achieve increased toughness and dimensional stability. These have been used for lining ponds and canals and as reinforcing patches under asphalt concrete overlays to prevent "reflection" of cracks in the old pavement beneath (6).

The advantages of asphalt materials include their availability, versatility in available physical forms, and potential for use in large-scale waterproof construction. Major disadvantages are their subgrade requirements, weathering, aging and erosion from turbulent water, and damage from mechanical equipment. The cost of asphalt liners is too high for consideration in most utility waste disposal facilities, and the limited data available indicate that asphalt liners are probably not suitable for containing most industrial wastes, including utility solid wastes (4, 12, 13).

Soil Cements. This type of lining material is composed of a mixture of soil, cement, water, and other additives. Soil cements are very hard, nonflexible compositions which have a high probability for cracking or breaking under stress caused by earth movement and settling, as well as by shrinkage during the curing process.

Preliminary data indicate that soil cements have limited chemical resistance and are probably suitable for confining such wastes as rubber and plastic wastes and oil refinery sludges (4). They are probably not suitable for holding inorganic wastes, such as electroplating sludge and utility solid wastes (4). Under test conditions, both portland cement and portland cement with lime composition have resulted in slight leakage when exposed to FGD sludge (5). Soil cements need further testing and evaluation before any recommendations can be made for their use as liner material for land disposal facilities.

The potential advantages of soil cements are their availability, relatively low cost, and wide range of applications. Major disadvantages for utility application are their subgrade requirements, prevalence of cracking between joints, and questionable permeability when exposed to utility wastes.

Stabilized FGD Sludge. Currently, there are only two commercial chemical processes commonly used to stabilize FGD sludge: the IU Conversion System Poz-O-Tec process, and the DRAVO Calcilox process. Both processes employ a mixture of FGD scrubber sludge, fly ash, bottom ash, lime, and other additives. The permeability is reported to be in the range of 10^{-6} to 10^{-8} cm/sec after curing in laboratory samples. Field permeabilities are found to be in the range of 10^{-4} to 10^{-6} cm/sec (14, 15).

Stabilized FGD sludge appears to be attractive as a lining material, since all of the essential ingredients can be found at or near the site. However, the use of stabilized sludge only to line disposal facilities has been limited. One application is at the Four Corners Station of the Arizona Public Service, which has an evaporation pond lined with 18-in. (45-cm) of compacted Poz-O-Tec. Another example is the Cheswick power station of the Duquesne Light Company, where three small wastewater ponds are lined with Poz-O-Tec.

Although stabilized sludge offers promising characteristics as a liner material, it suffers the same drawbacks as soil cements. In addition, large wastewater or sludge retention ponds that are to be lined with stabilized sludge can only be built after the power plant has been in operation for several years.

Polymeric Membranes

Flexible membrane liners are becoming increasingly popular as containment devices. Their relative ease of installation and resistance to a variety of chemicals, particularly inorganic chemicals, lend them to increased use at land disposal facilities for water pollution and gas migration control (2, 6, 16-18).

One way to classify flexible membrane liners is to group them as exposable and unexposable membranes (Table 9-2). Exposable membranes are formulated to resist ozone and ultraviolet exposure for a longer period of time than unexposable membranes. The service life of most exposable membranes is claimed to range from 15 to 30 years, whereas unexposable liners may only retain their integrity for 7 to 20 years if properly covered, or for two years if left exposed (19).

The manufacturer may incorporate variations of these materials, such as added plasticizers for greater flexibility, fabrics (scrims) to improve puncture and tear strength, and a variety of resins to increase resistance to specific chemicals and to reduce permeability and improve other physical characteristics (6, 18).

Additional information on membrane liners is available from the manufacturers and fabricators. The information must be evaluated carefully for relevance to the particular project. For a listing of companies in the liner industry, the reader is

Table 9-2

COMMON TYPES OF MEMBRANE LINERS

Exposable	Unexposable
Chlorosulfonated polyethylene (CSPE)	Polyvinyl Chloride (PVC)
Ethylene propylene rubber (EPDM)	Polyethylene (low-density)
Butyl rubber (synthetic rubber)	Polyester elastomer
Chlorinated Polyethylene (CPE)	PVC-OR (oil-resistant)
Neoprene	
High Density Polyethylene (HDPE)	
Modified HDPE	

referred to a recent EPA publication (6). Profiles of the more common membrane liners are presented below.

Chlorosulfonated Polyethylene (CSPE). CSPE, or Hypalon®, is the most widely used flexible liner at utility waste disposal facilities. Reinforced with many different scrims, it provides exceptional weather, ozone, and sunlight resistance. It is highly resistant to a wide range of corrosive chemicals (e.g., acids and alkalis), and does not support microbial growth. Service life is generally expected to exceed 20 years. Usually supplied in the unvulcanized form, it can be seamed by heat sealing or solvent welding. Among its disadvantages are its lack of hydrocarbon resistance, variability in compound formation, relatively high cost, and relatively low tensile strength when unsupported. It also has poor tensile and tear strength on aging, due to crosslinking caused by moisture, UV radiation, and heat.

Polyvinyl Chloride (PVC). PVC is another common flexible liner at utility waste disposal facilities. Its popularity stems from both its relatively low initial cost and its tolerance to a wide range of chemicals, oils, and greases. PVC can provide extended satisfactory service in many situations if covered with soil or water. It has a high strength-to-weight ratio and good resistance to puncture, abrasion, and microbial activity. PVC becomes stiff at low temperatures, making installation and maintenance very difficult in cold weather. It also has a poor tolerance to high temperatures.

Ethylene Propylene Rubber (EPDM). EPDM is a highly flexible, vulcanized rubber compound which has high resistance to weather and UV exposure, resists abrasion and tear, and has a good tolerance for temperature extremes (particularly high temperatures). EPDM is resistant to low concentrations of acids, alkalis, silicates, phosphates, and brines. It is not recommended for petroleum solvents or hydrocarbons. It can be sealed with a one-step EPDM adhesive, and has an expected service life of 15 to 25 years in normal applications.

Butyl Rubber. Butyl rubber is a vulcanized synthetic rubber with fair resistance to ozone and UV attack. It has low permeability to gases and water, and retains its flexibility throughout its service life. Butyl rubber is also highly resistant to temperature extremes, but less so than EPDM. This material has high tensile and tear strength, high puncture resistance, and desirable elongation qualities. However, it has very low resistance to hydrocarbons, petroleum solvents, and aromatic and halogenated solvents. It also possesses poor workability, seam strength, and sealability, requiring special vulcanizing adhesives.

Chlorinated Polyethylene (CPE). Presently, some utilities use reinforced CPE to line their waste disposal areas. CPE is a flexible thermoplastic that resembles a soft vinyl. It possesses excellent cold-crack resistance and good tensile and elongation strength. It has a limited range of tolerance to chemicals, oils, and acids, and poor resistance to wet and dry cycles.

CPE is unique in its compatibility with other plastics and rubbers while retaining most of its desirable characteristics, making it feasible to be used as a base material for a broad spectrum of lining materials designed for specific applications. CPE membranes are generally unvulcanized, and can thus be seamed by solvent adhesives, solvent welding, or heat sealing. Due to its elongation characteristics, it should be reinforced to prevent thinning.

Neoprene. Neoprene parallels natural rubber in some properties such as flexibility and strength. It is superior to natural rubber in resisting weathering, ozone, and UV attack. It is resistant to puncture, abrasion, and mechanical damage. Although it was developed primarily for containment of liquids with traces of hydrocarbons, it gives satisfactory service to certain waste combinations of oils and acids for which other materials are not suited for long-term use. Neoprene membranes are vulcanized, and consequently require curable adhesives to make seams. They are generally fabric reinforced and expensive compared to other membrane liners.

High-Density Polyethylene (HDPE and Modified HDPE). HDPE is a crystalline plastic material with good extensibility, tensile strength, and resistance to a broad spectrum of oils, chemicals, and solvents. It is tolerant to low temperatures. Initial material cost is low, and typical life expectancy exceeds 20 years. It possesses excellent weatherability, elongation properties, puncture resistance, and the highest tensile and tear resistance of all membrane materials. HDPE is very stiff compared to most of the other membranes described.

LINER SELECTION

Once the size and type of disposal facility have been determined, the utility engineer will choose the lining material(s) most suited to and economical for the specific purposes and service life. To select a liner, the engineer should consult and work with a reputable liner supplier, manufacturer, and/or installer.

Ideally, the liner should meet the following requirements:

- Compatibility and durability of the lining material, seams, and scrims with the waste to be contained at the temperatures required and for stress factors anticipated.
- Compatibility with geographical and topographical conditions.
- Low permeability to the waste over an extended period of time.
- Resistance to laceration, abrasion, and puncture from the waste to be contained, and to damage by wave action, mechanical equipment, soil erosion, and wind air foils.
- Reliability and low risk of failure.
- Relative ease of installation, quality control, repair, and maintenance.

The material that is most economical and can adequately fill the specific needs will be chosen. In making this decision, the engineer should consider the liner as the first layer of a multilayered system of different permeabilities and other physical characteristics. These layers extend from the waste itself through the liner and subgrade, the soil base, and finally the aquifer.

The engineer should consider and evaluate the following factors when selecting a liner or liners for the utility waste disposal facilities:

- Waste characteristics.
- Required service life.
- Required life of the liner after facility closure.
- Soils on nearby site, including subsoil.
- Hydrology and groundwater.
- Compatibility tests of liner material(s) with waste.
- Compatibility with geographical location.
- Acceptable flow out of impoundment (liner thickness).
- Type of liner monitoring system.
- Leak detection system.
- Reliability of materials, seams, joints, etc., and documented experience in the technology.
- Costs of candidate material(s) and installation.

Waste Type and Associated Site Service Life

The waste to be contained should be characterized with respect to temperature, form (liquid, sludge, solid), chemical composition (pH, TDS, toxic components, etc.), and corrosiveness.

The engineer should be able to predict with confidence the anticipated useful life or capacity of the facility to be lined. A landfill liner should last for extended periods, whereas many surface impoundments are either evaporating or holding ponds which may require the service of a liner for relatively short periods of time. The selection of a liner can be greatly affected by the anticipated service life required.

Site Characteristics

It is important to know (1) whether suitable liner soil is located on site or available from a borrow pit nearby, (2) whether it can be used as a liner (with or without compaction), and (3) whether it is suitable for use as a subgrade for other types of lining materials. Tests should be made to determine grain size, structural strength, and permeability to both water and waste fluid. Data on the groundwater level, flow rate, and permeability and thickness of the subsoil should be evaluated.

Compatibility with Waste

To assess liner compatibility, tests should be conducted to simulate the most diverse service conditions, including a wide range of temperatures, pH levels, effluent concentrations, upsets, accidental spills, periodic maintenance or shutdown, and shock loading. Failure to carefully assess these parameters can result in liner failure due to unpredicted synergistic effects.

Most membrane suppliers can provide the results of a series of standard immersion tests in a representative variety of acids, alkalis, and salt solutions at various concentrations and temperatures. A number of common oils and a few solvents are also checked. However, the manufacturer selected by the utility company should conduct, free of charge, testing under accelerated simulated field conditions. He will then submit his evaluation on the performance of the prospective liners with respect to the specific solid waste and site conditions.

Three compatibility test methods for membrane liner materials have been suggested: (1) immersion test, (2) pouch test, and (3) tab test (6). In these tests, the material is measured with respect to (1) percent volatile, (2) percent extractables, (3) tensile strength, (4) hardness, (5) thickness, (6) tear resistance, (7) puncture resistance, and (8) elongation before and after long-term contact of the liner with the waste to be contained (8). Visual inspection should be made for cracks, blisters, swelling, color changes, or softening.

The selection of a clay liner requires, at a minimum, testing of the following characteristics (20):

- Classification and plasticity index properties.
- Moulding water content (i.e., moisture content at which clay is optimally compacted).
- Moisture-density permeability curves.
- Permeability.
- Compatibility.

In the compatibility test, permeability to the waste to be contained is determined using a constant elevated pressure method (6).

Compatibilities of selected liner types with various industrial wastes are shown in Table 9-3. This table functions only as an initial guide, and, in many cases, specific combinations of liner materials and wastes must be tested before selecting acceptable liner materials. Utility solid wastes are inorganic and strongly alkaline, and contain high COD and soluble salt contents. To a certain extent, they are similar to electroplating sludge (high in heavy metals and soluble salt), caustic petroleum sludge (strongly alkaline and high in soluble salt), and acid pickling wastes (strongly acidic and high in soluble salt). It appears from Table 9-3 that asphalt, clay, soil cement, and certain polymeric membranes (PVC and CPE) would not be acceptable as liners for utility solid wastes. EPDM, butyl rubber, HDPE, and CSPE would be expected to perform satisfactorily. Until findings from the EPRI liner project (RP-1457) are published, the compatibility of various liners with utility solid wastes remains speculative.

Compatibility with Geographical Location

The liner must be compatible with existing climatic conditions at the site location (17). Wind, hail, ozone, rain, and freeze-thaw cycles accelerate the deterioration of most liners. Particular attention should be paid to temperature extremes and their duration. If the facility is also located in southern climates and at high altitudes, exposure to UV rays is more severe than for those at other locations.

Table 9-3

OVERVIEW OF LINER/INDUSTRIAL WASTE COMPATIBILITIES*

Liner Material	Caustic Petroleum Sludge	Acidic Steel-Pickling Waste	Electroplating Sludge	Toxic Pesticide Formulations	Oily Refinery Sludge	Toxic Pharmaceutical Waste	Rubber and Plastic Waste
Polyvinyl Chloride (oil resistant)	G†	F	F	G	G	G	G
Low Density Polyethylene	G	F	F	G	F	G	G
HDPE#	G	G	G	G	G	G	G
Butyl Rubber	G	G	G	F	P	F	G
Chlorinated Polyethylene	G	F	F	F	P	F	G
Ethylene Propylene Rubber	G	G	G	F	P	F	G
Chlorosulfonated Polyethylene	G	G	G	F	P	F	G
Asphalt Concrete	F	F	F	F	P	F	G
Soil Cement	F	P	P	G	G	G	G
Soil Asphalt	F	P	P	F	P	F	
Asphalt Membranes	F	F	F	F	P	F	G
Modified Bentonite	P	P	P	G	G	G	G
Compacted Clays	P	P	P	G	G	G	G

* Source: W. S. Stewart. State-of-the-Art Study of Land Impoundment Techniques. EPA 600/1-78-196, December 1978.
† G=good, F=fair, P=poor.
# Based on data from Universal Lining, Inc. (Unpublished, 1980).

Wind creates problems during installation and after the lining system is in place. During membrane installation, care must be taken to prevent the wind from getting under the edge of the liner. Wind also creates severe wave action in large impoundments which may cause the slope to slough under the liner unless slope protection is provided. Wind-borne abrasion is a serious consideration in arid desert applications. Liners with high abrasion resistance must be specified, or a protective soil cover must be placed on the exposed berms with attending rip-rap.

Other specific considerations with respect to geograhical location include water table fluctuation, backfill material, and damage of liner material by animals (particularly burrowing animals), insects, and fast-growing weeds and grasses.

Liner Thickness

Once the permeabilities have been obtained for the various layers that comprise the disposal system from waste to groundwater, one can calculate the thickness of a clay liner of a given permeability to meet the basic flow requirements. If a polymeric membrane liner is needed, its thickness is normally determined by the following factors:

- Service life required of the membrane.
- Temperature of the wastes.
- Abrasion characteristics of the waste, wave action, and type of substrate.
- Strength requirements with particular attention to the surcharge loading that may be placed on the liner.
- Seepage criteria relative to control of the inherent permeability over long periods of time (over 50 years).

Flexible polymeric membranes are available in thicknesses ranging from 20 to 140 mil (5 to 36 mm), with most in the 20 to 60 mil (5 to 15 mm) range.

Liner Guarantees

Although the liner guarantee plays a role in the liner selection process for most projects today, the term "guarantee" is still not well understood by those who specify and purchase liners for disposal sites. Normally, if degradation occurs within the term of the guarantee, the manufacturer will furnish replacement only. Usually the replacement is on a pro rata basis, but replacement costs and any contingent liability due to failure of the liner are not included.

The guarantee will not cover mechanical damage of any kind, vandalism, or catastrophes. Subgrade or structural failure or settlement will likewise be excluded from the guarantee.

The best guarantee is a specification that requires a certain degree of performance for both the installer and the materials, based on predefined standards and methods. When liners are used to hold liquids whose composition may be subject to seasonal variation (e.g., industrial wastes), the guarantee will not cover malfunctions due to attack by chemical or conditions that were not present in the original test samples.

LINER SYSTEM DESIGN

It is important to recognize that most lining materials, particularly polymeric membranes, are not structural units themselves (i.e., they cannot hold the pond together). The foundation and substrate must do this job regardless of whether the soil underneath is dry, wet, or saturated. Many cases of liner failure or malfunction are due to poor site design and construction operations (16, 21).

Contractor Selection Criteria

The utility company should choose a reputable engineering firm experienced in this area to do the facility design work, and a contractor experienced in liner installation to install the lining material. References from prospective installation contractors should include:

- Documentation of liner installations over 2 years old.
- Installation of at least 1 million sq ft (645 m^2) of flexible membrane liners.
- At least 5 years of experience installing the types of flexible membrane liners selected.
- A list of installations which are very similar to the specific application.
- A state license to operate as an installation contractor.
- Possession of the necessary equipment and manpower required to complete the lining installation.
- Proof of financial stability, and approval by the manufacturer/fabricator of liner materials.
- Ability to follow all installation specifications to ensure that proper methods are being used during installation of the liner.
- A quality control/quality assurance procedure to use during field operations.

Site Selection

The site should be carefully selected so that adverse environmental impacts will be minimal. In addition, future use of the land and water resources on or adjacent to the site property should be considered.

Site selection methodology has been discussed in the EPRI coal ash and FGD sludge disposal manuals (22, 23). The selection procedures normally entail literature review, site inspection, consultation with regulatory agencies, and subsurface investigation. Information needed for the evaluation of environmental impacts is presented in Table 9-4.

Engineering and Design

As stated earlier, the liner must be placed in a stable structure to perform satisfactorily. Facility design and inspection should be the responsibility of professional experts with a strong background in this field. Major design features in a lining system are discussed below. Most of these features are for polymeric membranes, and the information is taken from Small (17).

Liner Underdrains. Liner subdrainage is generally required when it becomes necessary to monitor leakage through the lining system, or to provide pressure relief from a high groundwater table. A typical underdrain system and its components are shown in Figures 9-1 and 9-2. Note that a porous layer of soil or geotextile is placed under the membrane liner to provide a direction for the liquid to flow. At various intervals, interceptor subdrains are tied to a main collection header to safely convey the liquid to a collection sump.

Gas Venting. Certain site-specific conditions require the venting of gas which may accumulate beneath the membrane liner. If appreciable quantities of organic matter are present in the underlying soils, or if natural gas is present in the region, gas production is inevitable. If the pressure is permitted to increase, the membrane will stretch and rise. Less hydrostatic pressure is available to restrain the membrane. As a result, the membrane floats to the surface.

Venting must also be included in the design when a fluctuating water table is present below the pond bottom. Effective distance varies with organic matter content, height of water table, and type of water present. The rise and fall of the water table creates an air-pumping mechanism which is potentially damaging to the membrane liner. The venting of this accumulating gas is best accomplished by providing a layer of uniformly graded sand. A geotextile may also be used to allow gas to pass

Table 9-4

SITE SELECTION DATA

Meteorologic	Pedologic	Geologic	Hydrologic
Precipitation	Physical properties	Geomorphic setting	Surface water
- Average annual	- Texture	- Active landforms	- Distance
- Form	- Grain size distribution	- Inactive landforms	- Type
- Distribution	- Porosity		- Quality
	- Hydraulic conductivity	Topographic setting	
Severe weather	- Infiltration rate		Groundwater
	- Runoff coefficient	- Slope	- Depth
Evaporation	- Unified soil classification	- Erosion potential	- Fluctuation
			- Quality
- Depth to water table	- Atterberg limits	Bedrock setting	- Flow rate
- Vegetation	- Thickness		- Transmissivity
		- Rock type	- Recharge
Temperature	Chemical properties	- Depth to bedrock	- Aquifer distribution
		- Structure	
	- pH	- Weathering	
		- Porosity	
	- Cation exchange capacity	- Hydraulic conductivity	
		- Infiltration rate	
		- Runoff coefficient	
		- pH	
		- Ion exchange	

Source: Modified from D. W. Miller. Groundwater Contamination: Fundamentals and Monitoring. Presented at the Chemical Manufacturers Association Seminar on Disposal of Hazardous Wastes, San Francisco, California, March 3-4, 1980.

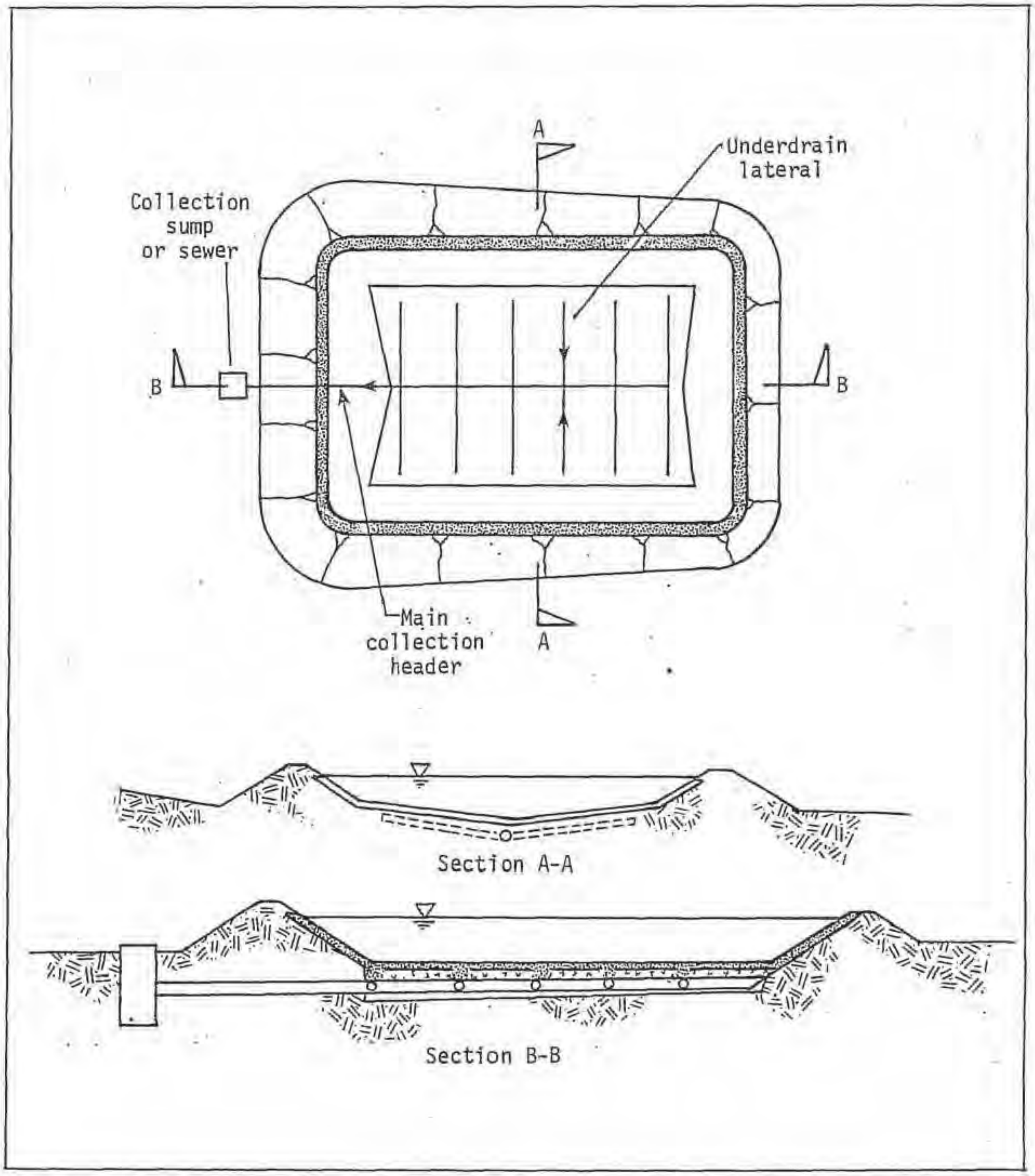

Figure 9-1. A Typical Underdrain System

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

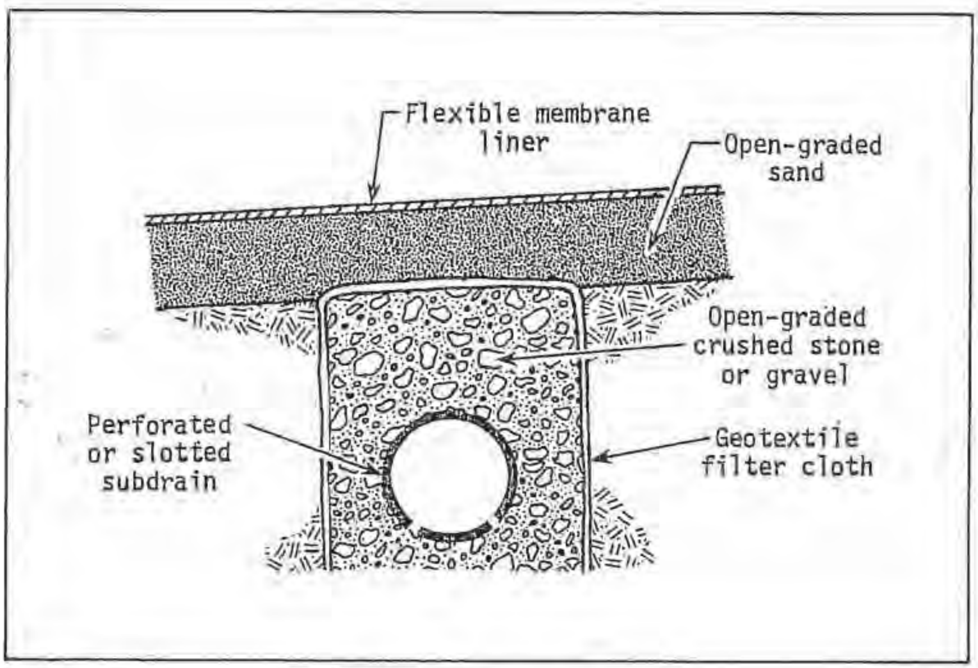

Figure 9-2. Underdrain Lateral Cross Section

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

through the fabric's cross section under a surcharge load. In order for these media to be effective, the bottom of the pond must slope up from its center to the toe of the dike a minimum of 2.5%, and certain membrane liners (e.g., CPE, CSPE, etc.) must be reinforced with a fabric.

The venting medium is carried across the entire bottom and up the side slopes (Figure 9-3). Venting to the atmosphere is accomplished at a predetermined frequency through gas vents located on the inside slope of the berm, approximately 1 ft (30 cm) down from the crown of the dike (Figure 9-4).

Embankment Slopes. In large projects where either the volume of earth-work is significant, or the overall embankment height is great enough to generate concern about the effects of slope failure, slope stability analysis of the embankment slopes is necessary. Slope lining does not increase the slope stability of an embankment; it only provides resistance to surface erosion. Soil stabilizers for erosion control should be evaluated for chemical compatibility with the membrane. Cementitious or chemical binding agents should be evaluated in terms of potential abrasion of the liner. Geotextiles provide an alternative method of preventing sloughing.

Erosion control measures should be included in the design whenever earth is exposed on an embankment slope (see Surface Water Controls in Section 6). There are numerous approaches to slope erosion control, as suggested by Small (17):

- Diversion ditches.
- Hydroseeding and mulching.
- Sodding.
- Membrane liners.
- Crushed stone surfacing (rip-rap).
- Bituminous paving.
- Geotextile fabrics (open-woven).
- Geotextile composites with concrete.
- Three-dimensional fiber matting used in conjunction with grass, ground cover, or crushed stone.
- Jute mesh used in conjunction with grass or ground cover.

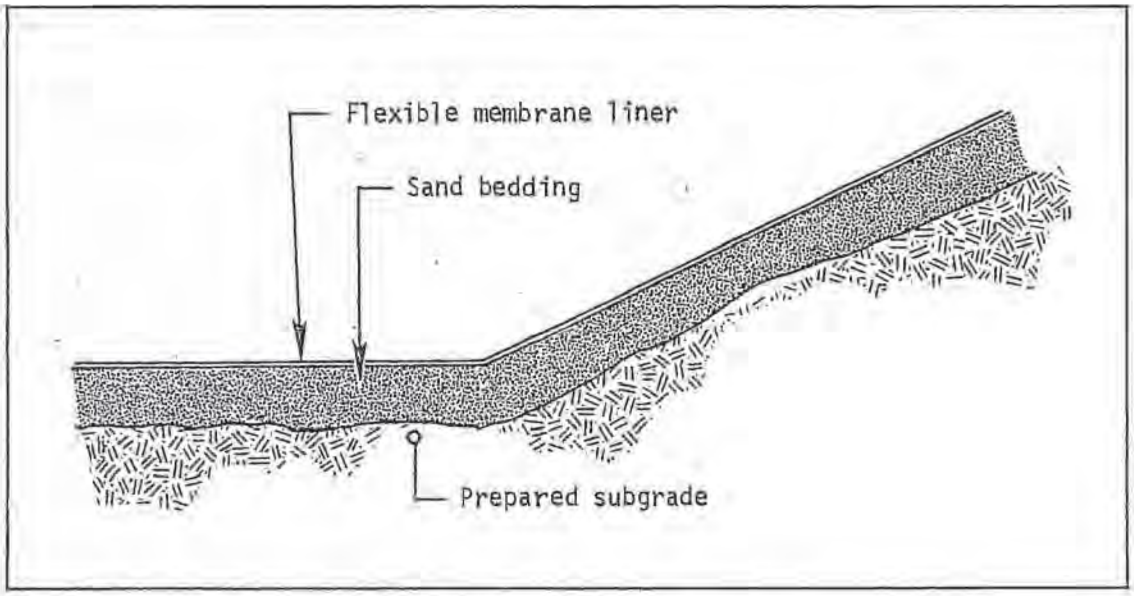

Figure 9-3. Underliner gas venting of a lining system.

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

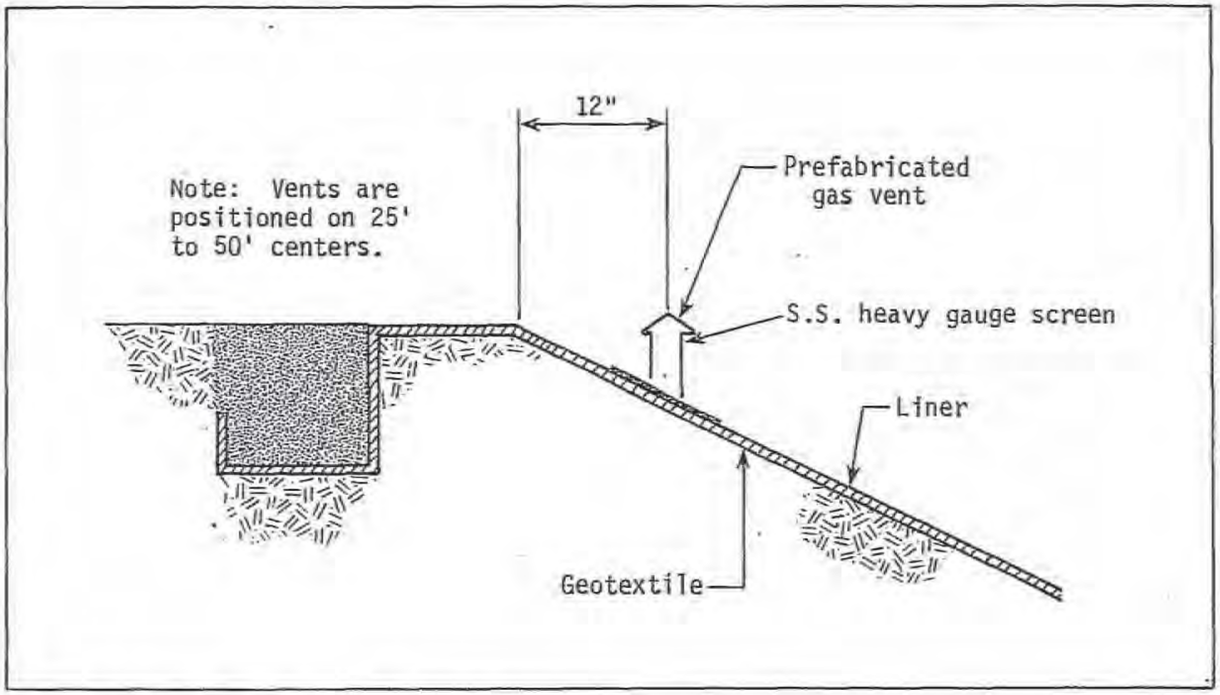

Figure 9-4. Prefabricated Gas Vent Details

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

The selection of an erosion control system depends on economics, length of service, effectiveness, and compatibility with climatic conditions. Maintenance of a slope after an erosion control scheme should also be considered.

Side Slope Protection. In a large pond, wind will play a significant role in the liner design. Side slope protection will be required to minimize the effects of damaging wave action.

The usual types of surface protection for the upstream slope are rock rip-rap (either dry-dumped or hand-placed) and concrete pavement. Other types of pavement that have been used are steel facing, bituminous pavement, and precast concrete blocks. The upstream slope protection should extend from the crest of the embankment to a safe distance below the minimum water level (usually several feet), and should ordinarily terminate on a supporting berm (Figure 9-5).

When a protective cover is being designed, it is important to know the characteristics of the water level (i.e., constant versus fluctuating). If drawdown in a fluctuating pond is rapid, the seepage forces in the earth cover must be considered in the stability analysis. Generally, the materials used to construct an earth cover should be free-draining to reduce the possibility of building up large seepage forces. In a pond where water levels are constant, the fetch is small and an earth cover is required for aesthetic reasons; crushed stone or an erosion control measure should be used over the minimum 18-in. (45-cm) well-graded sand cover.

Liner Anchoring. A polymeric membrane liner is usually anchored in earthen excavations by burying the edge in a 12-in. (30-cm) wide by 18-in. (45-cm) deep trench excavated at the perimeter of the area to be lined (Figure 9-6). The membrane should extend down the inside face, across the bottom, and three quarters of the way up the outside wall of the trench. The excavated material is then replaced and compacted. A geotextile underlay, when used, is anchored in the same manner. Areas of high wind and poor soil conditions may require deeper anchor trenches. The crown of the dike and the inside edge of the trench should be radiused and free of any rocks, sticks, stones, or sharp objects which could puncture or break the liner. The trench should be excavated straight and true to grade so as to facilitate installation of the membrane. This will prevent folds and wrinkles from forming in the material, necessitating cutting and additional seaming.

Perimeter anchoring may also be accomplished by attachment of the membrane to an existing or newly built concrete ring wall. The anchor system will consist of an

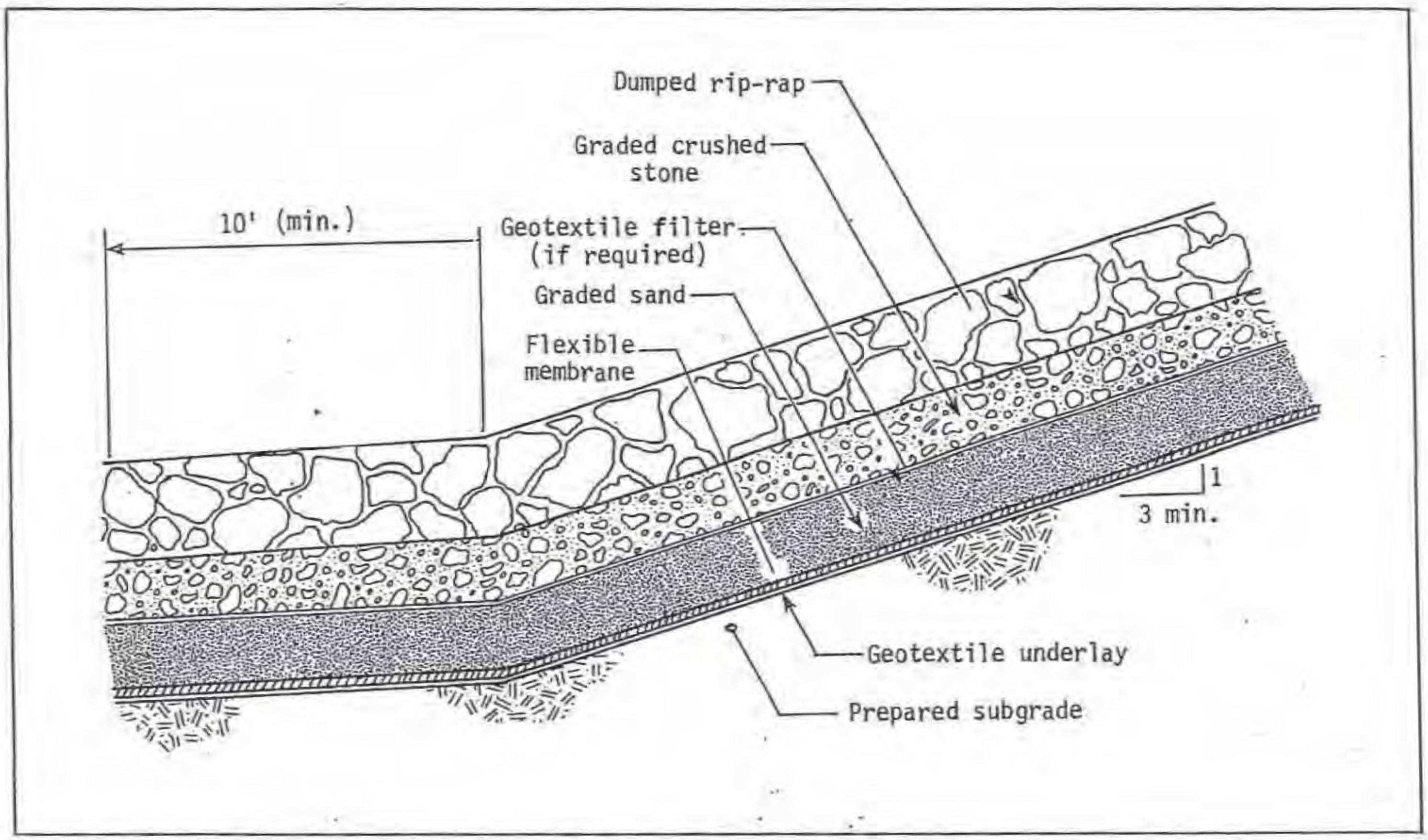

Figure 9-5. Details of slope protective cover for flexible membranes.

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

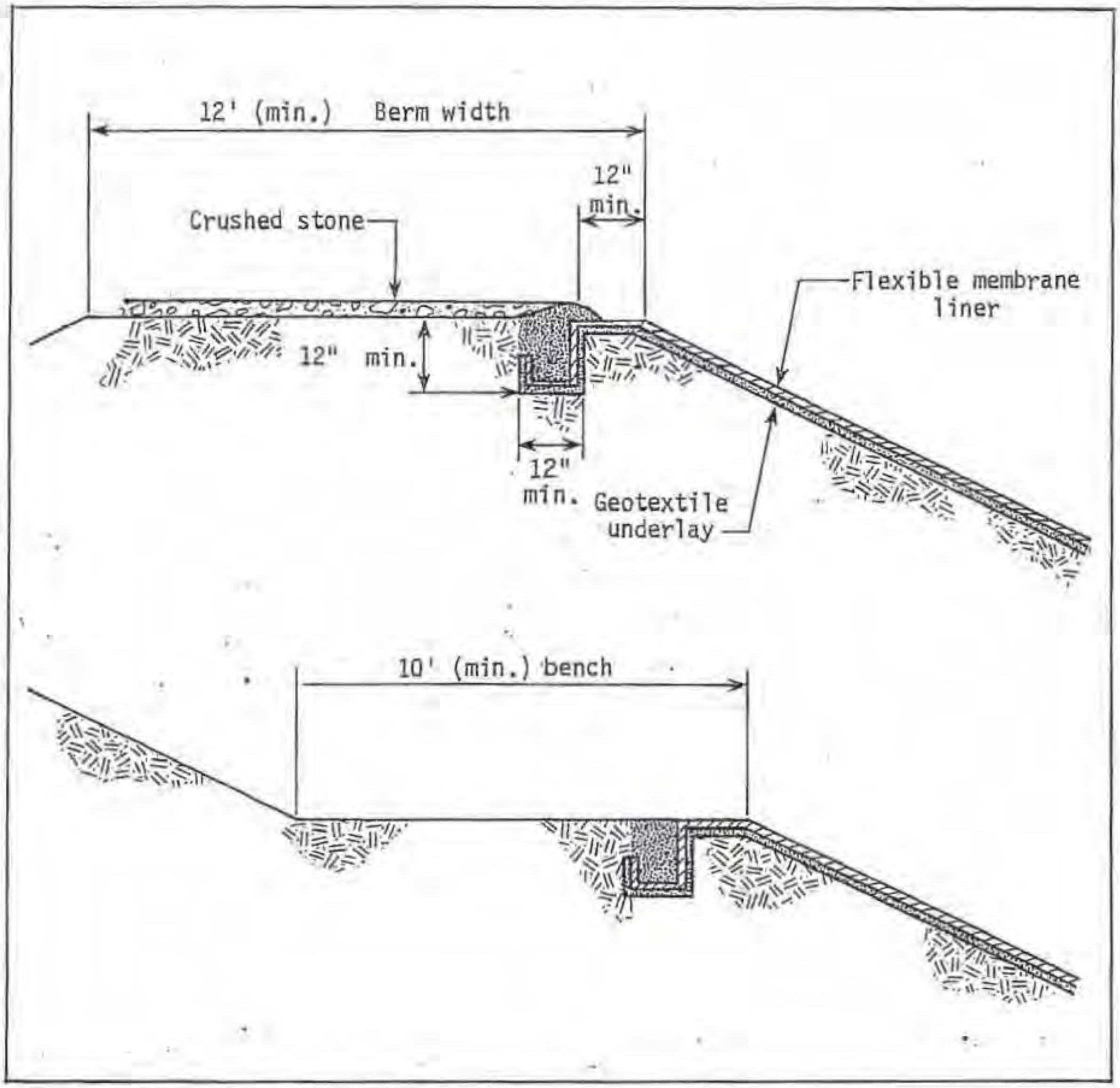

Figure 9-6. Typical Liner Anchorage

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

aluminum anchor bar approximately 0.25-in. by 2 in. (0.64 cm by 5.1 cm) in dimension, and 0.5-in. (1.28-cm) diameter stainless steel anchor bolts, 12 in. (30 cm) on center (Figure 9-7). A fiber washer may be used to prevent reaction. The inside edge of the concrete should be radiused, and an extra layer of material should be placed between the liner and the concrete to prevent abrasion. If feasible, the extra layer of chafer material should extend below the water level for additional impingement protection. The liner is then inserted over the bolts, and a mechanical seal is made with the anchor bar.

In situations where wind could cause uplift to the liner on the slopes, vents are required, and ballast tubes may be used. Ballast tubes are normally anchored in the common perimeter trench, and extend down the slope to the toe of the dike. These tubes are normally 8 to 12 in. (20 to 30 cm) in diameter, and are sand-filled. Where these are used in gas venting design, a geotextile is required to prevent the tubes from forming a seal between the liner and subgrade due to the surcharge.

LINER INSTALLATION PROCEDURES

Successful liner installation begins with thorough planning and culminates in well-engineered and proper installation of the material. The importance of sound installation techniques in any lining job cannot be stressed enough. Regardless of the type of membrane used, the success or failure of any job will depend heavily upon the experience and expertise of the installer.

Subgrade Preparation

The liner, which is a relatively thin barrier, must rest on a firm, smooth foundation. Ideally, the subgrade would consist of 4 to 6 in. (10 to 15 cm) of compacted coarse-grained material, such as sand. The maximum grain size of the material is somewhat dependent upon the type of liner material to be used, its thickness, and reinforcement. If recompacted or imported clay is used, or if the in situ soil is to be amended by the addition of cement or montmorillonite, a larger grain size in the subgrade can be tolerated, as the barrier will be thicker than polymeric membranes or asphaltic compositions. There are no specific recommendations for maximum grain size, but it seems logical that a clay liner which is 12 to 18 in. (30 to 46 cm) thick could easily tolerate stones as large as 1 in. (2.54 cm) in diameter in the subgrade. Subgrades for polymeric membranes should have a maximum grain size smaller than this, and specifications have been written which call for 100% of the subgrade to pass a No. 4 sieve on 20-mil (5-mm) materials (1).

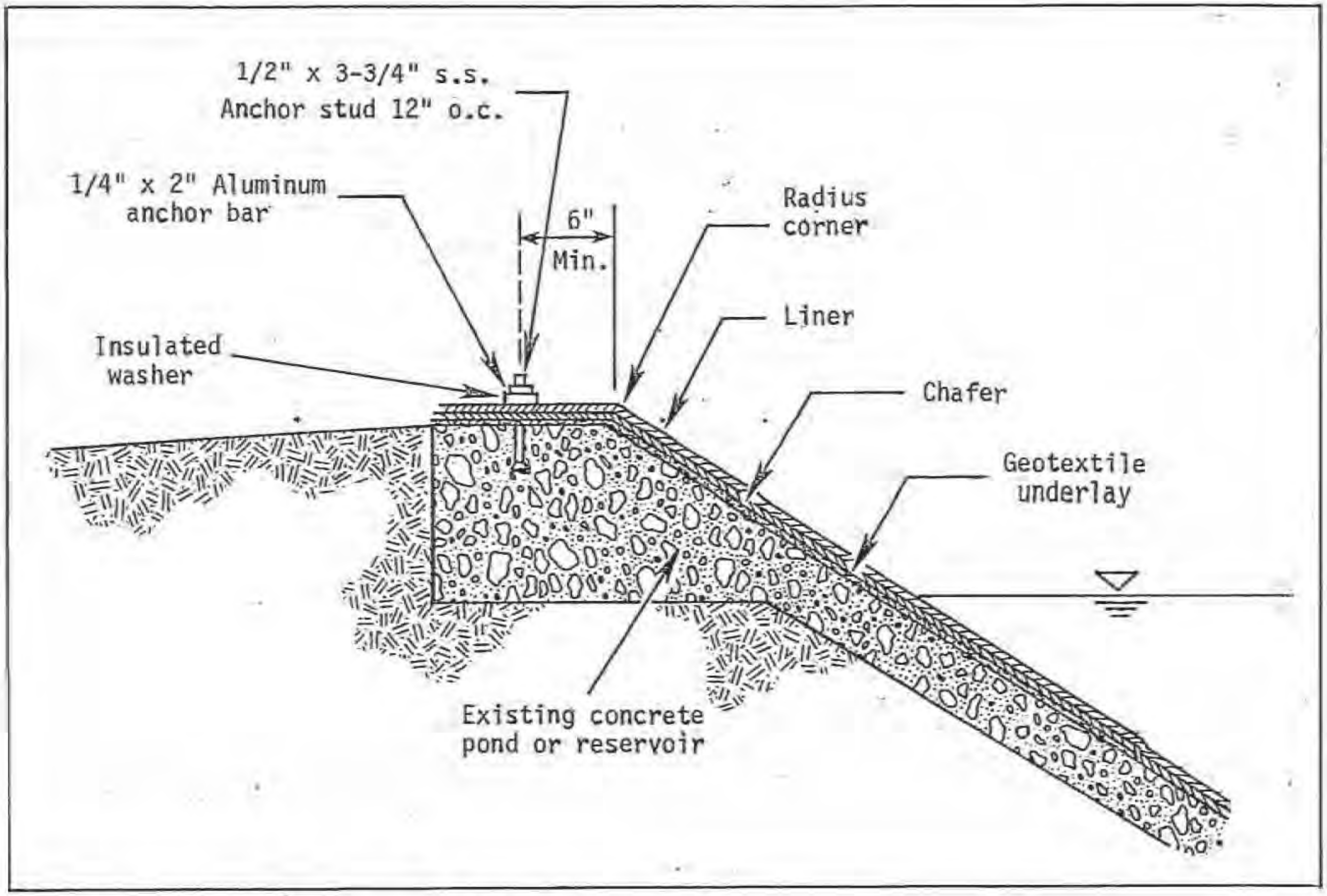

Figure 9-7. Liner Anchorage To Concrete Ponds

Source: D.M. Small. Establishing Installation Parameters for Rubber Liner Membranes. Presented at 117th American Chemical Society Meeting, Las Vegas, Nevada, May 22, 1980.

In all cases, the subgrade should be free of roots, branches, grasses, and other similar materials which could puncture the liner. The prepared subgrade should be sterilized by applying a reliable herbicide and discing it into the soil surface 2 to 4 in. (5 to 10 cm). Sufficient time should be allocated between treatment and placement of the liner. Subdrain and gas venting systems may be required for membrane lining.

The subgrade should be smooth. The liner materials should not be required to bridge over tire tracks and other depressions. The subgrade can be rolled or dragged to achieve an acceptable subgrade texture. The subgrade can be susceptible to differential settlement if not properly compacted. Obviously, the field inspection should include soil tests to ensure optimum compaction of the subgrade.

Liner Construction

Once the subgrade has been prepared, liner construction can begin. A critical aspect of liner construction is adequate quality control of materials and workmanship. Ideally, the quality control function should be performed for the utility by a party independent of the liner manufacturer, fabricator, installer, and earthwork contractor. That party should be responsible only to the utility. The utility should then be able to certify to a regulatory agency that the facility was constructed as planned. Often a quality control function is not included as part of a design and construction program. At a minimum, the utility, or its engineers who are ultimately responsible for the operation of the lined facility, must check the quality of the materials and installation workmanship on the job site before accepting the finished product.

Most lining materials require a unique installation procedure. A discussion of methods for installing clay, soil cement, ashalt, and polymeric materials is presented below. More specific details on the various phases of installation will be given for the polymeric materials.

Clay. The construction of a clay liner (e.g., bentonite) over the native soil is accomplished by use of conventional farm and earth-moving equipment. The grayish white granular material can be spread with a fertilizer, pesticide, or manure spreader.

Several methods are available for the application of a bentonite clay liner. Bentonite can be applied as a 1 or 2 in. (2.54- to 5.1-cm) thick membrane, and covered with 8 to 12 in. (20 to 30 cm) of earth or gravel to protect the liner from erosion or mechanical damage.

Bentonite may also be applied and mixed with the prewetted surface soil to form a uniform surface layer. Typical application rates range from 10 to 20 lb/cu yd (6 to 12 kg/m^3). For a treated bentonite, the rates are about 32 to 46 lb/cu yd (19 to 27 kg/m^3) (for permeabilities from 10^{-6} to 10^{-8} cm/sec) (8). After the material is spread, three to four passes with a rototiller are required to mix the clay to the appropriate depth, usually 4 to 6 in. (10 to 15 cm). Similarly, bentonite may be mixed with sand in a volume ratio of about 1:8 (31 lb/cu ft bentonite), and spread in a layer 2 to 4 in. (5 to 10 cm) thick, and covered. The soil-clay mixture is compacted to a minimum of 85% modified proctor. Flat steel-wheeled or rubber-tired rollers are recommended for compaction.

A slurry of bentonite (bentonite 0.5% by weight) or various soil sealants can be applied to existing (filled) ponds to decrease the permeability of the soil liner (6). The sealant settles, filling void spaces, and effectively seals the surface. However, the sealing effect is confined to the upper few centimeters and can be significantly diminished by the effects of wet/dry and freeze/thaw cycles. The sealant is also subject to shrinkage, cracking, and erosion from moving water.

In ponds or lagoons, it is necessary to protect the liner from erosion damage near inlet valves, or where wave action is significant. A 4- to 6-in. (10- to 15-cm) layer of crushed stone is generally placed over the liner. In landfills, a 4- to 6-in. (10- to 15-cm) layer of soil over the liner would serve as protection from mechanical damage by trucks, compactors, etc.

Soil Cement. Soil cement is a mixture of pulverized (well-graded) soil and measured amounts of portland cement and water, compacted to a high density. To date, no special construction techniques have been developed for large disposal facilities. In general, soil cement pavements are built using the following steps:

- Spread portland cement evenly and mix.
- Apply water and remix.
- Compact the mixture.
- Perform final grading for drainage.
- Cure the mixture.

Depending upon the soil type encountered, cement is added at a rate of 3 to 20% of the weight of the soil. The design mix should be tested for its tolerance for dry/wet and freeze/thaw cycles, permeability, and moisture-density relationships, using ASTM methods.

Soil cement is placed using road paving methods and equipment. It should not be placed in air temperatures below 45°F. The compacted density should be 98% of the laboratory maximum density. The compaction should proceed so that no more than one hour elapses between the spreading and compacting of a layer. The surface of a compacted layer must be kept moist by fog-spraying if another layer is to be applied. The finished liner should be allowed to cure sufficiently before use.

Soil cement must be sealed. The sealing compounds are bituminous liquids and emulsions sprayed onto the soil cement surface after it has been sprayed with water to reach its maximum water absorption level. This spraying should be done as soon after compaction as practical.

Asphalt. After the subgrade has been properly prepared and sterilized, a prime coat of hot liquid asphalt is applied to the surface and allowed to cure before paving. The hot asphalt concrete mix should be placed by spreaders equipped with hoppers and strike-off plates or screeds.

The edges of spreads should be smooth and sloped for 6 to 12 in. (15 to 30 cm) to provide a bonding surface with the adjacent spread. Cold surfaces should be heated with an infra-red heater just before forming joints. The asphalt concrete liner should be compacted as soon after spreading as possible. Ironing screeds, rollers, vibrators, or tampers may be used for compaction. When a liner thickness greater than 3 in. is required, multiple courses should be applied. All joints should be staggered to insure strength and low permeability for the liner as a whole.

Prefabricated asphalt panels require careful planning and workmanship for proper installation. The placement and bonding of the panels should be carefully planned before installation begins. The subgrade is excavated, smoothed, rolled, and soil applied if necessary. Panels are then either placed butted together or overlapped. Bonding is done with hot or cold asphalt mastic adhesives. If the panels are butted together, batten strips must be cemented over the joints (9).

There is a three-stage construction process for the asphalt emulsion sprayed on polypropylene fabric. First the fabric is spread on the ground. The fabric is in sheets 15 x 300 ft (4.5 x 91 m) which are sewed together. A mixture of water, a wetting agent, asbestos, and an asphalt emulsion is then sprayed on in two coats. The first coat is applied at a rate of 1 gal/yd^2 (4.55 l/m^2). When this coat dries, the evaporation of the water causes pinholes to develop in the membrane. A second coat of the mixture is sprayed at a rate of 0.4 - 0.5 gal/yd^2 (1.8 - 2.3 l/m^2). The final membrane is approximately 100 mil (25 mm) thick.

Membrane Liners. Proper subgrade preparation is equally important in the installation of membrane liners. Installation requires a significant planning effort prior to construction. This planning effort must consider the storage and security of all necessary equipment, manpower requirements, placement operation, field seaming, anchoring and sealing, quality control, inspection, and protection of the placed liners. The proper steps for construction of membrane liners are detailed below.

Plastic and rubber membranes are delivered to the site in large sheets or panels that are fabricated in a factory. The panels are removed from their containers and placed in position for installation. The panels can be quite large to minimize joining on the site, sometimes weighing as much as 5000 lb (2250 kg). Suitable handling equipment is required at the job site.

In placing the panels on the slope, the panels are rolled down the side onto the bottom, and placed in position for unfolding. The panels are positioned according to a carefully prepared diagram, and each panel is identified for placement. Each panel is then unfolded by the work crew and pulled into position. Positioning the panel and unfolding it from the pallet is best handled with a large front-end loader or forklift. By flapping the panel to force air underneath it, it can be floated into position. The panel is then held in place by weights (e.g., sandbags or tire casings) placed along its edge, preventing wind from raising the edges.

Once positioned, the edge of the panel covering the slope is folded into the anchor trench atop the berm. The trench is then backfilled with earth to hold the panel securely in place.

The first two panels are spread with one panel overlapping the other, as specified. As the first two panels are being joined, the third is positioned so that the seaming crew can start on it upon completion of the first seam. This procedure is continued until all seams are made. Material that cannot be seamed in the same day should not be unrolled. All loose ends should be secured against windlift at the end of each work day.

It is imperative that field seams be made strictly according to project specifications. The four most common seaming methods for synthetic rubber liners are: (1) adhesive lap splice; (2) gum tape lap splice; (3) tongue and groove splice; and (4) extrusion weld (24). Figure 9-8 illustrates how each of the first three field seaming techniques are accomplished.

In the case of modified HDPE and HDPE, a specially designed extrusion welding machine is used. This offers an advantage over other types of systems due to the high tensile strength it develops and the ability to fully control the welding process.

Once the seam has been completed, it should be allowed to stand long enough to develop full strength. An air lance test using 50 psi air directed through a 3/16 in. (0.19 cm) nozzle, held no more than 6 in. (15 cm) from the seam edge may be used to detect any holidays, tunnels, or fishmouths in the seam area. Any imperfections should be reaired as soon as practicable. Once testing has been completed, any exposed scrim (in the case of reinforced material) is to be flood coated with the same bodied solvent adhesive. The entire impoundment should be inspected to insure that all the field and factory seams are properly joined, no scrim is exposed and any damage which may have occurred during installation has been repaired. All patches should have rounded corners with the scrim properly flood coated to insure encapsulation.

When inspecting the liner during installation, wrinkles should be anticipated, since they compensate for material shrinkage, thermal expansion, and contraction. No large folds should be permitted as they contribute to increased aging.

Before inspecting seams, the installer must be consulted for estimates on the adhesive curing or drying times required before seam strength is sufficient for testing. Once bond strength has developed, all field seams, overlays, and patches must be carefully inspected and tested according to the methods described in the specifications. Commonly employed techniques include air lance, visual, vacuum, sonic, UV, and bubble testing. Pipe boots, splash pads, or attachments to concrete sumps or walls can be made either during or after field seaming. Upon completion of a pond liner, a minimum of 6 in. (15 cm) of fluid should be slowly introduced into the pond to prevent wind from distorting or blowing the liner. If the pond is to stand empty for a time, special venting and anchoring should be used.

When an unexposable landfill liner (e.g., PVC) requires protection from UV exposure, it should be protected by a soil layer of approximately 1 to 2 ft (30 to 60 cm)

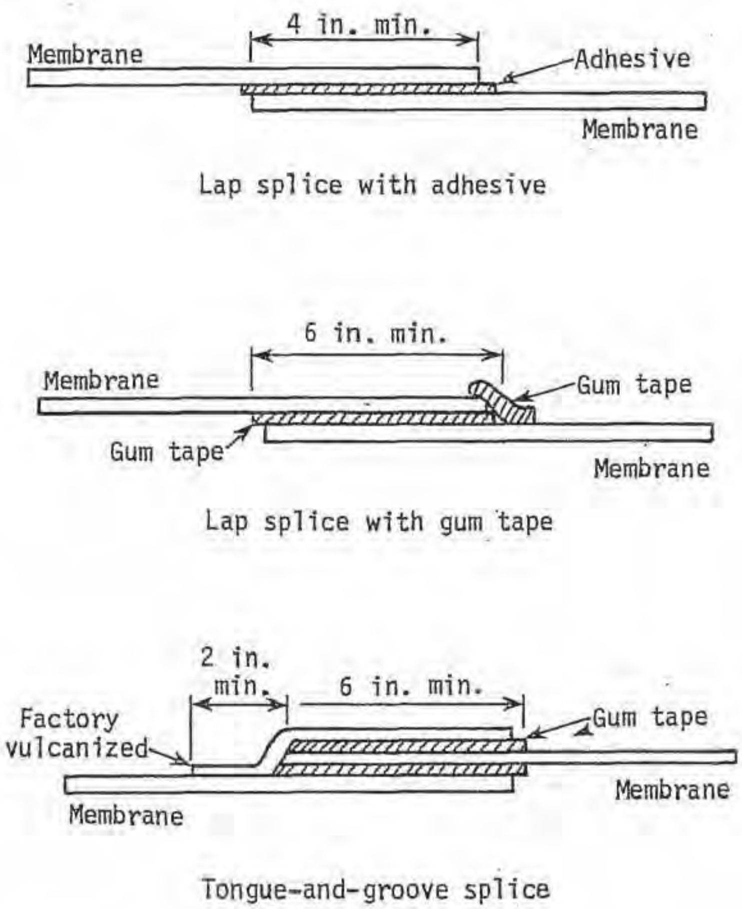

Figure 9-8. Field Seaming Techniques

Source: E.I. DuPont. "Succeeding with Liner Installation". Water and Sewage Works, 127 (4) :60-61, 1981.

thick. The cover material should not contain jagged rocks or other sharp objects that could damage the liner. Thus, it may be necessary to screen and sterilize the soil cover material prior to use.

Before a final cover is placed, the installed liner should be carefully inspected, particularly in areas of suspected liner damage. Sizeable areas of liner damage should be repaired immediately upon discovery in accordance with the recommended repair procedures of the liner manufacturer/installer. Major repaired liner areas or suspect areas should be marked and located on the as-built drawing.

In areas where potential erosion or wave action is likely to remove the earthen cover, a chemical soil stabilizer or stabilizing method(s) should be used to maintain soil stability.

At no time should vehicles be allowed in the area of the liner where the subsurface is muddy or unstable. Equipment with crawler treads should not be allowed to operate directly on the liner.

Leak Detection

There are several leak detection methods currently in use at reservoirs and disposal facilities. Among them are groundwater wells, lysimeters, piping systems below the liners, and electrical sensing systems.

The groundwater monitoring method is only suitable for detecting long-term contamination. Since it does not give an early warning, its usefulness as a detection measure is limited.

Lysimeters are subject to mechanical breakdown and malfunction. They are designed to extract test samples in very localized areas. Their reliability is questionable.

Perforated pipes placed below the liner are used to detect leaks, and in some cases, to collect leachate. Although this is a reliable method, it cannot pinpoint the exact location of a leak.

The electrical sensing system consists of a series of metal pins driven into the ground beneath the liner. The pins are connected by waterproof cable through a selector switch to a resistivity meter. With improved wiring (e.g., the use of a grid arrangement), the exact location of a leak can be pinpointed. Long-term reliability of the electrical sensing system is questionable due to changes in conductivity with age.

INTEGRATION OF LEACHATE COLLECTION SYSTEM

Leachate collection systems are seldom installed at lined or unlined utility waste disposal facilities. Since the purpose of lining is to eliminate leakage, only the leachate accumulated on top of the liner is usually collected. Underdrains are placed beneath a lined pond for purposes other than leachate collection, such as a backup protection system.

In fact, most liners are temporary on a geologic time scale and will ultimately leak. Some form of leachate detection and collection system should be installed. The text that follows provides only general information on various leachate collection systems. Their applications to utility waste disposal facilities should be evaluated on a case-by-case basis.

Dry Base System (25)

This system is commonly associated with lined landfills (Figure 9-9). It is designed to prevent ponding or accumulation of leachate which could escape through a rupture in a membrane liner or a crack in a clay liner. A leachate collection system for a dry base landfill should be designed for continuous removal of leachate, and developed to minimize the distance travelled from generation to collection.

The type of waste material may dictate leachate collection system spacing, but generally the spacing required to maintain a dry base will be less than for the other systems. The transmission of leachate along the base to the collection system is by gravity. Flow within the collection system is also by gravity, generally to one main collection point.

The design of the collection system and the liner must be closely coordinated. The slope of the liner, thickness, material, etc., will affect the actual construction and design of the leachate collection system. Since leachate is continuously removed, significant storage space may be required to temporarily hold the leachate prior to treatment and disposal.

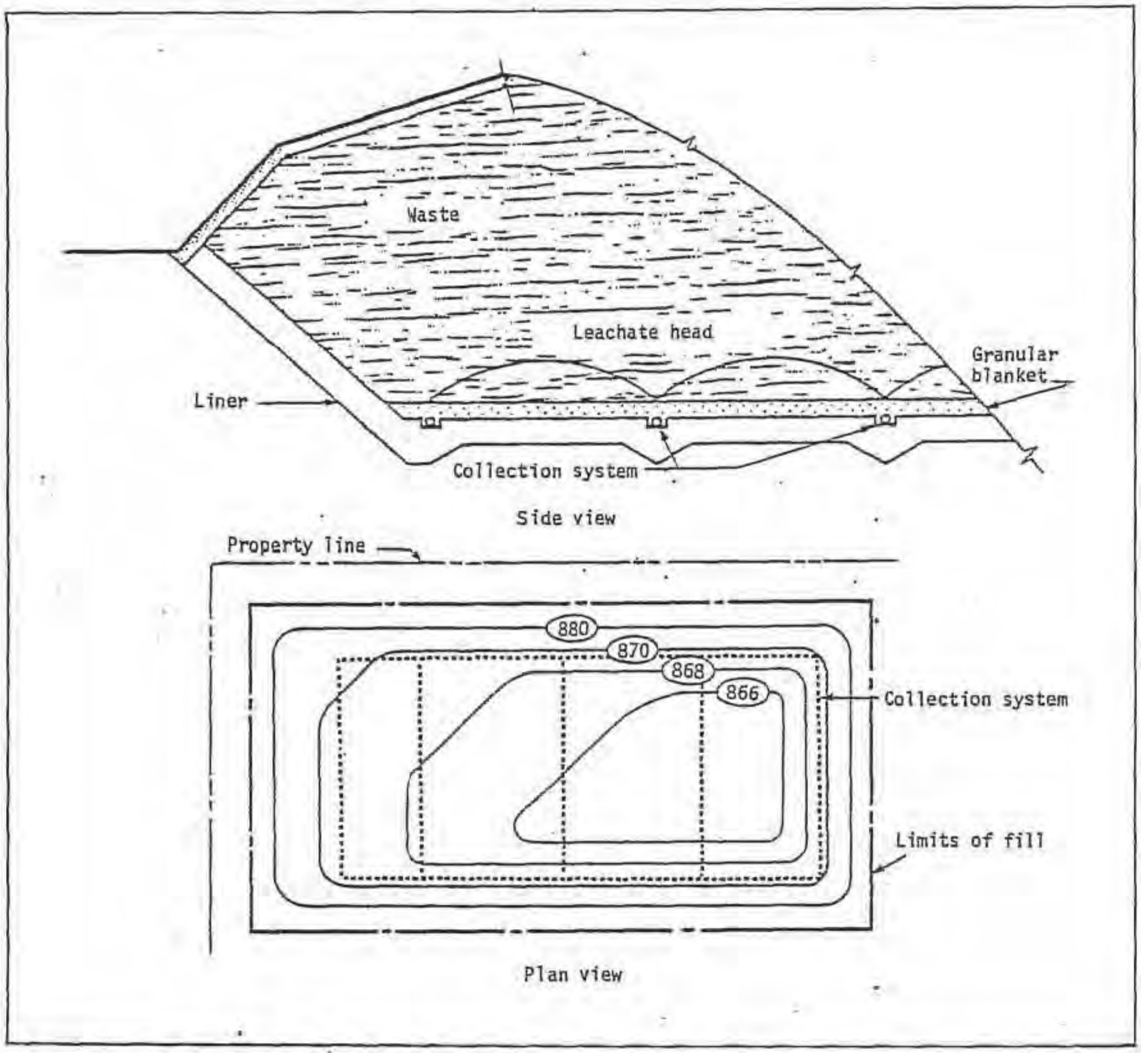

Figure 9-9. Dry base collection system for lined landfills.

Source: H.A. Koch. Leachate Collection System Design. In Hazardous Waste Management Practices. Short Course, July 9-11, 1980. University of Wisconsin, Madison, Wisconsin.

Wet Base System (25)

This system is used at landfills located in the zone of saturation in a homogeneous, impervious clay environment (Figure 9-10). The development of such a facility can be associated with the ponding of leachate within the landfill site itself. The leachate level to be maintained within the landfill site, usually below the level of surrounding groundwater, is referred to as the leachate maintenance level. Its purpose is to allow interior storage of leachate and to maintain an inward gradient, thus preventing leachate from migrating away from the site. Site-specific conditions may dictate adjustment of maintenance levels. Although the leachate levels are below groundwater, leachate may still move outward from various portions of the landfill site.

The wet base system associated with landfills in the zone of saturation is relatively simple, and does not require extensive lateral collection systems to continuously remove all leachate as it is generated. The placement and construction of the leachate collection system is more flexible and less critical than in a lined landfill site.

Reparative System (25)

This system is typically comprised of cutoff walls and interception trenches allowing the collection of leachate that generally moves outward from a site in a lateral direction (Figures 9-11 and 9-12). Reparative systems are used to correct existing landfills which have adversely impacted the surrounding surface or groundwater resources.

The design of a reparative system is highly dependent upon the properties and layering of existing soils, groundwater, and bedrock at a site. Such systems range from those utilizing a gravel-filled trench with a pipe to those utilizing bentonite slurry cutoff walls, groundwater interception trenches, and/or interior leachate withdrawal wells.

Backup Collection System (25)

This system is usually developed in a landfill site, since installation of a leachate collection system after waste material has been deposited would be unrealistic. Generally, it is expected that such backup systems would not have to be used, but are constructed for the remote possibility that they may be required. Since such systems are not expected to be used, it should be simple in design; the quantity of leachate that would be handled is also expected to be small.

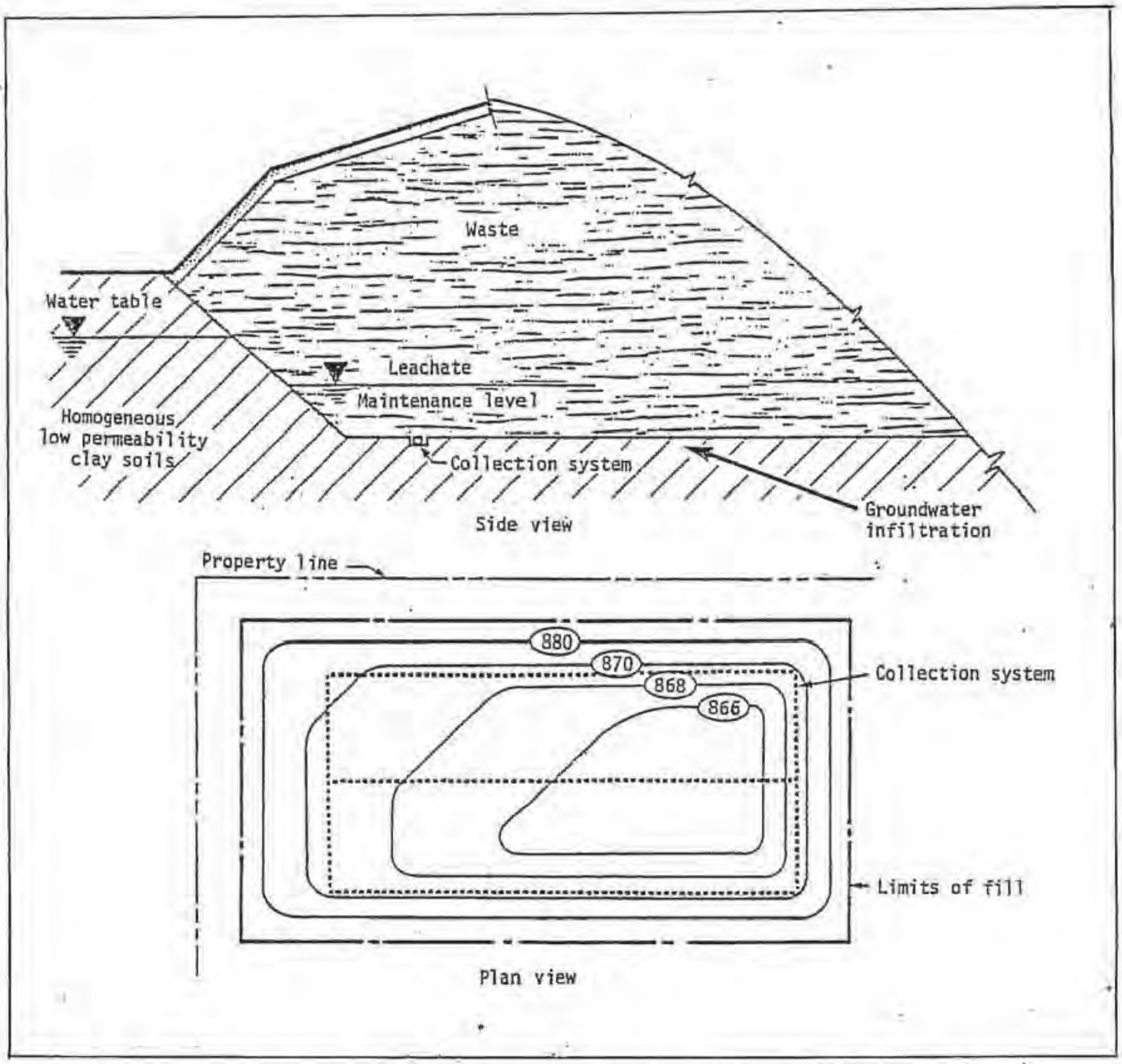

Figure 9-10. Wet base collection system for landfills in the zone of saturation.

Source: H.A. Koch. Leachate Collection System Design. In Hazardous Waste Management Practices. Short Course, July 9-11, 1980. University of Wisconsin, Madison, Wisconsin.

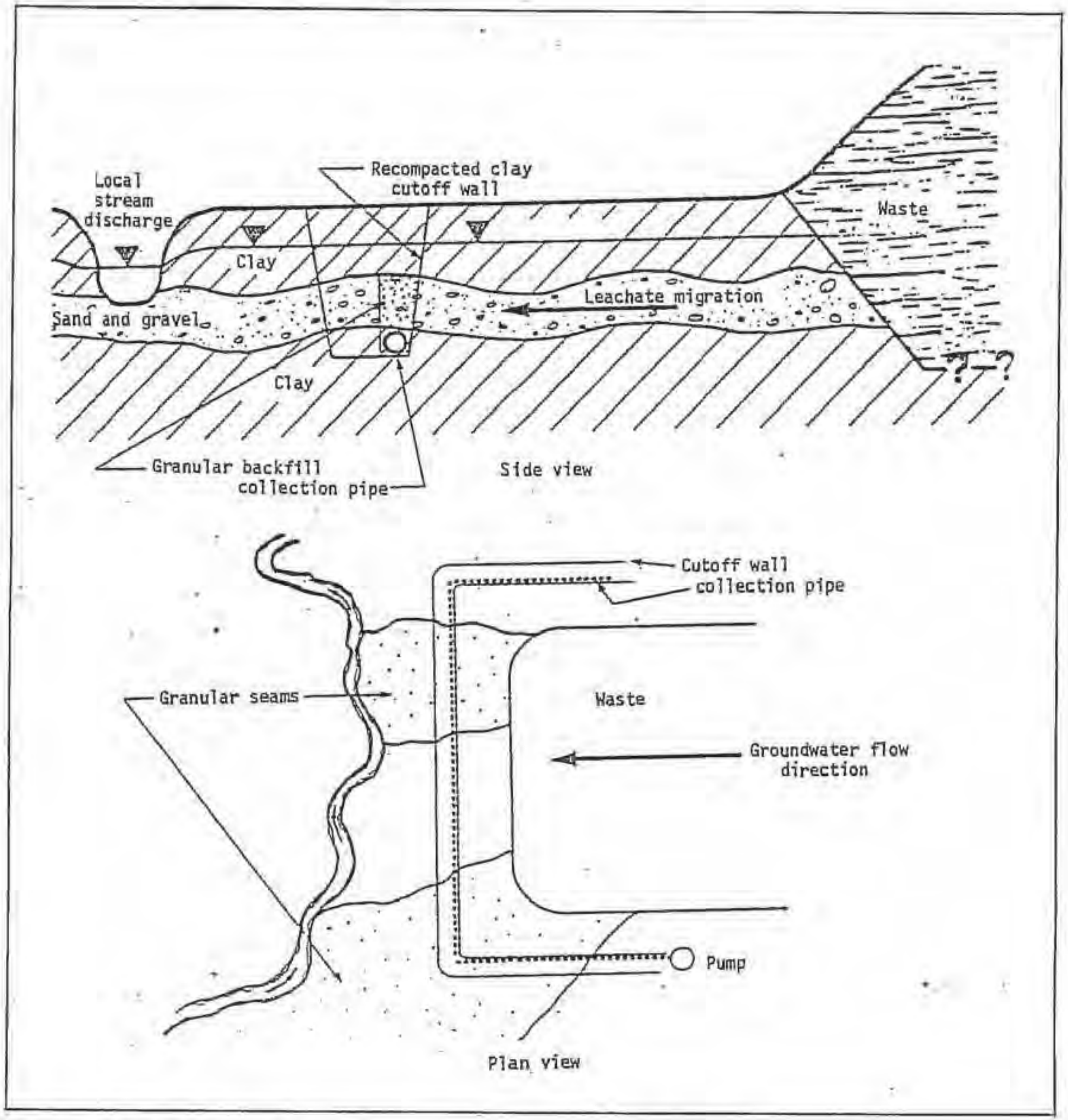

Figure 9-11. Reparative system - common cutoff wall and trench.

Source: H.A. Koch. Leachate Collection System Design. In Hazardous Waste Management Practices. Short Course, July 9-11, 1980. University of Wisconsin, Madison, Wisconsin.

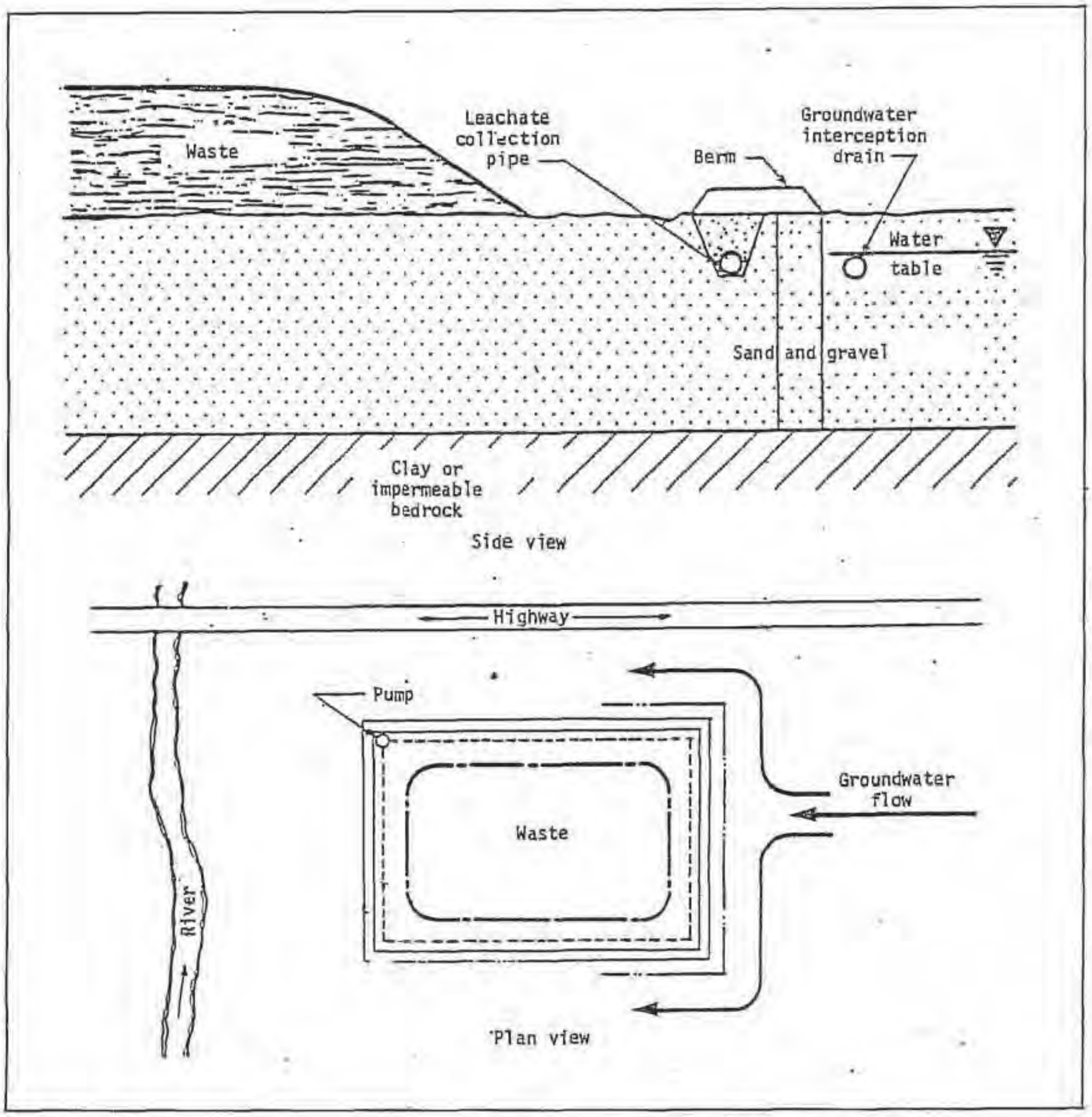

Figure 9-12. Reparative system - Bentonite slurry trenches.

Source: H.A. Koch. Leachate Collection System Design. In Hazardous Waste Management Practices. Short Course, July 9-11, 1980. University of Wisconsin, Madison, Wisconsin.

The simplest backup leachate collection systems may consist of a pipe buried in a gravel trench at the lowest point of the landfill site leading to a leachate removal facility, such as a sump pump (Figure 9-13). In the event that a quantity of leachate accumulates at the lowest portion of the landfill site, the leachate is removed through the backup collection system.

Some backup collection systems are constructed entirely during initial site construction. Other systems may be partially constructed during site preparation, but activated sometime after landfilling has ceased. These latter systems generally consist of sumps filled with granular materials. A caisson rig is used to drill into the sump at a later date, and a pump is then placed at the base of the caisson to remove leachate. In either case, periodic monitoring of leachate quantities within the landfill site is necessary to determine when a backup collection system is to be activated.

COST ESTIMATION

To conduct a cost analysis, the preliminary design criteria for the disposal facility should be established. The engineering design and specifications are generally performed by a qualified engineering firm. This subsection presents routes for bidding and variables in cost estimation. The reader is referred to Section 11 for actual cost estimating methods.

Bidding Routes

For membrane liners, the utility can proceed through one of the following routes for bidding:

- Manufacturer - may provide the material, fabrication, and installation as a package.
- Fabricator - normally buys the material in roll form, and fabricates it. He also provides installation consultation. The utility may choose to install the material using site personnel and an advisor supplied by the fabricator.
- Installer - will buy and install the fabricated material; limited liability is part of the agreement.
- General contractor - can be a liner manufacturer, a fabricator/installer, or the one who does earth work.

For clay or admixed liners, the utility can go directly to the supplier, who is normally a general contractor.

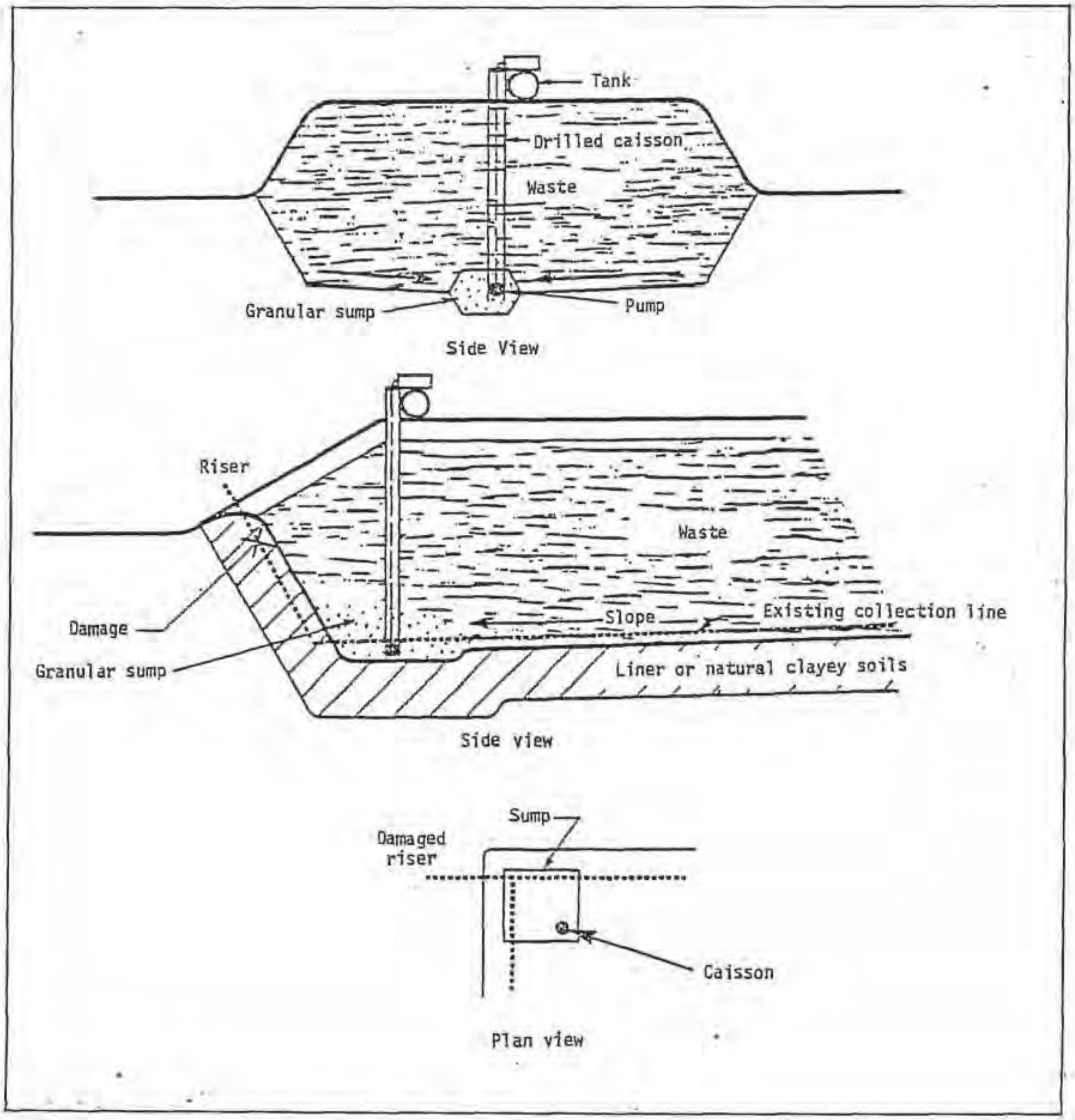

Figure 9-13. Backup Leachate Collection System

Source: H.A. Koch. Leachate Collection System Design. In Hazardous Waste Management Practices. Short Course, July 9-11, 1980. University of Wisconsin, Madison, Wisconsin.

Variables in Cost Estimation

The costs of lining materials have increased markedly in recent years, particularly for polymeric membranes. The material cost is only part of the total cost of construction of a lined disposal facility. Numerous variables affect cost determination, including:

- Mobilization or transportation.
- Weight or thickness of the material selected.
- Reinforcement.
- Subgrade preparation.
- Backfill (cover) requirement.
- Anticipated longevity.
- Other special requirements based on soil or atmospheric conditions (e.g., geotextile underlay for structural support, leachate and gas control systems, etc.).

Complete specifications must be developed before detailed costs can be determined.

Other costs associated with lining a disposal facility, which are not included in the estimation, are hydrogeological investigation, permit application, site excavation, groundwater monitoring, and closure and post-closure activities (i.e., final cover, revegetation, and monitoring). These costs are considered a part of the disposal facility, irrespective of a lining system.

Major cost items for membrane lining systems are the material, subgrade preparation, and installation. Transportation is generally not a major factor in cost estimation, since the materials are normally available from suppliers/installers within 300 miles (480 km) of the job site. Once the system is in place, the O&M costs are minimal.

Major cost items for clay and admixed lining systems are material and transportation. Subgrade preparation and installation costs are normally lower for these systems (O&M costs are greater) than for membrane lining systems.

Regardless of the material selected, lining a disposal facility is an expensive endeavor. Every phase of the lining system should be carefully planned and implemented.

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Section 10

RECOVERY AND MARKETING OF UTILITY BY-PRODUCTS

Ever-increasing attention has been focused on the reuse of coal combustion by-products as a means of averting possible land disposal impacts. Fly ash and bottom ash have been the most widely used by-products in the United States, while FGD wastes have been commonly used for structural applications in Japan and West Germany. Considerable research has been devoted to the development of additional reuse options and improved material quality controls. Given both the increasing cost of disposal and the expanding government market for combustion by-products resulting from RCRA, coal-fired utilities should give serious consideration to the recovery and sale of their ash and FGD sludge as another potential disposal option.

In order for the reader to gain a fundamental understanding of utility by-products recovery and their marketing potential, the following areas should be considered:

- Physical and chemical properties of by-products.
- Potential commercial by-product uses and use specifications.
- By-product handling and storage.
- By-product market characteristics.
- Marketing structures.

Available information on these areas is reviewed in the following pages. Discussion of the latter two areas is brief, due to the lack of U.S. marketing experience on the part of both combustion by-product producers and users. All five subject areas will be treated in detail in the EPRI Coal Combustion By-Product Utilization Manual (RP-1850), which was recently begun and is due to be completed in October 1982.

UTILITY WASTE CHARACTERISTICS

Utilization of coal combustion by-products is primarily a function of their physical and chemical properties. Coal combustion results in a residue consisting of the inorganic mineral constituents in the coal and any organic matter which is not fully burned. The inorganic mineral constituents, whose residue is ash, comprise from 3 to 30% of the coal. During combustion, this ash is distributed into two parts: bottom ash and fly ash.

Fly ash comprises from 10 to 85% of the coal ash residue (depending on combustion equipment), and forms as spherical particles ranging in diameter from 0.5 to 100 microns. Color varies from light tan to black, depending on the carbon content. Up to 20% by volume of the fly ash is made up of very lightweight particles called cenospheres. These are spheres of silicate glass ranging from 20 to 200 microns in diameter and filled with nitrogen and carbon dioxide.

The major components of ash are silica, alumina, iron oxide, and calcium oxide (Table 10-1). The oxides of these elements comprise 95 to 99% of the total composition of fly ash. Fly ash also contains small quantities of magnesium (Mg), titanium (Ti), sulfur (S), sodium (Na), and potassium (K). These elements are usually found in ash in the amounts of 0.5 to 3.5%. Very small quantities of other elements are also present in fly ash. Table 10-2 presents examples of the average trace element composition, indicating that the trace metal content of a particular ash is dependent on the type and source of the coal and the combustion conditions.

Ash physical properties are related to the chemical composition, combustion conditions, and particulate control. Boilers fired by underfeed and traveling grate stokers produce a relatively coarse fly ash, with approximately 95% of the ash greater than 5 microns (1). Spreader stoker units produce more fly ash than bottom ash, with 10 to 45% of the ash less than 10 microns (1). Cyclone units produce more bottom ash than fly ash, but the fly ash is very fine, with 90% less than 10 microns (1). In boilers firing pulverized coal, 65% of the ash is less than 10 microns (1). The percentage of fine material is higher for ash collected by electrostatic precipitator than by mechanical collector (2).

Bottom ash is composed primarily of coarser, heavier particles than the fly ash, ranging from 0.002 to 1 in (50 microns to 2.54 cm) in diameter. Bottom ash is gray to black in color, and generally angular with a porous surface. If collected as slag, it is usually black and angular with a glass-like appearance. Table 10-3 shows the chemical composition of bottom ashes from six utility plants.

In addition to ash wastes, flue gas cleaning can also generate a sludge or a dry waste. This waste is typically the product of flue gas desulfurization, although some scrubbers installed in the late 1960s were designed primarily for particulate removal. Sulfur dioxide is removed from boiler flue gas by contacting flue gas with

Table 10-1

CHEMICAL COMPOSITION OF FLY ASHES ACCORDING TO COAL RANK: MAJOR AND MINOR SPECIES (WEIGHT PERCENT)

Chemical	Eastern Bituminous			Western Subbituminous			Western Lignite		
	Range	Median	Total No. of Observations	Range	Median	Total No. of Observations	Range	Median	Total No. of Observations
Sodium Oxide, Na_2O	0.05-2.04	0.53	21	0.15-2.14	1.04	8	0.60-8.10	3.45	8
Potassium Oxide, K_2O	0.92-4.00	2.53	20	0.50-1.80	0.99	8	0.20-1.02	0.50	8
Magnesium Oxide, MgO	0.50-5.50	1.24	23	1.10-5.90	2.96	12	3.3-12.75	6.79	10
Calcium Oxide, CaO	0.26-13.15	2.88	21	1.80-30.40	13.81	12	11.7-35.44	22.29	10
Silicon Dioxide, SiO_2	36.00-57.00	48.76	22	31.00-64.80	49.69	9	2.20-46.1	30.69	8
Aluminum Oxide, Al_2O_3	16.25-30.30	23.26	22	18.70-37.00	23.04	12	10.7-25.3	15.48	10
Iron Oxide, Fe_2O_3	3.88-35.40	16.44	23	3.07-21.50	6.48	12	2.9-14.15	8.87	10
Titanium Dioxide, TiO_2	1.00-2.50	1.45	19	0.68-1.66	1.09	11	0.52-1.60	0.74	8
Phosphorus Pentoxide, P_2O_5	0.02-0.42	2.73	16	0.19-0.70	0.38	6	0.02-0.76	0.25	5
Sulfur Trioxide, SO_3	0.09-3.30	0.78	17	0.10-5.23	1.66	12	0.32-7.20	3.14	8

Source: K. L. Ladd, Jr., and R. H. Boyd, Jr. By-Products from Coal Fired Electric Utilities - A Resource for Recovery and Utilization. Presented at the Second Conference on Air Quality Management in the Electric Power Industry, University of Texas, Ausutin, Texas, January 22-25, 1980.

Table 10-2

RANGE IN AMOUNT OF TRACE ELEMENTS PRESENT IN COAL ASHES (ppm)

Element	Anthracites			High Volatile Bituminous			Low Volatile Bituminous			Medium Volatile Bituminous			Lignites and Subbituminous		
	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average
Ag	1	1	*	3	1	*	1.4	1	*	1	1	*	50	1	*
B	130	63	90	2800	90	770	180	76	123	780	74	218	1900	320	1020
Ba	1340	540	866	4660	210	1253	2700	96	740	1800	230	896	13900	550	5027
Be	11	6	9	60	4	17	40	6	16	31	4	13	28	1	6
Co	165	10	81	305	12	64	440	26	172	290	10	105	310	11	45
Cr	395	210	304	315	74	193	490	120	221	230	36	169	140	11	54
Cu	540	96	405	770	30	293	850	76	379	560	130	313	3020	58	655
Ga	71	30	42	98	17	40	135	10	41	52	10	*	30	10	23
Ge	20	20	*	285	20	*	20	20	*	20	20	*	100	20	*
La	220	115	142	270	29	111	180	56	110	140	19	83	90	34	62
Mn	365	58	270	700	31	170	780	40	280	4400	125	1432	1030	310	688
Ni	320	125	220	610	45	154	350	61	141	440	20	263	420	20	1298
Pb	120	41	81	1500	32	183	170	23	89	210	52	96	165	20	60
Sc	82	50	61	78	7	32	155	15	50	110	7	56	58	2	18
Sn	4250	19	962	825	10	171	230	10	92	160	29	75	660	10	156
Sr	340	80	177	9600	170	1987	2500	66	818	1600	40	668	8000	230	4660
V	310	210	248	840	60	249	480	115	278	860	170	390	250	20	125
Y	120	70	106	285	29	102	460	37	152	340	37	151	120	21	51
Yb	12	5	8	15	3	10	23	4	10	13	4	9	10	2	4
Zn	350	155	*	1200	50	310	550	62	231	460	50	195	320	50	*
Zr	1200	370	688	1450	115	411	620	220	458	540	180	326	490	100	245

* Insufficient data to compute an average value.

Source: S. Torrey, ed. Coal Ash Utilization. Noyes Data Corporation, Park Ridge, New Jersey, 1978, pp. 370.

Table 10-3

CHEMICAL COMPOSITION OF BOTTOM ASH FROM VARIOUS UTILITY PLANTS

Compound or Element	Percent Composition by Weight					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
SiO_2	58.	59.	50.	59.	NR*	49.
Al_2O_3	25.	18.5	17.	17.	NR	19.
Fe_2O_3	4.0	9.0	5.5	3.0	30.4	16.0
CaO	4.3	4.8	13.0	3.5	4.9	6.4
SO_3	0.3	0.3	0.5	0.1	0.4	NR
MgO	0.88	0.92	1.61	1.17	NR	2.06
Na_2O	1.77	1.01	0.64	0.43	NR	0.67
K_2O	0.8	1.0	0.5	1.5	NR	1.9
P_2O_5	1.06	0.05	0.30	0.75	NR	NR

* NR = not recorded.

Source: K. L. Ladd, Jr., and R. H. Boyd, Jr. By-Products from Coal Fired Electric Utilities - A Resource for Recovery and Utilization. Presented at the Second Conference on Air Quality Management in the Electric Power Industry, University of Texas, Austin, Texas, January 22-25, 1980.

an alkali-containing absorbent. Particulate removal scrubbers may also contain alkaline material for pH control. In wet FGD systems, the reagent primarily used is lime (CaO) or limestone ($CaCO_3$). Some installations supplement these reagents with alkaline fly ash; a few use fly ash or a sodium salt (hydroxide or carbonate) exclusively (4). Dry FGD systems will probably use a sodium-based alkali (e.g., nahcolite or trona) or a calcium-based alkali.

Scrubber wastes consist, in general, of the products of desulfurization reactions, unreacted sorbent, and fly ash. Typical wet scrubber sludges are mixtures of residual fly ash, calcium hydroxide, calcium carbonate, calcium sulfate, calcium sulfite, and water. The waste product drawn from the scrubber system is a slurry containing 5 to 15% solids. Analyses of scrubber liquor and sludge solids are shown in Tables 10-4 and 10-5, respectively. Based on the values in Table 10-5, SO_3/SO_4 values range from 0.09 to 7.75, with an average value of 1.54.

Preliminary research into dry FGD waste characteristics indicated that fly ash constitutes 60 to 71.5% of the dry wastes, while the remaining 28.5 to 40% is made up by spent sorbent and reactants (2). Dry FGD systems using nahcolite (a mineral form of $NaHCO_3$), for example, produce a waste mixture containing 40 percent spent sorbent (17% Na_2CO_3, 35% Na_2SO_3, 14% Na_2SO_4, 1% $NaHCO_3$, 27% inert mineral components), with the remaining 60% consisting of fly ash (4). The sulfite/sulfate ratio of the spent sorbent is 2.5. Nahcolite may also remove significant quantities of NO_2 from the stack gases, producing sodium nitrite and nitrate.

In calcium-based dry FGD wastes, fly ash was found to amount to approximately 71.5%, while spent sorbent comprised the remaining 28.5%. The major constituents of the spent sorbent were found to be $CaSO_3$ and $CaSO_4$, amounting to 14.6 and 8.9%, respectively (i.e., sulfite/sulfate ratio of 1.64). Unreacted lime concentrations were minor (1.6%), as were concentrations of $CaCO_3$ (2.1%) and water (1.3%) (4).

The composition of a specific FGD waste is highly variable and site-specific, and is a function of a number of interrelated factors reflecting combustion and gas cleaning operations. The major factors are the chemical and physical characteristics of the coal (e.g., ash and sulfur content, heating value), boiler type, the presence and efficiency of upstream fly ash removal, scrubber type and efficiency, sorbent type, stoichiometric ratio, and the degree of oxidation and/or stabilization/fixation.

Table 10-4

RANGE OF CONCENTRATIONS OF CONSTITUENTS IN SCRUBBER LIQUORS

Constituent	Range of Concentration at Potential Discharge Point (mg/l)		
Aluminum (Al)	0.03	to	0.3
Antimony (Sb)	0.09	to	2.3
Arsenic (As)	<0.004	to	0.3
Beryllium (Be)	<0.002	to	0.14
Boron (B)	8.0	to	46.
Cadmium (Cd)	0.004	to	0.11
Calcium (Ca)	520.	to	3,000.
Chromium (Cr)	0.01	to	0.5
Cobalt (Co)	0.10	to	0.7
Copper (Cu)	<0.002	to	0.2
Iron (Fe)	0.02	to	8.1
Lead (Pb)	0.01	to	0.4
Magnesium (Mg)	3.0	to	2,750.
Manganese (Mn)	0.09	to	2.5
Mercury (Hg)	0.0004	to	0.07
Molybdenum (Mo)	0.91	to	6.3
Nickel (Ni)	0.05	to	1.5
Potassium (K)	5.9	to	32.
Selenium (Se)	<0.001	to	2.2
Silicon (Si)	0.2	to	3.3
Silver (Ag)	0.005	to	0.6
Sodium (Na)	14.0	to	2,400.
Tin (Sn)	3.1	to	3.5
Vanadium (V)	<0.001	to	0.67
Zinc (Zn)	0.01	to	0.35
Carbonate (CO_3)	<0.01	to	<10.
Chloride (Cl)	420.	to	4,800.
Fluoride (F)	0.07	to	10.
Sulfite (SO_3)	0.8	to	3,500.
Sulfate (SO_4)	720.	to	10,000.
Phosphate (PO_4)	0.03	to	0.41
Nitrogen (N) (total)	<0.001	to	0.002
Chemical Oxygen Demand	60.	to	390.
TDS	3,200.	to	15,000.
Total Alkalinity (as $CaCO_3$)	41.	to	150.
Conductance, mho/cm	0.003	to	0.015
Turbidity, Jackson Units	<3.	to	<10.
pH	3.04	to	10.7

Source: M. Baker, Jr., Inc. State-of-the-Art of FGD Sludge Fixation. FP-671, Vol. 3, Electric Power Research Institute, Palo Alto, California.

Table 10-5

PHASE COMPOSITION OF FGD WASTE SOLIDS IN WEIGHT PERCENT

Formula	TVA Shawnee Limestone (2/1/73)	TVA Shawnee Limestone (7/12/73)	TVA Shawnee Limestone (6/15/74)	TVA Shawnee Lime (3/19/74)	SCE Mohave Limestone (3/30/73)	GM Parma Double Alkali (7/17/74)	APS Cholla Limestone (4/1/74)	DLC Phillips Lime (6/17/74)
$CaSO_4 \cdot 2H_2O$	21.9	15.4	31.2	6.3	84.6	48.3	17.3	19.0
$CaSO_3 \cdot 1/2H_2O$	18.5	21.4	21.8	48.8	8.0	12.9	10.8	12.9
$CaSO_4 \cdot 1/2H_2O$	-	-	-	-	-	19.2	-	-
$CaCO_3$	38.7	20.2	4.5	2.5	6.3	7.7	2.5	0.2
$MgSO_4 \cdot 6H_2O$	4.6	3.7	1.9	1.9	-	-	-	-
Fly Ash	20.1	40.9	40.1	40.5	3.0	7.4	58.7	59.7

Source: M. Baker, Jr., Inc. State-of-the-Art of FGD Sludge Fixation. FP-671, Vol. 3, Electric Power Research Institute, Palo Alto, California.

Processing of the raw scrubber wastes can significantly change the chemical and physical properties. Oxidation of the sludge (i.e., forced oxidation), for example, decreases the sulfite-to-sulfate ratio, and produces gypsum, which has excellent potential for reuse. Stabilization by blending and chemical fixation generally changes at least the physical properties of these wastes, and sometimes the chemical structure. The solids content and bulk density increase. Typical additions include lime, fly ash, and blast furnace slag. Chemically, the sludge components (calcium sulfites/sulfates) react in a pozzolanic reaction with alumino silicates contained in the above additives, forming high-specific-volume compounds (2, 4). Stabilization of FGD sludges, by processes such as Dravo, Poz-O-Tec, and Chemifix, has been widely investigated and applied on a commercial basis. Detailed descriptions of the above processes are provided in Section 7.

COMBUSTION WASTE UTILIZATION

Most utility by-product reuse research and practice has been directed at fly ash, bottom ash, and boiler slag. The FGD waste problem is relatively new. Wet FGD has been practiced on a wide scale for approximately 13 years, while dry FGD technology is only now achieving commercial acceptance. Consequently, little research has been conducted on FGD wastes, and the number of accepted or proposed uses is limited. The use of fly ash, on the other hand, is virtually as old as combustion itself, going back at least as far as ancient Rome, where volcanic ash was used in mortar for roads and aqueducts. Thus, a far wider range of reuse options is available for ash and slag.

Estimates of coal ash reuse in the United States during the period from 1966 to 1977 range from 12 to 21% (3). In 1978, 15.4% of collected fly ash was utilized, while the respective utilization percentages for bottom ash and boiler slag were 38.7 and 69.2%. The corresponding total ash utilization in the United States in 1978 was 24.3% (1, 5, 6).

European ash reuse is significantly greater, on the order of 80% in Germany, 50% in Great Britain and Finland, 65% in France, and 35% in Poland (1). These figures are slightly misleading, however, as U.S. ash production is over four times greater than that of any European country (2). In terms of absolute quantities, U.S. coal ash utilization, as well as quantities of ash disposed, exceeds that of any other nation.

Tables 10-6 and 10-7 list the principal existing and potential uses for ash and FGD waste. In the discussion which follows, only those uses which have developed beyond the experimental stage will be considered in detail, although other potential future applications will be mentioned. While these potential markets may be significant some day, they do not now represent an important recovery option.

Ash Utilization

Cement and Concrete. In 1972, approximately one third of all fly ash utilization was for cement or concrete (1). Fly ash is valuable in cement or concrete because of its pozzolanic properties (7, 8). A pozzolan is a siliceous or siliceous aluminous material with little cementitious value, which, in finely divided form and in the presence of moisture, reacts with calcium hydroxide and other alkaline earth hydroxides to form compounds with cementitious properties. Predominately (25 to 80%) alumino-silicate in structure, fly ash is finely divided as it is generated. When mixed with lime and water, fly ash forms insoluble calcium silicate, a cementitious compound. Pozzolanic cements are stronger, more resistant to sulfate attack, more workable, and less permeable than nonpozzolanic cements; they shrink less and evolve less heat during curing, thereby reducing tendencies to crack. Fly ash concrete clings less tenaciously to forms, and retains sharper corners and details (7).

As a pozzolan, fly ash can be used as a raw material in portland cement, as an ingredient in blended cements, or as an admixture with portland cement in concrete. As a raw material, fly ash is a source of silicon, aluminum, and iron in cement. Since it occurs in an essentially pulverized state, further grinding is seldom necessary, thus reducing energy costs. Perhaps the commonest application worldwide is the use of fly ash as an ingredient in blended cements (9). In the United States, such applications must meet ASTM C 595-76 or C618 and AASHD standards. To comply with ASTM requirements for Type IP cement, blended cements produced by intergrinding fly ash with portland cement clinker must contain between 15 and 40% ash by weight. This type of concrete is used mainly in mass applications, such as dams. At least eight major Bureau of Reclamation dams in the western United States are made of concrete containing fly ash pozzolans (2).

Fly ash can also be used as an additive in ferrocement. The addition of ash improves the workability, penetrability, ease of finishing, long-term strength, and sulfate resistance. In ordinary concrete, hydration of portland cement liberates $Ca(OH)_2$, which combines with sulfates in the environment to yield $CaSO_4$. The $CaSO_4$

Table 10-6

SUMMARY OF ASH UTILIZATION CONCEPTS

Utilization Option	Status: Experimental or Pilot — Fly Ash	Experimental or Pilot — Bottom Ash and Slag	Full-Scale — Fly Ash	Full-Scale — Bottom Ash and Slag
Pozzolan mixed with cement	x		x	
Cement clinker	x	x	x	x
Mixed with ferrocement	x		x	
Partial replacement for cement in concrete production	x	x	x	x
Partial replacement for cement in structural concrete	x		x	
Partial replacement for cement in mass concrete dams	x		x	
Road base stabilization	x	x	x	x
Lightweight aggregate	x	x	x	x
Fill for roads, construction, etc.	x	x	x	x
Filler in asphalt mix	x		x	
Oil well cementing	x		x	
Alumina recovery	x			
Vanadium recovery	x	x		
Substrate courses (heavy construction)		x		x
Ice control		x		x
Asphalt shingles		x		x
Sandblasting grit		x		x
Dike repair and building		x		x
Aggregate		x		x
Roofing granules		x		x
Antiskid material	x	x		x
Mine fire control	x			
Agriculture	x	x		
Mineral wool	x			
Magnetite recovery	x	x		
Filler in rubber and plastic	x			
Bricks	x			
Flue gas desulfurization (FGD)	x		x	
Grouting	x			
Municipal sewage sludge treatment	x		x	
FGD sludge treatment	x	x	x	x

Table 10-7

SUMMARY OF FGD SLUDGE UTILIZATION CONCEPTS

Utilization Option	Status: Experimental	Status: Pilot Demonstration	Status: Full-Scale
Recovery of aluminum	x	x	
Recovery of calcium oxide	x		
Recovery of calcium carbonate	x		
Manufacture of portland cement	x		
Manufacture of concrete admixture	x	x	x
Manufacture of calcium silicate brick	x	x	
Manufacture of aerated concrete	x	x	
Manufacture of poured concrete	x	x	
Manufacture of concrete block	x	x	
Manufacture of gypsum wallboard	x	x	x
Manufacture of lightweight aggregate	x		
Manufacture of mineral aggregate	x		
Manufacture of mineral wool	x	x	
Manufacture of gypsum-plastic	x	x	x
Land recovery	x		
Surface mine reclamation	x		
Deep mine reclamation	x	x	
Road base	x	x	
Agricultural soil stabilization	x		
Artificial reefs	x	x	
Pond liners	x	x	

Source: Adapted from Michael Baker, Jr., Inc. State-of-the-Art of FGD Sludge Fixation. FP-671, Vol. 3, Electric Power Research, Palo Alto, California.

occupies a greater volume than the original $Ca(OH)_2$, leading to disruption and disintegration of the concrete. Fly asn, however, combines with the $Ca(OH)_2$ to form stable cementitious compounds, thereby reducing the susceptibility of concrete to sulfate attack.

Aside from its role as a pozzolan, ash can also be used to make aggregate that can replace sand or gravel in concrete. Aggregate is produced by heating pelletized ash to approximately 2300°F (1260°C) (sintering). The heat needed for this process is produced in part from carbon in the ash, an advantage not shared by clays and shales, other sources of aggregate. A carbon content of 3 to 10% is best for sintering (7). Iron oxide acts as a flux in the sinter mix, although excessive iron can be detrimental in any product made from the aggregate. Sintered fly ash is inert, durable, and may be stored outside, unlike raw fly ash. Ground, sintered fly ash has more pozzolanic strength than the original ash (7). Using aggregate made from sintered fly ash in concrete gives about a 25% weight reduction in floors and columns when used as a replacement for sand and gravel.

Fly ash has been used less widely in the United States than in European countries. Rigid standards, inconsistent ash composition due to changes in combustion processes and ash handling procedures followed by individual utility stations, and inadequate data on proper mixing proportions have combined to limit the market for fly ash concrete. Nonetheless, fly ash has been used in a variety of concrete products (e.g., concrete block, precast concrete products), in dams and water projects in the West, and in parking lots and airport runways. As part of "Transpo 72," a portion of the parking lot at Dulles Airport was paved with a blend of 3% lime, 8% FGD sludge, 59% fly ash, and 30% aggregate (4). Despite problems in preparing the subcourses and laying the pavement, the pavement has performed very satisfactorily (4). As both the aggregate and cementitious components of concrete, fly ash was also used to pave part of the runways at Newark Airport (10). Material costs were about half those of conventional cement and concrete, and labor and maintenance costs for installation and upkeep have been significantly reduced (10).

In order to produce a really good marketable product, utilities need to control the fineness of their fly ash. Additional separators may be required to upgrade the ash. Ideally, 99% of the ash should be finer than 200 mesh (7). Also, the amount of carbon in fly ash is a limiting factor, just as pyrites restrict the use of bottom ash/boiler slag. For example, bituminous ash with its higher carbon and iron content sinters better than lignite ash, while lignite ash with its high lime content works better as a replacement for portland cement. Utilities should take steps to control or eliminate such problem areas, provided the costs of implementing these measures are commensurate with the economic benefits. At some stations, for example, the color of the ash being generated is used to evaluate combustion conditions. Controlling ash color results in significant savings in fuel costs, as well as an improved fly ash.

Fill Material. In 1972, approximately 25% of the reused fly ash, and 35% of the reused bottom ash and slag, was used in structural fill. The material properties considered to be most important when using ash as fill material are grain size, density, compaction characteristics, shear strength, permeability, and chemical stability (2). Fly ash has been used as a structural fill material in Europe for a number of years in highway embankments and dikes (2).

Erosion and liquefaction are the major problems associated with ash fills. External erosion can be controlled through the use of a proper cover. Internal erosion and liquefaction are both related to loose packing and excess pore water pressure. These can be controlled to some extent through proper compaction and drainage system design. In some respects, bottom ash and slag work better as fill material than does fly ash.

Base Course Stabilization. Soils, wet or dry, that exhibit marked and sustained resistance to deformation under repeated or continuing loads are said to be stable. Fly ash on its own is unsuitable as a subbase or road-base material because of its inherent instabilities (11). Mixed with lime, however, fly ash has stabilization properties superior to those of lime alone in most soil types. This is due largely to the pozzolanic character of fly ash; a soil-cement type reaction is induced (12, 13).

In general, lime-fly ash-soil mixtures have higher compressive strengths than the soils alone, although this can vary with fly ash type (14). Lime-fly ash is more effective in stabilizing granular soils than fat clay soils, indicating the influence of surface area (particle size) on the rate of the pozzolanic reaction (14). Lime-fly ash bases and subbases have been constructed at Newark Airport, the Portland, Maine, Terminal, and the Portland International Airport. All have been in service for several years with no significant problems (15). In those installations where lime-fly ash did not perform well, improper installation can usually be cited as the major cause.

The performance of lime-fly ash stabilized base courses is affected by the same factors that affect the performance of base courses stabilized with other materials. Lime-fly ash materials are no more sensitive to these factors or construction anomalies than are other stabilizing materials.

Alumina Recovery. Although still in the development phase, the recovery of alumina from fly ash is a potential use with more immediate applicability than other experimental concepts. Fly ash normally contains 15 to 30% alumina. Processes have been developed whereby 95 to 98% of this alumina can be recovered. In general, these processes involve sintering the coal with a salt-soda at 1000°F (537.8°C) or a limestone-gypsum mixture at 1400°F (760°C), followed by leaching with hydrochloric or sulfuric acid (5, 16). The costs of producing alumina from ash are 30 to 130% higher than producing alumina from bauxite (8, 20). Although approximately 90% of the bauxite is imported, the high cost of processing coal ash, the dispersed locations of power plants, and the domestic availability of higher grade alternate materials have not made fly ash an attractive alternative to bauxite. However, in the future, fly ash has the potential for supplying 90% of the U.S. aluminum market (5).

Agriculture. Ash use for agriculture is potentially beneficial both as a source of nutrients, and as a soil conditioner for marginal soils. It has been demonstrated that the use of fly ash as fertilizer can increase aerial biomass compared to control plots (17, 18). However, ash may reduce the ratio of harvestable grain or fruit to biomass (17). In addition, the levels of many trace elements in plant tissues (e.g., boron, molybdenum, and selenium) may be elevated, possibly to concentrations that are phytotoxic to plants and unsafe for animal consumption (17, 18, 19). Fly ash is not a particularly good source of macronutrients such as nitrogen, potassium, and phosphorus. As a result, ash is not considered a particularly good substitute for conventional fertilizers.

The addition of ash to sandy or clayey soils can produce a medium-textured soil. Poorly drained soils mixed with ash show increased water infiltration rates, greater total pore space, and higher moisture availability (20). Alkaline ash can neutralize acidic mine spoils/refuse, converting them to usable soil. Thus, it appears that fly ash has its greatest agricultural application as a soil conditioner for heavily used, poorly drained, or marginal soils not used for food crops.

Mineral Wool Insulation. The process developed by TVA to spin mineral wool insulation fiber from boiler slag is more energy-efficient than the production of conventional mineral wool, with estimated savings on the order of 4 to 5 million Btu per ton of insulation produced (5, 21). Commercial implementation of the process and full-scale production have been restricted, however, because of possible radiation hazards. Certain TVA waste products emit a low-level radioactive gas (radon), and, since coal contains traces of natural radioactivity, no TVA waste material (including ash and slag) is being used. It has not been firmly established whether slag mineral wool insulation does emit radiation; the halt in development and production is a precaution.

Air Pollution Control. The natural alkalinity of many types of fly ash makes them good candidates for removing SO_2 in flue gas. It has been established that sufficient fly ash alkali can be reacted in a wet scrubber to reduce SO_2 in flue gas to below federal standards when burning lignite with approximately 0.75 to 0.8% sulfur in a cyclone-fired boiler (14). Higher sulfur coals require the addition of lime to provide enough alkali. Currently, 11 power plants use or are planning to use lime-fly ash scrubbing systems. Two utilities, Minnesota Power and Light and Public Service of Colorado, use fly ash exclusively in some of their scrubbers.

Magnetite Recovery. Studies also show that it is possible to remove marketable metals from fly ash (22). Between 10 and 15% of bituminous coal fly ash may be recovered as a magnetic fraction. Presently, Halomet, Inc., operates a magnetite recovery facility at Masontown, Pennsylvania. This facility treats 400,000 tons of fly ash annually, recovering and selling about 60,000 tons of magnitite a year (15% recovery). TVA is also planning to build a magnetite recovery facility by 1982; recovered magnetite will be used in coal washing and coal dust control operations at the same power plant (5).

Other Applications. Bituminous paving mixtures have been designed to include mineral fillers since about 1980. Ash works well as a mineral filler, providing better resistance to water than limestone dust (7).

Fly and bottom ashes have been suggested as fillers or replacements for clays in certain plastics and rubber. The addition of fly and bottom ash mixtures to tire rubber failed to increase skid resistance, and proved detrimental with regard to wear, tensile and hot-tear strengths, and resilience (23). The present inability to provide ash with a uniform, constant composition makes ash use in high-quality plastics unlikely.

FGD Sludge Utilization

As noted earlier, there has been relatively little research conducted on recovery and reuse technologies for FGD sludges as compared to ash. Consequently, the number of proven reuse options currently available is limited. Most of these uses rely on oxidized or stabilized sludges, as untreated and unprocessed FGD sludges have very poor structural properties (4). Raw FGD sludge is currently being considered for use as a soil conditioner in agricultural application, especially in the arid Southwest (4). In general, sludges are not considered to be competitive fertilizers.

Of the treated sludges, no by-product uses for Dravo-stabilized sludges have been identified, other than possible use as a landfill liner (4). Most of the experience using stabilized sludge for structural purposes is limited to pozzolanic products, such as those produced by the IUCS process.

Base, Fill, and Liner. Properly proportioned, compacted, and cured lime, fly ash, and FGD sludge mixtures produce a strong, stiff material which can be used in embankments, subgrades, subbases, and bases for pavement (2). The material is generally impermeable and lighter in weight than most compacted soils. However, it exhibits poor freeze-thaw durability. Calcium sulfate enhances the strength development of lime/ fly ash/water mixtures (24). A calcium sulfoaluminate hydrate is formed. At the optimum composition, the material is five times stronger than the mix without the calcium sulfate. Although FGD sludges are less effective than pure $CaSO_4$, they provide some of the same benefits. Consequently, an FGD sludge with a low sulfite-to-sulfate ratio is most desirable for optimum performance.

FGD sludge from the Mohave Power Plant (of the Southern California Edison Company) has been used in the construction of a road base for a parking lot and sections of a public highway in Arizona (4). Stabilized sludge from Duquesne Light Company's Elrama Station has been used for subbase construction for a municipal parking lot and commercial warehouse facility. The Elrama Station also used some of its fixated sludge to construct pond berms and liners for its wastewater and coal pile runoff ponds. Arizona Public Services's Four Corners Plant uses fixated sludge as a liner for their evaporation pond.

Mineral Recovery. Lime- and limestone-based scrubbing wastes can be a source of calcium in the extraction of alumina from low-grade ores (e.g., clay and coal ash) (25). The economics of the process are still such that the process is not competitive with bauxite alumina. However, the use of FGD sludges in the process yields a calcium silicate ($Ca_2Si_2O_3$) waste product which can be used in portland cement. The total process economics (alumina cost per ton) could be made competitive with conventional bauxite processes, if the alumina recovery processing plant could be connected with a portland cement plant.

Bench-scale processes have been developed to recover elemental sulfur from FGD sludges. None have been implemented on a full scale because other sources of sulfur have been plentiful and available at less cost (4). New uses are being developed for sulfur, however, such as its use as a binder in nonasphalt paving material. If tests currently underway prove successful, a major new market for sulfur could develop. In fact, the potential market for sulfur in these applications may exceed the current supply (26). If the market opens up, sulfur recovery from flue gas desulfurization systems would be a major supplier.

Gypsum. In Japan and certain European nations, FGD sludge is used in the production of gypsum and wallboard. FGD sludge solids, as noted previously, are composed primarily of calcium sulfite and calcium sulfate. To produce commercial-grade gypsum (calcium sulfate), the sludge must be oxidized to convert the sulfite to sulfate. The resulting gypsum contains more impurities than conventional gypsum, due to the fly ash or variations in the lime or limestone.

The major physical criterion affecting the acceptability of oxidized sludge as a gypsum for wallboard use has been particle size; the major chemical criterion for such by-product reuse has been chlorine (Cl) content (27). According to ASTM standards, and as confirmed by both domestic and foreign wallboard manufacturers, oxidized sludge containing predominantly calcium sulfate dewatered to more than 80% solids exhibits a particle size suitable for the production of home product materials. The variation of particle size appears to be directly related to the degree of oxidation, which in itself is a function of the pH of the FGD system.

Calcium chloride concentration is a direct function of both the FGD waste treatment process and the Cl content of the fuel. Increased recycling builds up considerable concentrations of salts, particularly calcium chloride. In a typical eastern subbituminous fuel containing greater than 3% sulfur, equilibrium calcium chloride concentrations approaching 100,000 parts per million have been projected. FGD systems which utilize the forced oxidation process to produce a gypsum by-product require less makeup water, because a higher percentage of solids is produced and more water is recycled in the scrubber system.

According to wallboard manufacturers, soluble Cl affects calcining temperature, set time, and stucco slurry consistency. High Cl levels in the sludge can also corrode nails used to install the wallboard. Wallboard manufacturers, however, vary in their maximum limitation of Cl salt in gypsum-like material. Maximum acceptable concentrations of calcium chloride range between 200 and 1,000 ppm. One of the major problems facing the utility industry in the recovery of oxidized sludge is the removal of calcium chloride from the waste material without generating a wastewater contaminant problem.

Fly ash also contributes enough tint to the gypsum to yield an off-spec, off-white wallboard. Furthermore, the presence of iron and certain salts from entrained fly ash can also cause bonding problems. Consequently, strength is reduced, and more stucco is required to achieve the given strength of finished plaster or wallboard. The hydrous sulfate salt levels are also limited by specifications of 0.02 to 0.03%, as they affect moisture pickup and bonding characteristics of the stucco in the core of the wallboard. Hydrous clays of up to 1.0 and 2.0% may be tolerated. Sulfite content of the gypsum is also a critical factor. Despite these problems, commercially acceptable gypsum wallboard has been produced from FGD by-products, as Japanese experience has demonstrated. Utilities may find uses for gypsum with high fly ash content within the cement industry (4).

There are, however, two disadvantages to the use of abatement gypsum in existing cement and calcining plants: off-spec particle size and excessive free water. Existing plants have equipment set up to handle rock-size (0.25- to 2.0-in, or 0.635- to 5.08-cm) gypsum. This equipment cannot effectively handle the consistently small crystalline size of abatement gypsum. In calcining operations, the excessive free water (which is 20% as compared to 3% for crude gypsum) would have to be driven off. However, free moisture may not be a problem in cement manufacturing (due to the exothermic nature of the reactions), with the exception of its effects on material handling. New plants could be designed to handle the abatement product, or the utility could compact and dry the abatement product to overcome these problems. Also, abatement gypsum could be viewed as a source of high-purity gypsum to blend with crude gypsum.

Dry FGD Wastes

Because these systems have only recently been applied on a utility scale, there has been little research directed toward reusing the wastes. However, because of the chemical nature of the wastes, it is possible to predict potential uses.

There are several technologies available for recovering sulfur compounds from dry FGD wastes. Three processes, the copper oxide regeneration process, the RESOX aqueous process, and the aqueous carbonate process (ACP), have been applied to dry FGD wastes with mixed results (28).

Regeneration of sodium compounds from dry FGD wastes, by methods such as ACP, carbonation, evaporative crystallization, acidification with H_2SO_4, and the Ampot process, has also been tested by adopting the technical concept already developed and applied in other industrial fields. These recovery schemes have a potential to be combined with any simple dry FGD process, such as dry injection and spray drying. The most extensively developed of these methods, the ACP process, showed promising results on a pilot scale (28).

Specific conventional reuse options include waste utilization in concrete mixtures as a cement substitute, as well as in cement manufacturing a gypsum substitute (28). Dry waste may be incorporated into bituminous paving mixtures. The lime-additive wastes may serve as a low-cost structural material (e.g., subbases and nonstructural walls). The wastes could be sintered and used as light-weight aggregates for buildings, foundations, or subbases (28). The dry FGD wastes probably possess the same potential for industrial utilization, mineral wool utilization, and mineral recovery as do conventional wet FGD sludges. In addition, nahcolite-based wastes may have value as fertilizers if the nitrogen content is sufficiently high (28).

RESEARCH AND DEVELOPMENT IN REUSE OF UTILITY BY-PRODUCTS

Although substitution of combustion by-products for raw materials in construction aggregates is practiced extensively in foreign countries, these materials have not been as widely accepted or used in the United States. One of the main reasons was reported to be the lack of laboratory data on field properties, construction handling, and performance experience with these materials. Other important factors include:

- Reliance upon somewhat rigid materials and construction specifications within the industry, which tend to exclude utilization of coal ash materials, rather than permitting their acceptance upon proof of equal or better performance.
- Lack of consideration of the unique properties of combustion by-products, i.e., applying criteria developed for conventional materials to materials inherently different.
- Lack of confidence in developing the necessary techniques to effectively utilize combustion by-products prior to an acute shortage of conventional materials.

Research has thus been undertaken in the areas shown in Table 10-8. Research into construction material aggregates conducted at the University of Wisconsin (in conjunction with the National Slag Association) covers such aspects as sources, material properties, optimum doses, tests, specifications, proportioning, blending, compaction, strength, and other factors. Research into aggregate requirements for bituminous mixtures (i.e., procedures for mix design, specifications, etc.) at the University of Texas is designed to assess the desired properties for bituminous mixtures, including measurement of the deterioration rate constants for bituminous pavings made from combustion by-products.

At the University of Wisconsin, ongoing research also compares aggregate requirements for portland cement concrete mixtures, which involves investigations into procedures for mix design, specifications, tests, etc., to achieve desired properties for these mixes. Also, to determine the technical aspects of abatement gypsum and its substitutability, research is being conducted on mix composition, crystal size, and structure, as well as testing under operating conditions.

As shown in Table 10-8, research is also being conducted on the identification and development of new uses for the proven products. For example, the State University of New York is studying the use of stabilized brick-like FGD wastes (using the IUCS process) to create artificial reefs for marine habitats.

Research into the emerging technologies for combustion by-product uses can be grouped into two categories: new utilization options and utilization of waste constituents (Table 10-8). Within each category, several processes are being researched from a technical and economic standpoint to assess their applicabilities for near-term commercial development. Under the first category, for example, ongoing investigations include industrial utilization of sodium-based wastes by the pulp and paper industry in the bleaching process. Sodium sulfate wastes may also be used by glass manufacturers in batch glass formation. In Japan, for example, about 80% of the sodium wet scrubbing plants produce sodium sulfite for paper mills. The remaining plants oxidize the sulfite to sulfate, which is then either used in the glass industry or is purged in wastewater.

Research conducted under the second category encompasses technologies for mineral wool insulation, magnetite recovery, and mineral recovery. The results indicate that the commercial manufacture of mineral wool insulation from bottom ash, fly ash, or limestone-modified fly ash may be feasible. TVA, for example, has already developed the technology to spin mineral wool insulation fibers from boiler slag.

Table 10-8

AREAS OF ONGOING R&D PROJECTS IN REUSE OF UTILITY BY-PRODUCTS

I. IMPROVEMENT OF EXISTING COMBUSTION BY-PRODUCT REUSES

- Upgrading product quality for present uses in displacing raw materials; design, practice, and specifications for aggregates as construction materials.
- New uses for proven products.

II. DEVELOPMENT OF NEW TECHNOLOGIES FOR REUSE OF BY-PRODUCTS OR THEIR CONSTITUENTS

- New utilization options for by-products.
- Utilization of by-product constituents.

Concepts for recovering minerals from coal ashes existed 50 years ago, but the technologies were not considered economical. Though still in the developmental phase, the recovery of aluminum from fly ash is a potential use with more immediate applicability than other experimental concepts. Fly ash normally contains 15 to 30% aluminum. Processes for aluminum recovery are being investigated by Oak Ridge National Laboratory, Ames Laboratory, and Iowa State University. Results indicate 95 to 98% aluminum recovery by means of different sintering processes.

A comprehensive list of by-product uses currently being investigated on an experimental and/or pilot scale (for improvement and/or development) is given in Tables 10-6 and 10-7.

WASTE HANDLING FOR REUSE PURPOSES

To stimulate interest in the user industries for combustion by-products, utilities will have to assume the responsibility for producing a sufficient and continuous supply of the desired material. Associated problems that may be encountered include (1) seasonal variations in by-product generation as a function of seasonal demand for electricity; (2) dispersed nature of the utility plants as compared to the markets; and (3) geographical variations in by-product characteristics. For example, the distribution of the ash supplies shows higher tonnages in the northeastern, eastern, southeastern, midwestern, deep southern, and Rocky Mountain states (4). The distribution of FGD sludge supplies is even more limited, consisting primarily of the midwestern, deep southern, and Rocky Mountain states. Furthermore, the characteristics of the ash and sludge vary from region to region. Western ashes tend to be more alkaline and lower in iron oxides than are eastern ashes. Consequently, a market for alkaline ash in Pennsylvania, for instance, could be starved for supplies despite piles of coal ash from eastern coals located nearby. Similarly, a coal-cleaning process requiring an ash with a high iron content could work well in Ohio or Tennessee, but would be much more costly in Colorado. Major mass concrete dam projects in the West are located far from the biggest sources of ash, the eastern power plants. Furthermore, there are fluctuations in by-products demand as related to the seasonality of different industries (e.g., construction industry).

To facilitate provisions for overcoming the above seasonal and/or geographical variability of by-product generation and use, utilities must give special attention to the associated problems of by-product handling, especially their storage and transportation. Numerous combinations exist for the handling of each form of coal-fired power plant waste material. The choice of the appropriate combination will depend primarily on waste characteristics, reuse options, economics, and environmental concerns to each waste type.

Of the utility companies surveyed for this manual, it was found that equipment and subsequent procedures for handling are the same, whether the utility wastes are to be sold for recovery or transported to a disposal site. The only variation between the utilities was that by-product customers frequently utilized their own transportation for pick-up from the utilities. In cases where utilities provided the transportation, hauling was performed either by the utility-hired trucks or by utility-hired outside haulers.

Utility surveys, furthermore, revealed that it is impractical to reuse utility wastes once they are disposed of, due to (1) some undesirable qualities acquired by disposal (such as appearance, texture, structure), and (2) economic considerations related to excavation of the disposed wastes. For these reasons, reuse of utility waste in conjunction with closure and in-situ conversion of wet to dry disposal practices is not considered in the following discussion.

The subsequent discussion is focused on the description of different alternatives for collecting, storing, conveying, and transporting combustion by-products for reuse purposes. A list of these alternatives is provided in Table 10-9. By-product treatments are mentioned only in terms of their interrelationships with handling options; detailed descriptions of waste treatment technologies are provided in Section 10 of this report.

Fly Ash Collection, Conveyance, and Storage

Currently available methods for fly ash removal from stack gases include wet scrubbers, mechanical collectors, fabric filters, and electrostatic precipitators. Detailed descriptions of these systems can be found in EPRI's Coal Ash Disposal Manual (29). After separation from the above air pollution control devices into hoppers, fly ash can be handled by either dry or wet systems (30).

If fly ash is collected by a dry handling system, there are three pneumatic methods which can be utilized for conveying the material from the collection source to the temporary storage (silo) or sluicing area: the vacuum system, the pressure system, and a combination vacuum-pressure system (29, 30).

Table 10-9

ALTERNATIVES FOR BY-PRODUCT HANDLING

By-Product	Storage	Conveyance and Transportation
Fly Ash	Dry: Silos Wet: Dewatering Bins Settling Ponds or Basins Surge Piles	Pneumatic Pipelines Trucks Rail Barge
Bottom Ash	Dewatering Bins Settling Ponds or Basins Surge Piles	Pipelines Trucks Rail Barge
FGD Sludge	Storage Tanks Settling Ponds Surge Piles	Belt Conveyors Pipelines Trucks Rail Barge

Vacuum systems are limited with respect to the effective distance to which they can transport fly ash. The maximum distance to which a vacuum system can convey material is contingent upon the system configuration and the plant's altitude above sea level. Vacuum for conveying fly ash is produced either hydraulically or mechanically. Hydraulic vacuum systems discharge high-pressure water (100 to 300 psi) to create the air flow and vacuum necessary to convey ash. Alternate means of vacuum production are by mechanical vacuum pumps, which are of either the dry or water-injected positive displacement type, or the water-sealed rotary bucket type. The water-injected positive displacement vacuum systems should not be used where flue gases are high in sulfur dioxide content. Dry vacuum pumps or water-sealed rotary bucket pumps should instead be used to avoid dry corrosion problems encountered by the water-injected systems (29, 30).

Pressure systems are typically used where the conveyance length is too great for a vacuum system, or where the altitude curtails the possibility of a vacuum system. Pressure systems employ the use of air locks to transfer fly ash from a hopper at one pressure. Air locks are available in a wide range of capacities to meet any handling rate required of a pressurized conveyance system. Positive displacement blowers are used to produce the air flow and pressure required for the conveyance system (29, 30).

Combination vacuum/pressure systems are generally utilized when conveyor length exceeds the capability of a vacuum system to obtain a satisfactory conveyance rate. This type of system permits the use of vacuum to remove fly ash from hoppers at a high rate to a collecting point nearby, where the fly ash is continuously transferred to a pressurized conveyor. Consequently, both types of systems are utilized to their best advantage. The vacuum system, with its simplified controls, can remove fly ash at an optimum rate within the plant. The pressure system, reduced to one transfer point with a minimum of controls, can subsequently deliver the collected fly ash to any point on the plant's property up to several thousand feet (31).

The vacuum-pressure system provides the least complex controls of any long-distance pneumatic conveyance system by combining the simplicity of vacuum system controls with those of a two- or three-point pressure system. This contrasts with the complexity of controls required by an all-pressure system using a multiplicity of air-locks to achieve the same conveyance rates (31).

Fly ash collected and conveyed by dry systems is stored in a fly ash storage silo. Storage silos may be of carbon steel or hollow concrete stave construction. Flat-bottom silos are equipped with aeration stones or slides to fluidize dust and induce flow to the discharge outlets (31). Motor-driven blowers supply the fluidizing air. Heaters may be required to prevent moisture from forming in the silo. Silos are provided with self-cleaning vent bag filters of adequate size to prevent the discharge of dust along with displaced air as the silo is being filled. Alternately, venting can be provided by a duct from the silo roof back to the precipitator inlet. In some cases, it may be necessary to install a low-pressure blower in the vent duct to overcome losses which might prevent proper release of air and cause pressure buildup in the silo or drop-out of fly ash in the duct (31). Upon removal from the silo for transportation purposes, the fly ash is wetted to 10 to 20% moisture by weight to improve upon the handling characteristics and lessen any dust problems (31).

When directing dry fly ash to the sluicing area, the ash is pneumatically conveyed to a water ejector, where it is mixed with a high velocity water jet to 10 to 20% solids by weight, and finally sluiced to a dewatering area independently or in a combination fly ash/bottom ash. As an intermediate step, fly ash can also be mixed with bottom ash in a mixing tank prior to sluicing (31). To reduce the waste sluicing volume, fly ash dewatering can be performed either by primary dewatering or secondary dewatering. Primary dewatering systems, such as dewatering bins or settling ponds, can also serve as temporary holding facilities for ash prior to its sale for reuse (31). If removed by a wet collector from the air pollution control devices, fly ash is transported wet (sluiced) directly to the dewatering area. The use of water will affect some of the physical and chemical properties, generally by dissolving fly ash particles and/or the chemical deposits on their surfaces.

Bottom Ash/Boiler Slag Collection, Conveyance, and Storage

The open gate construction of dry bottom boilers permits the bottom ash to fall through the bottom grate into water-filled hoppers. Within wet bottom boilers, the solid base at the bottom of the fire box has an opening to allow the boiler slag to flow into a water-filled hopper where the ash solidifies upon quenching. Hoppers require large storage capacities, steep self-feeding slopes, and water containment to quench the ash and to ensure a high rate of delivery to the conveyor system.

llowing the above procedure, bottom ash/boiler slag is gravity-fed into a clinker grinder, where the coarse material is crushed to 1/4- to 1-1/2-in. (0.635- to 3.81-cm) diameter particles. After crushing is complete, the ash is fed into an adapter or sump, from which it is sluiced by means of ejector or centrifugal pumps to dewatering systems (such as settling ponds or bins). Dewatering may be accomplished either independently or in combination with fly ash (as described earlier in this section). The settling pond can also serve as a temporary holding facility prior to reuse. The ash is then removed from the pond and stacked to allow the water to drain prior to being transported. When the bottom ash/boiler slag is collected specifically for commercial value, it is often sluiced to dewatering bins (31). This type of handling allows for a much more rapid dewatering and easier loading of ash for subsequent transport.

FGD Waste Collection, Conveyance, and Storage

Wet FGD Wastes. Slurry that leaves the absorber part of a wet scrubber is directed to a reaction/recycle tank (which is a part of the wet FGD system), where precipitation of calcium sulfate and sulfite takes place. The precipitated solids are then conveyed by pumping a bleed stream to a sludge dewatering device. A detailed description of FGD sludge handling systems is presented in the EPRI FGD Sludge Disposal Manual (32).

The extent of dewatering effected will generally depend on the type of transport to be utilized. If transportation is by pipeline, FGD sludge must be maintained at a pumpable slurry of 15 to 35% solids by weight; truck or rail transport will generally require dewatering to a solids content of at least 60% by weight (32).

Temporary storage is an integral part of the FGD sludge reuse system. Storage of wet sludges is provided by means of holding tanks or ponds, while storage of dewatered sludge is in surge piles (32). Reclaiming sludge through gravity-fed hoppers or storage in bins is not advisable, as the sludge is usually not free-flowing and will clog the equipment.

Surge piles are the most commonly used method for temporary storage of dewatered FGD sludge. The following physical and chemical properties of FGD sludge are important in the site design of the surge storage pile (32):

- The bulk density determines surge pile volume required for storage of a specified tonnage of dry sludge. Knowledge of the bulk density is also necessary for the sizing of placement and reclaim equipment. Information on sludge densities, as a function of dewatering methods, is given in Section 7.

- The angle of repose (i.e., the angle to the horizontal made by the surface of a normal, freely formed surge pile) is important in determining the surge pile slope, configuration, and volume. The value is highly dependent on the sludge composition, varying from virtually zero for sulfite sludges to values approaching 60° for dewatered gypsum.
- Sludges of high porosity will pick up and retain moisture. In cold climates, freezing of surface moisture will bind the sludge together in a solid mass, and make reclaiming difficult, if not impossible.
- If portions of the sludge are water-soluble (such as with dual-alkali sludges), it may be necessary to collect storm water runoff and seepage from the surge pile.
- The cementing tendency of some FGD sludge may affect reclaiming.
- Corrosivity can be controlled by using protective coatings on equipment; but when abrasion is also present, the effectiveness of the coating is reduced. Protection against the combination of corrosion and abrasion is necessary to keep maintenance costs at a reasonable level.

The common surge piles used for storage of dewatered FGD sludges are at ground level, uncovered. They are usually conical, parallel windrow, and radial windrow type. The surface selected for the surge pile should be firm, solid, well drained, and not subject to flooding. The surface should also be raised with a good slope away from the pile area. Drainage from the pile should be collected in a ditch along either the low point or line of the raised area. The surge pile areas should be cleared of all debris and organic matter before the pile is laid down (32).

Surge pile size is based on FGD production rate and the desired retention time. The capacity required for surge piles is usually limited to a maximum of 5 days' FGD production. However, both land availability and surge pile height limitations may restrict surge pile capacity. Pile height may also be limited by soil conditions, FGD sludge characteristics, placing and reclaiming equipment, and the need to insure a safe operation (32).

Dry FGD Wastes. Dry FGD processes result in the formation of waste products that are collected dry along with fly ash. Consequently, dry FGD wastes can be handled in a manner similar to dry fly ash (28).

Transportation of Combustion By-Products

By-product transport equipment is required to accommodate the large volumes of materials generated by a utility. Options for on-site and off-site transportation are affected by both waste properties and hauling distance. For the transport of dry wastes, a variety of systems can be utilized, including pneumatic systems and belt conveyors. The applicable bulk-commodity transportation modes also include trucks, trains, and barges. For wet wastes, pipelines provide an additional method for material transport. Pneumatic systems were previously discussed in this section; the remaining five transportation alternatives are outlined (see Table 10-10) in terms of their respective applicabilities, advantages, and disadvantages. Additional information on the hauling distances, ground condition requirements, adverse slope tolerances, and hauling weight ranges of these transportation methods is presented in Table 10-10 (32). For short-distance hauling, front-end loaders, dozers, and scrapers can also be utilized. Applicabilities and limitations of these methods are also summarized in Table 10-11.

It should be noted that storage and transportation of fly ash, bottom ash/boiler slag, and FGD sludge are not addressed by the Department of Transportation regulations contained in CFR 49, as these regulations pertain specifically to the storage, containerization, and transportation of hazardous wastes.

Numerous combinations exist for the treatment and handling of each form of coal combustion wastes. The choice of the appropriate combination will be based primarily on by-product characteristics, reuse options, market specifications, economics, and environmental concerns. Since transportation constitutes a vital part of the overall cost picture, it may place economic constraints on the by-product uses. It is thus necessary for the utilities to carefully examine reuse options, especially in terms of transportation costs. Detailed information on the development of general transportation cost curves associated with the applicable bulk-commodity transportation modes is given in the EPRI manuals on the disposal of coal ash and FGD sludge (29, 32).

MARKET CHARACTERIZATION

The initial step in any marketing process is to determine which products can be sold to industrial users. This step constitutes a marketing feasibility study or market survey. Its purpose is to locate potential buyers for the recovered by-product.

Table 10-10

UTILITY WASTE TRANSPORT METHODS

Type	Applications/Comments	Advantages	Disadvantages
Belt Conveyors	Popular FGD transport system. Long (several hundred feet or more) systems are usually permanent when material flow is constant and both loading and discharge points are fixed. Short conveyors (wheel- or skid-mounted) have a great deal of flexibility and can be moved to different locations.	High degree of flexibility. Longer utilization lives than trucks. Lower depreciation than trucks.	Limited to dry handling systems. Capital costs relatively high.
Pipeline	Most widely used for wet transport. If supernatant is to be returned to the station, return lines will be needed. Conventional pumping and piping materials are generally suitable if the pH is near neutral.	Applicable to a wide range of systems.	Abrasive nature of sludge and fly ash may lead to failure from erosion. Limited to wet wastes. Provisions for flushing and cleaning of the lines should be included.
Trucks	Most widely used mode of dry waste transport. Can be utilized for wet, but dry hauling preferred.	Flexible accommodation of quantity fluctuation. Inherent system reliability with standby provided by additional vehicles. Requires low capital investment.	Wet waste is more difficult to haul, requiring enclosed vehicles. High public visibility. Labor-intensive.

Table 10-10 (continued)

Type	Applications/Comments	Advantages	Disadvantages
Rail	In theory, rail cars may be used to transport both wet and dry wastes, wet waste transport has not been demonstrated.	Haul larger loads. Less visible publicly than trucks.	Open cars not suitable to wet wastes. Enclosed cars for wet wastes difficult to empty due to settling. No specially designed wet waste cars have been developed. Rail cars not as versatile as trucks. Rail cars not as readily available on a contract basic with short notice. Rail traffic not as continuous as trucks.
Barge	Practical in isolated cases, but does not show the possibility of wide acceptance. At present, no utilities identified as utilizing barge transport.	Low unit cost.	Off-loading of a barge would require additional transport. Barging limited to utilities on or near navigable waterways or stations which require a long transport distance (greater than 100 miles).

Table 10-11

ADDITIONAL INFORMATION ON SHORT- AND LONG-DISTANCE TRANSPORTATION METHODS

Transportation Method	Haul Length (ft)								Ground Condition		Maximum Adverse Grade (%)						Total Tonnages		
											3	5	10	15	20	+20			
Conveyor	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	4			1
Front-end loader, roller tires	2	1	2	4					1	3	1	1	1	2	3	4	1	1	
Front-end loader, crawler	1	3	4						1	1	1	1	1	2	3	4	1	1	
Dozer, rubber tires	1	1	2						1	4	1	1	2	4			1	1	
Dozer, crawler	1	4							1	1	1	1	2	2	4			1	
Wheeled scraper, conventional		2	1	1	1	2	4	4	1	2	1	1	2	4			2	1	1
Wheeled scraper, tandem-powered		2	1	1	1	3	4		1	1	1	1	1	2	2	4	2	1	1
Wheeled scraper, elevated	2	1	1	1	2	4			1	3	1	1	2	4			2	1	
Truck, rear dump		3	1	1	1	1	1	1	1	3	1	1	1	3	4			1	1
Truck/semi trailer, rear dump		3	1	1	1	1	1	1	1	4	1	1	1	4	4			1	1
Truck/semi trailer, bottom dump			3	2	1	1	1	1	1		1	2	3	4				1	1
Train							4	1	1		1	4						2	1

1 - Should be considered.
2 - May be considered.
3 - May be considered under certain conditions.
4 - May be considered, special situation.

Source: Adapted from M. Baker, Jr. Inc. FGD Sludge Disposal Manual. EPRI FP-977, Project 786-1, Electric Power Research Institute, Palo Alto, California, January 1979.

However, in order to investigate the feasibility of marketing utility by-products, both supply and demand factors, their projected growth, and the competition, barriers, and constraints to market entry need to be considered.

Market Characterization for Conventional Uses

In pursuing the above considerations, a market survey for conventional uses of by-products should follow these general steps:

1. Determination of demand (present and projected; seasonal variations) for raw materials currently in use, for which utility by-products may be substituted.
2. Determination of supply (present and projected; seasonal variations) for utility by-products.
3. Determination of supply/demand relationships (present, projected, and seasonal).

In the first step, total demand quantities, both present and projected, are assessed for each raw material for which FGC by-products may be substituted. Investigations show, for example, that the present total domestic gypsum demand is approximately 25 million tons, roughly one third of the total world demand (33).

Determination of total demand also involves analyses of the industries which use the raw material under consideration, and the geographic distribution of these industries. Further analyses will include seasonal demand distribution patterns. For example, gypsum demand exhibits seasonal distribution patterns, since it is closely dependent on the construction industry (33).

This step should also involve development of total U.S. demand (present and projected) for the above raw materials as a function of industry type. The geographic distribution of each of these industries is then determined.

The second step involves a detailed assessment of the supply of by-products, including allowances for seasonal variations in production due to seasonal demand for electricity. Supply, like demand, should be characterized with regard to industry groups and geographic distributions.

Once the demand and supply quantities have been determined (Steps 1 and 2), the relationships between these quantities can be established. Geographic distribution patterns play an important role, as any gain made by selling rather than disposing of by-products may be offset by excessive transportation costs.

By superimposing by-product generation data on the respective industry demand data, areas of overabundance or shortage can also be identified. Analyses should also be performed to determine the seasonality of the supply/demand relationships with respect to (1) fluctuations in supply, which are related to seasonal changes in the demand for electricity; and (2) fluctuations in demand, which are related to seasonal variations in the consuming industries.

Market Characterization for New Technology Products

As was discussed earlier, there are several emerging technologies for utilization of combustion by-products. The potential of these technologies for market entry is similarly based on supply/demand relationships and the associated costs, but in a manner different from that described for conventional uses. The methodology and approach to be used in conducting market analyses for new technology products are illustrated below for metal recovery, one of the most promising technologies.

The analysis of market characteristics for recoverable metals from fly ash (i.e., iron oxide, aluminum, and titanium oxide) would involve the following considerations:

1. Determination of the total annual domestic production (present and projected) of a given metal, and its price.
2. Determination of the total annual U.S. imported quantities (present and projected) of a metal, and the associated price.
3. Determination of the total annual U.S. exported quantities of the above metal, and the associated price.
4. Determination of the total annual U.S. supply of a given metal (U.S. supply equals domestic production plus imports minus exports).
5. Determination of total annual U.S. consumption of the above metal.
6. Total U.S. annual quantity of the above metal available from fly ash, and the associated cost.

A comparison of items 4 and 5 above will result in the supply/demand relationships for a given metal and the associated prices, assuming that the metal products meet market specifications. If a certain metal must be imported to meet U.S. demand, a readily available domestic source, such as fly ash, may appear economically attractive to the producers of that metal, providing that the cost of extraction is competitive with the import cost.

However, if the demand for a given metal exceeds its domestic supply, but the cost of extraction from fly ash is higher than the import cost, recovery of the metal from fly ash will not be economical. Likewise, recovery of a metal from fly ash may be found to be uneconomical because of the abundance of its ore.

Similarly, when analyzing market characteristics for mineral wool insulation, consideration should be given, in addition to the above steps, to rising energy prices, decreases in supply, and available tax credits, which result in a nationwide increase in insulation sales. Since most commercial mineral wool is presently manufactured from steel slag, the future growth rate of the insulation industry could be satisfied by the use of coal ash mineral wool. Also, since fiberglass insulation is petroleum-based, coal ash mineral wool would provide an opportunity to reduce petroleum use. On a national basis, coal ash may reduce the cost of insulation due to the introduction of a broader resource base.

Competition, Barriers, and Constraints to Market Entry

When the potential market for utility by-products has been reviewed, present conditions of supply and demand must be examined. In particular, the competition from suppliers of the raw materials for which utility by-products would be substituted must be assessed. The recommended approach consists of the following steps:

- Identification of the present suppliers of raw materials.
- Determination of supply locations.
- Estimation of "net" demand for utility by-products after identification and exclusion of committed demand capacity.
- Identification of the competition, barriers, and constraints to market entry, and formulation of approaches.

In this way, specific information can be developed concerning net supply and demand by geographical region. With regard to demand, each industry receives its supply of raw materials from a specific supplier. This specific supply can be identified along with the industries for which the present demand exceeds supply. Such information will reveal all of the existing shortage areas for raw materials. In turn, potential distribution points for combustion by-products can be identified. Superimposing the locations of the utilities will then reveal the existing regional capacities for by-product use in each user industry.

However, in order to penetrate other utility by-product markets, or to expand the existing ones, each individual industry may need to overcome market entry problems alone. Several approaches should be examined. For example, in order for utility by-products to replace raw materials (either fully or partially), they must be competitive in price with raw materials. It is thus necessary to compile a list of as-delivered costs for raw materials at each demand point, since this cost is a prime consideration to the potential user.

The major problem that may be encountered is the dispersed nature of power plants as compared to industrial users. Furthermore, the characteristics of the ash and sludge vary from region to region. The most appropriate sludge for a particular application may be produced far from the area where it is needed. Beyond a certain distance, transportation costs become excessive; within that distance, available markets can rapidly become oversaturated as ash and sludge supplies exceed all local needs.

It is therefore necessary to analyze transportation costs as part of the market assessment. Such analyses involve converting data on prices for different modes of transportation (e.g., trucks, rail, barge) into the cost-equivalent distances that by-products could be hauled. The next step involves using the data on power plant locations to determine the geographical extent of potential markets.

Freight rates have long favored virgin material producers. The advent of municipal resource recovery has brought this inequity to the forefront, and numerous congressional bills have been proposed to create a more favorable rate structure for used materials. While the existing rate structure must be used in developing transportation cost models, surveys of rate status and plans by the Interstate Commerce Commission will also be needed.

Another consideration in by-product marketing is the industry bias against the use of recovered materials. For example, the metal producers may not have an interest in extracting aluminum from fly ash, as opposed to some lower grade natural ores which contain more aluminum than fly ash. Also, some users of virgin materials have a vested interest in the extraction of those materials. Another example is that of "aesthetic" specifications, such as color or odor. FGD gypsum, for instance, is off-white, and may be refused by some users, since gypsum must be white to be used in certain wallboard applications. Consequently, those specifications which are not technically founded, and which may be in the process of change within certain industries, will need to be identified during the course of an investigation of by-product marketing feasibility.

In addition to the above analyses of market entry problems, other options need to be investigated, such as process changes that could be integrated into the utility to produce a by-product which meets industry specifications. These changes may be designed to assure by-product quality standardization, improve by-product characteristics to meet use specifications, or generate by-products that may be in demand (e.g., gypsum production by forced oxidation).

Another consideration is the regulations that govern by-product use in industry. The legal constraints can be positive or negative. Negative constraints placed on users might be the preclusion of by-product use in certain structural applications (e.g., recycled steel in bridge girders). This type of constraint is usually technically justified, and cannot readily be changed. The associated markets are therefore to be avoided. Conversely, the impending promulgation of RCRA Section 6002 regulations requiring the use of fly ash in certain applications is a positive constraint which will have a substantial effect on the user and producer industries. Such laws will undoubtedly expand both the market and the marketing structures available to utilities, but it is too soon to determine exactly how these laws will affect the market.

As part of an overall marketing effort, an investigation of the current regulatory scene related to by-product utilization should focus primarily on RCRA Section 6002, Federal Procurement, with particular attention given to Subtitles E and F. In addition, applicable state utility by-product reuse regulations must be reviewed for those states in which the by-product is produced, or through which it will be transported. These state regulations should be carefully compared with RCRA regulations.

MARKETING STRUCTURES

In recovered material user industries, new ventures by material suppliers are traditionally handled in the following sequence:

1. Market survey.
2. Likely market selection.
3. Determination of quality requirements.
4. Solicitation of Letters of Intent to Bid.
5. Negotiation of pricing structure.
6. Development of contract.

Although variations on this sequence are quite common, this is the standard approach, and it is readily applicable to FGD by-product marketing. Particular emphasis should be placed on those marketing structures with which selected user industries are most familiar and comfortable.

To illustrate how FGD sludge (gypsum) marketing currently proceeds, consider a utility that plans to install a new FGD system. It might first assign several people to perform a preliminary by-product market survey. Visits might be made to wallboard or cement manufacturers within a specified distance from the power plant. During such visits, the utility might become aware of a local shortage of gypsum, and possibly encourage the manufacturers to seriously consider utilizing the oxidized sludge. Conversely, this shortage, coupled with an awareness of the near-term requirements for gypsum, would enable utility personnel to advise their upper management of the need to pursue by-product recovery.

Should the inquiries identify a viable market for the oxidized sludge, the utility would proceed in developing a technical data base. Such a data base is best provided by a vendor generating a similar waste material at another location. In addition, the end user would require samples of a similar waste material for analysis by his technical staff.

Quite often, the information generated by the vendor does not match that needed by the end user. Once common technical ground has been established, the end user might indicate the problem areas associated with utilizing this material. The vendor would provide the costs associated with additional treatment and/or operational changes. Assuming that these additional costs do not exceed a favorable sales price, contract negotiation could proceed.

As the seller of the by-product, the utility must be aware of its responsibilities in the three-party contract. Failure to generate the product due to a power failure would be the responsibility of the utility. Failure to treat the material adequately due to equipment malfunction or unacceptable quality assurance service would be the vendor's responsibility. Should the end user refuse to receive acceptable material, he must assume responsibility. Clarification of responsibilities, duties, and activities will establish a basis for the contract.

Marketing of combustion by-products will require a close working relationship between the producer (utility), the user, and the broker. Technical personnel on the utility staff are usually unfamiliar with the gypsum manufacturing process. To overcome this, a broker (the waste treatment system designer) can act as a liaison between the producer (utility) and the user (cement/wallboard manufacturer). The vendor possesses a knowledge of the treatment equipment and the chemical and physical composition of the material, and employs a technical staff who can work directly with the user. Should modifications in material composition be required, the vendor is best qualified to effect such changes for the aforementioned reasons.

A natural consequence of such services would be to provide quality assurance personnel to operate the system, such that the material generated would adhere to user requirements. The above types of interfaces and potential services have been proposed to several utilities nationwide. However, final contractual terms of this type have yet to be developed by anyone in the United States.

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Section 11

ESTIMATING THE COST FOR UPGRADING WASTE DISPOSAL SITES

The selection of an approach for upgrading a utility waste disposal site depends on many factors. For a given set of deficiencies, however, there are only a limited number of proven corrective techniques. The ultimate choice between comparable techniques is often based on cost. The purpose of this section is to provide the reader with cost estimating instructions and guidelines for a comparative economic assessment. Cost estimating equations are presented for each upgrading alternative discussed in Sections 6 through 10 of this manual.

The comparative cost evaluation of upgrading alternatives presented here follows the revenue requirement calculations presented in EPRI's Technical Assessment Guide (TAG) (1). A simplified version of this methodology is proposed, in which future revenue requirements for each alternative are expressed in terms of present worth, and then averaged into a "levelized" estimate of annual revenue requirements. This methodology allows for equitable comparisons of alternative projects with differing lifespans, capital requirements, and operating costs. The selection of an upgrading approach is therefore based on the lowest utility revenue requirements.

In the text that follows, major categories of expenditure, or "cost items," are defined and discussed to show how each contributes to the total picture of a project's revenue requirements. Estimating cost equations are then presented for each upgrading alternative.

COST METHODOLOGY

The "revenue requirement" method for economic comparison of upgrading alternatives develops an estimate of total levelized revenue requirements for each alternative.

Table 11-1 lists the cost components contained in the levelized cost derivation. Each of the variables (A through TLRR) is derived either by using the cost equations and curves presented for each upgrade option, or by applying a cost factor (e.g., tax, capacity factor, etc.) to a component cost item or component cost total. Definitions of the variables are presented below. The calculation of variable for each

Table 11-1

COST ITEMS FOR ESTIMATING REVENUE REQUIREMENTS

CAPITAL COSTS			
On-Site Capital	A		
Off-Site Capital	B		
Engineering Overhead & Fees	C		
Sales Tax	D		
Project Contingency	E		
Process Contingency	F		
Total Plant Investment	TPI		
Construction Adjustment Factor	x CAF		
Total Plant Investment, Adjusted	TPI*	TPI*	
Royalty Allowance		G	
Reproduction Costs		H	
Inventory Capital		I	
Initial Catalyst and Chemicals		J	
Land Cost		K	
Total Capital Requirement		TCR	
Levelized Annual Fixed Charge Rate		x LAFCR	
Levelized Cost of Capital		LCR	LCR
OPERATING COSTS			
Fixed Operating Costs			
Operating Labor	L		
Maintenance Labor	M		
Maintenance Materials	N		
Overhead Charges	P		
Total Fixed Operating Costs	FOM	FOM	
Variable Operating Costs			
Steam	Q		
Process Water	R		
Electricity	S		
Chemicals	T		
Other Consumables	U		
Waste Disposal	V		
Variable Maintenance Costs	W		
By-Product Credits	(X)		
Total Variable Operating Costs	VOM		
Capacity Factor	x CF		
Total Variable Operating Costs, Adjusted	VOM*	VOM*	
Total Operating Costs		TOM	
Levelizing Factor		x LF	
Levelized Operating Costs		LOM	LOM
TOTAL LEVELIZED REVENUE REQUIREMENTS			TLRR

upgrading alternative is then presented in tabular form (Tables 11-4 through 11-52, and Figures 11-2 through 11-14). Using this method, the reader can compute individual component costs as well as the levelized annual revenue requirement for the upgrading system.

CAPITAL COSTS

- A - On-Site Capital Cost. All costs are in mid-1980 dollars unless otherwise indicated. Identify when Sales Tax and Contractor Overhead and Fee are included.

- B - Off-Site Capital Cost. These costs, if applicable, include investments in roads, laboratories, etc. Disposal sites which are part of this project should be included under On-Site Capital Cost if operated by the utility.

- C - Engineering Overhead and Fees. If not already included in A or B, these costs are commonly 10 to 15% of total capital.

- D - Sales Tax. If not already included in A or B.

- E - Project Contingency. Typically 10 to 30% of A through D, this reflects the level of accuracy (or lack thereof) expected from capital cost estimates.

- F - Process Contingency. Typically 0 to 25% of A through E, this reflects the level of uncertainty associated with implementing a project. Commonly used alternatives would have a low value for this item unless such projects are subject to substantial unforeseen capital costs.

- TPI - Total Plant Investment. The sum of A through F, this estimate (in mid-1980 dollars) is prior to the actual construction.

- CAF - Construction Adjustment Factor. Assuming uniform expenditures over the construction period, this factor adjusts for escalation of the TPI estimate during construction. This factor also makes allowance for funds used during construction (AFDC). The equation is:

$$CAF = \frac{1}{M}\sum_{j=1}^{M}\left(\frac{1+i}{1+e}\right)^{j-1} \qquad (11\text{-}1)$$

  where M is the construction period in months or years, i is the interest rate (computed as 8% annually in the TAG), and e is the apparent escalation rate (6% annually in the TAG). Values for typical construction periods are given as follows:

Construction Period	CAF
1 month	1.00000
2 months	1.00083
3 months	1.00166
6 months	1.00416
1 year	1.00917
1-1/2 years	1.01422
2 years	1.01930
3 years	1.02958

- TPI* - Total Plant Investment, Adjusted. This product of TPI and CAF is the estimated postconstruction cost of in-place capital investment.
- G - Royalty Allowance. If any, this initial capital cost may already be included in a previous cost category.
- H - Preproduction Costs. Near the end of the construction period, these "startup" costs are incurred for operator training, equipment checkout, and minor equipment changes or modifications. This allowance commonly contains 1 month of fixed operating costs, 1 month of variable operating costs, and 2% of TPI* for equipment changes and modifications.
- I - Inventory Capital. This "backup" supply of consumables (including variable maintenance supplies, but excluding steam, water, and electricity) is not commonly consumed during the actual operation of the project. For this reason, it should be "capitalized" (included as part of capital investment). Common practice is to allow for a 1 month supply of these consumables as inventory capital.
- J - Initial Catalyst and Chemicals. These are initially contained within the process equipment costs prior to operation, and are not stored as part of inventory capital. These costs may already be included with previous capital items.
- K - Land. Commonly overlooked or omitted, all land contributing exclusively to the siting and operation of this project should be costed. This includes land used for storage sites, disposal sites, and special roads if the use is exclusively for the project being costed. Use $5,500 per acre to cost previously acquired land if more accurate cost estimates are not available.
- TCR - Total Capital Requirement. This is the sum of TPI* and cost items G through K.
- LAFCR - Levelized Annual Fixed Charge Rate. This factor is applied to the Total Capital Requirement to estimate the "levelized" cost of capital. As mentioned previously, the levelized approach reduces the future stream of capital expenditures to its total net worth, and then "annualizes" this sum to a single annual payment. The LAFCR accomplishes this levelizing calculation for capital costs. The LAFCR computation is shown in Table 11-2. Factors used for typical lifespans are shown below:

Lifespan (yrs)	LAFCR
5	0.34
10	0.23
15	0.20
20	0.19
25	0.18
30	0.18

- LCR - Levelized Cost of Capital. This is the product of the TCR and the LAFCR.

Table 11-2

COMPONENTS OF THE LEVELIZED ANNUAL FIXED CHARGE RATE (LAFCR)*

A	Debt Ratio	50%			
B	Debt Cost†	x 8%			
C	Return to ebt (A x B)	4%		4%	
D	Preferred Stock Ratio	15%			
E	Preferred Stock Cost	x 8.5%			
F	Return to Preferred Stock (D x E)	1.275%	1.275%		
G	Common Stock Ratio	35%			
H	Common Stock Cost	x 13.5%			
I	Return to Common Stock (G x H)	4.725%	4.725%		
J	Return to Equity (F + I)		6%	6%	
K	Weighted Cost of Capital (C + J)#			10%	10%
L	Sinking Fund Depreciation**				0.61%
M	Retirement Dispersion Allowance**				0.56%
N	Levelized Annual Income Tax*				4.7%
O	Property Taxes and Insurance				2.0%
Total (LAFCR) (K + L + M + N + O)					17.87%††

* See EPRI's Technical Assessment Guide (1) for elaboration.

† Interest rate.

Discount rate.

** At 10% discount rate over 30-year lifespan.

†† Use 18%.

OPERATING COSTS

Fixed Operating Costs

All operating costs are annual estimates in mid-1980 dollars. Though long-range costs are variable from an economic perspective, certain short-range operating costs are relatively fixed and do not vary appreciably with hours of plant operation. It is these latter costs that are termed fixed operating costs.

- L - Operating Labor. In the absence of site-specific information, this item is costed at a rate of $13.85/person-hour ($10.25/hour, plus a 35% payroll burden) for 24 hours/day, 365 days/year. This approach (2) for operating personnel is equivalent to multiplying the number of persons (or "partial persons") per shift by $121,326 ($13.85 x 24 x 365).
- M - Maintenance Labor. Total fixed maintenance costs include both labor and materials. Each of these costs can be estimated as a percentage of the installed cost of capital facilities (TPI*). These percentages are affected by the nature of the processing conditions and the type of design. In general, waste disposal processes are assumed to require 4% of TPI* for Maintenance Labor.
- N - Maintenance Materials. Waste disposal processes are assumed to require 6% of TPI* for Maintenance Materials.
- P - Overhead Charges. This allowance for administrative and support labor is commonly assumed to be 30% of L and M.
- FOM - Total Fixed Operating Costs. This sum of fixed operating and maintenance costs is computed as the sum of L through P. In subsequent years, this total is expected to escalate in accordance with general inflation.

Variable Operating Costs

The methodology presented in the TAG calls for estimating variable operating costs as if the plant were being operated 24 hours per day, 365 days per year. After these costs are estimated, their sum is adjusted by a factor which reflects declining plant utilization over a 30-year lifespan (1).

- Q - Steam. In the absence of site-specific information, assume $2.50/10^6 Btu for low-pressure (i.e., up to 70 psi) steam.
- R - Process Water. Estimated at $0.45/1000 gallons.
- S - Electricity. Estimated at $0.035/kWh.
- T - Chemicals. Assume lime at $38/ton and limestone at $11/ton.
- U - Other Consumables.
- V - Waste Disposal (Off-Site). If not included elsewhere, assume $9/ton for sludge and $4.50/ton for dry, granular solids. Wastewater is assumed to be included under overall plant capital and operating costs.

- W - Variable Maintenance Costs. If not included elsewhere.

- (X) - By-Product Credits. This negative number estimates the value of first-year by-products, if any.

- VOM - Total Variable Operating Costs. This is the sum of Q through (X) (where (X) is negative).

- CF - Capacity Factor. This factor adjusts estimates of variable operating costs so that they reflect declining plant utilization over a 30-year lifespan. Utilized plant capacity is assumed to average 70% for years 1 through 10, 65% for years 11 through 20, and 60% for years 21 through 30. Uniform present-worth factors (PWF_{20}, the uniform series present-worth factor for a 20-year period at 10% interest) are then applied and discounted to compute the CF as follows:

$$CF = [0.7\ (PWF_{10}) + 0.65\ (PWF_{20} - PWF_{10}) + 0.6\ 1/2\ (PWF_{30} - PWF_{20})] \times CRF_{30} \qquad (11\text{-}2)$$

$$= [0.7\ (6.144) + 0.65\ (8.514 - 6.144) + 0.6\ (9.427 - 8.514)] \times 0.10608$$

$$= 0.6776$$

$$\cong 0.68$$

where CRF_{30} is the uniform series capital recovery factor for 30 years at 10% interest. In essence, the CF is merely an average rate of capacity utilization over the life of the facility. A similar approach used for facility lifespans other than 30 years gives the following factors, assuming the plant is new.

Lifespan (yrs)	CF
5	0.70
10	0.70
15	0.69
20	0.69
25	0.68
30	0.68

For plants already in operation which are being upgraded, CF can be recalculated by looking up appropriate values for CRF and PWF. For an older plant with a total lifespan of 30 years, values for CF (given in terms of remaining lifespan) are as follows.

Remaining Lifespan (yrs)	CF
5	0.60
10	0.60
15	0.62
20	0.64
25	0.66

- VOM^* - Total Variable Operating Costs, Adjusted. The product of VOM and CF. This adjustment for average lifetime capacity is necessary, because Q through X are estimated at 100% capacity utilization.

- TOM - Total Operating Costs. This is the sum of fixed (FOM) and variable (VOM^*) operating and maintenance costs for 1980.

- LF - Levelizing Factor. This factor is applied to Total Operating Costs (TOM) to estimate Levelized Operating Costs (LOM). Levelization of operating costs is necessary to account for the time value of money and anticipated long-term inflation (1). To accomplish this, the levelizing factor sums the present worth of future annual operating costs, and then applies a capital recovery factor to "annualize" the total into equal, levelized annual payments. The equation is as follows:

$$LF = CRF\sum_{j=1}^{N}\left(\frac{1+e}{1+r}\right)^{j} \qquad (11\text{-}3)$$

where CRF is the uniform series capital recovery factor over project lifespan N at 10% interest, e is the apparent escalation rate (6%), and r is the discount rate (10%). Values for typical lifespans are given below.

Lifespan (yrs)	LF
1	1.060
5	1.182
10	1.335
15	1.485
20	1.629
25	1.763
30	1.886

- LOM - Levelized Operating Costs. This the product of TOM and LF.

TOTAL PROJECT COSTS

- TLRR - Total Levelized Revenue Requirements. This is the sum of LCR and LOM. This is the ultimate objective of this costing methodology, and is the figure that should be used when comparing alternative waste disposal projects.

USE OF COST ESTIMATING TABLES

Completion of Table 11-1 is necessary for estimating the total revenue requirements of a project alternative. To complete this table, the reader must calculate cost items A through X and factors CAF, LAFCR, CF, and LF. The tables which follow (11-4 through 11-52) guide the reader in estimating these cost items and factors for alternative upgrading techniques. A list of the systems and components for which cost equations are provided are listed in Table 11-3.

A methodical approach for using the cost tables is shown in Figure 11-1. Assumptions concerning materials, labor, construction period, and plant lifespan have been made for each alternative; costs are in 1980 dollars. The cost equations are presented in sufficient detail to allow the assumptions to be modified to fit a specific set of circumstances. If typical costs for labor or materials vary substantially from those assumed, the unit costs in the equations can be adjusted where appropriate. For a different construction period or plant lifespan, appropriate values of CAF, LAFCR, CF, and/or LF can be obtained using the tables given with the variable definitions, or they can be recalculated.

REFERENCES

1. Technical Assessment Guide. Palo Alto, California: Electric Power Research Institute, July 1979. PS-1201-SR.

2. Economic Premises for Electric Power Generating Plants. Palo Alto, California: Electric Power Research Institute, May 19, 1980.

(6) → To TABLE 11-1

COST ESTIMATING EQUATIONS: PIPELINES
(With Subvariable Calculations† and System Assumptions††)

Variable (5)	Cost Equation (1)	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Included in A
C	0.15 x A	
D	0	Included in A
E	0.20 (A + C)	
F	0.15 (A + C + E)	
CAF	0.985	Construction period equals 4 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.23	Lifespan equals 10 years
L	0	Not applicable
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 x M	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.68	Implemented when system is new
LF	1.335	

(3)

Approach

(1) Identify subvariables needed to calculate variables.

(2) Determine information required to perform subvariable calculations.

(3) Modify equations and factors to account for any special conditions present in a specific project.

(4) Calculate subvariables applicable to the project.

(5) Calculate variables.

(6) Enter variable quantities in Table 11-1 for estimation of revenue requirements.

† Subvariable Calculations: ← (4)

A_1 = Cost of trench excavation

= ($2.17/ft) x (Length of Trench, ft), if pipeline is underground.

A_2 = Cost of piping material and installation (2)

= (Unit Cost, $/ft) x (Length of Piping, ft); for Unit Cost, see Table 11-50.

A_3 = Cost of sand bedding material and installation

= ($1.06/linear ft of trench) x (Length of Trench, ft), if pipeline is underground.

A_4 = Cost of backfill and compaction (using 8 in. lifts)

= ($1.81/linear ft of trench) x (Length of Trench, ft), if pipeline is underground.

†† Assumptions:

1. Trench has a 4-ft-wide bottom and is 5 ft deep; banks are sloped 1:2.
2. Excavation is done with a tractor backhoe.
3. Every 5 linear ft of trench require 1 yd^3 of sand bedding.
4. Possible charges for installing pipeline on private property are not considered.

Figure 11-1. Approach for Using Tables to Calculate Revenue Requirements.

Table 11-3

GUIDE TO COST ESTIMATING EQUATIONS
(Tables 11-4 to 11-52)

Table 11-3 (continued)

Table 11-4

COST ESTIMATING EQUATIONS: BELT CONVEYORS - HORIZONTAL AND INCLINED
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.15 x A	
F	0	Included in E
CAF	1.00416	Construction period equals 6 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x L_1	
M	0	Included in L
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	$0.035/kWh x ($S_1 + S_2$)	
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-4 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of belting, terminals, takeups, stringers, idlers, drive and motor, trusses, walkways

= $400/ft x (Conveyor Length, ft), for Conveyor Length of 75 to 500 ft.

A_2 = Cost of installation

= 0.40 x A_1.

L_1 = Labor requirements

= (100 Worker-Hours/yr/100 ft of conveyor) x (Total Conveyor Length, ft).

S_1 = Electricity (kWh/yr) to drive conveyor empty and to move load horizontally

= (8760 hr/yr) x (0.7457 kW/HP) x (1.1) x (BS/100) x (CC/170 + 0.29), where BS = belt speed, ft/minute; CC = conveyor center (length of conveyor, ft); 1.1 = an adjustment for losses in drive machinery.

S_2 = Electricity (kWh/yr) to lift load vertical distance (for inclined conveyors)

= (8760 hr/yr) x (0.7457 kW/HP) x (1.1) x (TH) x (VL) ÷ 990, where TH = tons per hour of material to be conveyed; VL = vertical lift of conveyor, ft; 1.1 = an adjustment for losses in drive machinery.

†† Assumptions:

1. 24-in. wide steel belt with 35-degree troughing idlers.
2. Maximum speed of belt equals 200 ft/min.
3. Capital costs exclude foundation, anchor bolts, and housing.

Table 11-5

COST ESTIMATING EQUATIONS: BERMS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.2 (A + C)	
F	0.15 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	All soil for berms from borrow pits; no new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 40 hr	Assume berm needs to be repaired once per year due to storm damage
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable

Table 11-5 (continued)

Variable	Cost Equation	Remarks
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of compaction

= (Unit Cost, $/yd^3) x (Height of Berm, ft) x (Width of Berm, ft) x (Length of Berm, ft) ÷ 27 ft^3/yd^3; for Unit Cost, see Table 11-42.

A_2 = Cost of excavation and hauling of on-site material

= (Unit Cost, $/yd^3) x (Soil Material, yd^3); for Unit Cost, see Figure 11-2.

†† Assumptions:

1. Borrow pit for soil material is on site.
2. Berm repair is needed once per year as a result of storm damage.

Table 11-6

COST ESTIMATING EQUATIONS: BLENDING (SLUDGE/FLY ASH)
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Included in A
C	$0.096\ (A_1)^{0.76} + 0.25 \times A_3$	
D	0	Included in A
E	0.20 (A + C)	
F	0	Included in E
CAF	1.0193	Construction period equals 2 years
G	0	Not applicable
H	$0.02 \times TPI^* + 1/12\ (FOM + VOM)$	
I	1/12 (N + W)	
J	0	Included in H
K	$\$5500/acre \times K_1$	
LAFCR	0.18	Life span equals 30 years
L	$\$13.85/hr \times L_1$	
M	0.04 x A	
N	$0.06 \times TPI^*$	
P	0.3 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	$\$0.035/kWh \times S_1$	
T	0	Not applicable
U	0	Not applicable
V	0	No additional costs incurred

Table 11-6 (continued)

Variable	Cost Equation	Remarks
W	\$17/hr x W_1	
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products at some sites
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = On-site construction cost for sludge/fly ash mixing

= See Figure 11-3.

A_2 = Cost of services, utilities, and miscellaneous items

= 0.015 x A_1.

A_3 = Cost of engineering, design, and supervision

= 8900 x 1.294 x EQ, where EQ = number of major equipment pieces.

A_4 = Construction expenses

= 0.25 x $(A_1)^{0.83}$

K_1 = Acre requirements

= $\leq$2 acres for Plant Size of 200 MW or less

= 2 to 3 acres for Plant Size of 200 to 500 MW

= 3 to 5 acres for Plant Size of 500 to 1500 MW.

L_1 = Labor requirements for O&M, worker-hours

= 4980 x (Plant Size, MW)$^{0.314}$ for Plant Size of 200 to 500 MW

= 9920 x (Plant Size, MW)$^{0.203}$ for Plant Size of 500 to 1500 MW.

S_1 = Electricity required, kWh/yr

= See Figure 11-4.

Table 11-6 (continued)

W_1 = Labor requirements for chemical analyses

= 1000 hr/yr for Plant Size of 1000 MW or less

= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

†† Assumptions:

1. Plant lifetime is 30 yr.
2. Three plant sizes are considered--200, 500, and 1500 MW. The 1500-MW plant is assumed to be three 500-MW units.
3. Total operating life of 127,500 hours, with average annual capacity of 4250 hr.
4. Power unit input heat requirement of 9000 Btu/kWh.
5. Coal heating value of 10,500 Btu/lb.
6. Coal analysis (wt%): 3.5% sulfur (S), dry; 16.0% ash.
7. Limestone scrubbing process with 1.5 stoichiometry based on SO_2 removed.
8. SO_2 removed to meet New Source Performance Standards (NSPS).
9. Eighty percent of the ash present in coal is emitted as fly ash.
10. Ninety-five percent of the S in coal is emitted as SO_2.
11. Sludge is assumed to be primarily calcium sulfite hemihydrate, with 15% of the total SO_2 removed being oxidized to gypsum.
12. Fly ash and SO_2 are removed simultaneously in the scrubber system.
13. Effluent from the FGD system is 15% solids.
14. Gravity thickening and vacuum filtration are used to dewater sludge to a solids content of 60%.
15. Sludge/fly ash blending increases solids content to 74%.

Table 11-7

COST ESTIMATING EQUATIONS: BORROW
(With Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Included in A
C	0.25 x A	
D	0	Included in A
E	0.15 (A + C)	
F	0	Included in E
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	0	Not applicable
J	0	Not applicable
K	0	Not applicable
LAFCR	0.23	Life span equals 10 years
L	0	Not applicable
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable

Table 11-7 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of borrow material

= (\$/yd^3) x (Amount of Material, yd^3), if borrow is offsite; for \$/yd^3, see Table 11-46.

A_2 = Cost of borrow excavation and hauling

= (Cost of on-site excavation and hauling, \$/yd^3) x (Volume of borrow, yd^3); see Figure 11-2 for cost of on-site excavation and hauling

= [(Cost of off-site excavation, \$/yd^3) + (Cost of off-site hauling, \$/yd^3)] x (Volume of borrow, yd^3); See Figure 11-5 for cost of off-site hauling.

A_3 = Cost of placing and compacting borrow

= (\$1.04/yd^3) x (Amount of Borrow, yd^3).

†† Assumptions

1. Compaction is to 8 in. lifts using a sheepsfoot.
2. Material amounts are calculated as placed and compacted volumes.

Table 11-8

COST ESTIMATING EQUATIONS: BOTTOM SEALING
(Including Subvariable Calculations[†])

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.4 (A + C)	
F	0.25 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 96 hr	Cost per year of monitoring
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Included in A_2
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-8 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of drilling and casing

= ($7/linear foot) x (Number of Linear Feet).

A_2 = Cost of grout curtain

= (Unit Cost, $/yd^3) x (0.25) x (Thickness of Bottom Seal, ft) x (Length of Bottom Seal, ft) x (Width of Bottom Seal, ft) ÷ 27 ft^3/yd^3, where 0.25 equals the average fraction of grouted subsurface material filled with grout; for Unit Cost, see Table 11-47.

A_3 = Cost of grout injection

= ($100/yd^3) x (0.25) x (Thickness of Bottom Seal, ft) x (Length of Bottom Seal, ft) x (Width of Bottom Seal, ft) ÷ 27 ft^3/yd^3, where 0.25 equals the average fraction of grouted subsurface material filled with grout.

Table 11-9

COST ESTIMATING EQUATIONS: CHUTES
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.2 (A + C)	
F	0.15 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 40 hr	Assume chute needs to be repaired once per year due to storm damage
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-9 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of excavation

= (\$2.30/yd^3) x (Cross Section of Chute, ft^2) x (Length of Chute, ft) ÷ 27 ft^3/yd^3.

A_2 = Cost of spreading

= (\$0.76/yd^3) x (Cross Section of Chute, ft^2) x (Length of Chute, ft) ÷ 27 ft^3/yd^3.

A_3 = Cost of concrete liner

= (\$2.56/ft^2) x (Area Lined with Concrete, ft^2).

†† Assumptions:

1. Vegetation costs are presented elsewhere.
2. Chute repair is needed once per year as a result of storm damage.

Table 11-10

COST ESTIMATING EQUATIONS: COVER
(Including Subvariable Calculations†)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Included in A
C	0.15 x A	
D	0	Included in A
E	0.15 (A + C)	
F	0.15 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	0	Not applicable
J	0	Not applicable
K	0	All cover soil comes from borrow pits
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-10 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of excavation and hauling of on-site materials

= (Unit Cost, \$/yd^3) x (Amount of On-Site Material, yd^3); for Unit Cost, see Figure 11-2.

A_2 = Cost of off-site excavation

= (Unit Cost, \$/yd^3) x (Amount of Off-Site Material, yd^3);
Unit Cost = \$1.24/yd^3 (earth);
= \$1.75/yd^3 (clay).

A_3 = Cost of hauling off-site material

= (Unit Cost, \$/yd^3) x (Amount of Off-Site Material, yd^3); for Unit Cost, see Figure 11-5.

A_4 = Cost of compaction

= (Unit Cost, \$/yd^3) x (Area to be Compacted, ft^2) x (Thickness of Material, ft) ÷ 27 ft^3/yd^3; for Unit Cost, see Table 11-45.

Table 11-11

COST ESTIMATING EQUATIONS: DEWATERING OF ASHES - DEWATERING BINS (WITH WATER RECYCLE) (Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$2A_1 + 2A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11}$	
B	0	Included in A
C	0	Included in A
D	$0.06\ (2A_1 + 2A_2)$	Other subvariable costs have tax included
E	0.20 (A + D)	
F	0	Included in E
CAF	1.0193	Construction period equals 2 years
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 (N + W)	
J	0	Not applicable
K	$5500/acre x K_1	
LAFCR	0.18	Life span equals 30 years
L	$L_1 + L_2 + L_3 + L_4 + L_5$	
M	0	Included in L
N	$N_1 + N_2 + N_3 + N_4 + N_5$	
P	0.3 x L	
Q	0	Not applicable
R	0	Considered negligible
S	$S_1 + S_2 + S_3 + S_4 + S_5$	
T	0	Not applicable

Table 11-11 (continued)

Variable	Cost Equation	Remarks
U	0	Not applicable
V	0	No additional costs incurred
W	$\$17/hr \times W_1$	
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products at some sites
CF	0.70	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of dewatering bin concrete, equipment, design, and installation labor

= 3520 x (Bin Capacity, tons)$^{0.45}$, for Bin Capacity of 200 to 1000 tons

= 462 x (Bin Capacity, tons)$^{0.75}$, for Bin Capacity of 1000 to 2000 tons.

A_2 = Cost for dewatering bin foundation excavation and construction

= $15/ft^3 x 2 ft x ([Dewatering Bin Diameter, ft] + 8)^2.

A_3 = Cost of ash settling tank/basin equipment, concrete, steel, and installation labor

= 530 x (Settling Tank/Basin Area, ft^2)$^{0.41}$, for Settling Tank/Basin Area of 700 to 2800 ft^2

= 18 x (Settling Tank/Basin Area, ft^2)$^{0.84}$, for Settling Tank/Basin Area of 2800 to 22,500 ft^2.

A_4 = Cost of water storage tank concrete, steel, and installation labor

= 23.6 x (Tank Volume, ft^3)$^{0.82}$, for Tank Volume of 1.5 x 10^4 to 4 x 10^6 ft^3.

A_5 = Cost of ash hopper overflow bin pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

Table 11-11 (continued)

A_6 = Cost of water storage tank water return pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_7 = Cost of ash settling tank sludge pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 7590 x (Pumping Capacity, gpm)$^{0.51}$, for Pumping Capacity of 50 to 5000 gpm.

A_8 = Cost of water storage tank sludge pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 7590 x (Pumping Capacity, gpm)$^{0.51}$, for Pumping Capacity of 50 to 5000 gpm.

A_9 = Cost of electricity during construction and installation

= $0.15\ (2A_1) + 0.20\ (A_3 + A_4 + A_5 + A_6)$.

A_{10} = Cost of miscellaneous items for construction and installation

= $0.15\ (2A_1 + 2A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9)$.

A_{11} = Cost of piping

= $0.15\ (2A_1 + 2A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10})$.

K_1 = Acre requirements

= $\leq$4 acres for Plant Size of 200 MW or less

= 4 to 5 acres for Plant Size of 200 to 500 MW

= 5 to 8 acres for Plant Size of 500 to 1500 MW.

L_1 = Labor cost for ash settling basin

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-6.

L_2 = Labor cost for ash hopper overflow bin pumping

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-7.

L_3 = Labor cost for water storage tank water return pumping

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-7.

Table 11-11 (continued)

L_4 = Labor cost for O&M of ash settling tank sludge pump

= \$13.85/hr x (Labor Requirement, worker-hours), where Labor Requirement

= 220 x (Pumping Capacity, gpm)$^{0.42}$ for Pumping Capacity of 20 to 5000 gpm.

L_5 = Labor cost for O&M of water storage tank sludge pumping

= \$13.85/hr x (Labor Requirement, worker-hours), where Labor Requirement
= 220 x (Pumping Capacity, gpm)$^{0.42}$ for Pumping Capacity of 20 to 5000 gpm.

N_1 = Cost of maintenance materials for ash settling tank

= 2.61 x (Settling Tank Area, ft^2)$^{0.77}$, for Settling Tank Area of 400 to 100,000 ft^2.

N_2 = Cost of maintenance materials for ash hopper overflow bin pumping

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_3 = Cost of maintenance materials for water storage tank water return pumping

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_4 = Cost of maintenance materials for ash settling tank sludge pumping

= 162 x (Pumping Capacity, gpm)$^{0.66}$, for Pumping Capacity of 20 to 4000 gpm.

N_5 = Cost of maintenance materials for water storage tank sludge pumping

= 162 x (Pumping Capacity, gpm)$^{0.66}$, for Pumping Capacity of 20 to 4000 gpm.

S_1 = Cost of electricity for ash settling tank

= \$0.035/kWh x 3200 kWh, for Settling Tank Area of 100 to 4000 ft^2

= \$0.035/kWh x 12.3 x (Settling Tank Area, ft^2)$^{0.67}$, for Settling Tank Area of 4000 to 13,000 ft^2.

S_2 = Cost of electricity for ash hopper overflow bin pumping

= \$0.035/kWh x 83,200 x (Flow Rate, mgd)$^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_3 = Cost of electricity for water storage tank water return pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd)$^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_4 = Cost of electricity for ash settling tank sludge pump

= \$0.035/kWh x 23.9 x (Flow Rate, gpm)$^{0.98}$, for Flow Rate of 20 to 2500 gpm.

S_5 = Cost of electricity for water storage tank sludge pumping

= \$0.035/kWh x 23.9 x (Flow Rate, gpm)$^{0.98}$, for Flow Rate of 20 to 2500 gpm.

Table 11-11 (continued)

W_1 = Labor requirements for chemical analyses

= 1000 hr/yr for Plant Size of 1000 MW or less

= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

†† Assumptions:

1. Three plant sizes are considered--200, 500, and 1500 MW. The 1500-MW plant is assumed to be three 500-MW units.
2. Plant lifetime is 30 yr.
3. Total operating life is 127,500 hours, with average annual capacity of 4250 hr.
4. Power unit input heat requirement of 9000 Btu/kWh.
5. Coal heating value of 10,500 Btu/lb.
6. Coal analysis (wt%): 3.5% sulfur (S), dry; 16.0% ash.
7. Fly ash is removed from flue gas separately from SO_2.
8. Coal ash is 80% fly ash, 20% bottom ash.
9. Density of ash is 2 g/cm^3.
10. Two dewatering bins are considered necessary for continuous operation.
11. Center-fed ash settling tanks are used for 30- to 170-ft diameter units; rectangular settling tanks are used for larger surface areas.
12. Sidewall depth for ash settling tanks is 12 ft.
13. Excavation costs for ash settling tanks are based on a Class 3 material (fine sand, silt with no more than 25% clay) and use of a 3/4-yd^3 Bucyrus Erie 20-H Backhoe. A 1.5-in. diameter pipe handrail is included in the steel costs.
14. Water storage tank storage time is 8 hr.
15. On-site capital cost for pumps includes underground structure housing and piping.
16. Power used for pumping is based on 10 minutes of pumping per hour.
17. Dewatering bin concrete slab has average thickness of 2 ft.

Table 11-12

COST ESTIMATING EQUATIONS: DEWATERING OF ASHES - PONDS OR SETTLING BASINS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$2A_1 + A_3 + A_4 + A_6 + A_7 + A_8$	If ash ponds are used
	$2A_2 + A_3 + A_5 + A_6 + A_7 + A_8$	If settling basins are used
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Included in E
CAF	1.0193	Construction period equals 2 years
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 (N + W)	
J	0	Not applicable
K	$5500/acre x K_1	
LAFCR	0.18	Life span equals 30 years
L	$2L_1 + L_3 + L_4$	If ash ponds are used
	$2L_2 + L_3 + L_5$	If settling basins are used
M	0	Included in L
N	$2N_1 + N_2 + N_3$	If ash ponds are used
	$N_2 + N_4$	If settling basins are used
P	0.3 (L + M)	
Q	0	Not applicable

Table 11-12 (continued)

Variable	Cost Equation	Remarks
R	0	Not applicable
S	$2S_1 + S_2 + S_3$	If ash ponds are used
	$S_2 + S_4$	If settling basins are used
T	0	Not applicable
U	0	Not applicable
V	0	No additional costs incurred
W	$17/hr x W_1	
(X)	0	Waste quantities, characteristics, and local markets may allow sale of by-products for some sites
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = On-site capital costs for ash ponds (per pond)

= 6050 x (Ash Pond Volume, acre-ft)$^{0.62}$, for Ash Pond Volume of 15 to 30 acre-ft

= 3550 x (Ash Pond Volume, acre-ft)$^{0.78}$, for Ash Pond Volume of 30 to 150 acre-ft.

A_2 = Cost of ash settling basin equipment, concrete, steel, and installation labor (for one compartment)

= 530 x (Settling Basin Area, ft^2)$^{0.41}$, for Settling Basin Area of 700 to 2800 ft^2

= 18 x (Settling Basin Area, ft^2)$^{0.84}$, for Settling Basin Area of 2800 to 22,500 ft^2.

Table 11-12 (continued)

A_3 = Cost of ash hopper overflow bin pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_4 = Cost of ash pond recirculation pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_5 = Cost of settling basin recirculation pump

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_6 = Cost of electricity during construction and installation period

= 0.15 x $2A_1$ + 0.20 ($A_3 + A_4$), if ash settling ponds are used

= 0.10 x $2A_2$ + 0.20 ($A_3 + A_5$), if settling basins are used.

A_7 = Cost of miscellaneous items for construction and installation

= 0.15 ($A_1 + A_2 + A_3 + A_4 + A_5 + A_6$).

A_8 = Cost of piping

= 0.15 ($A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7$).

K_1 = Acre requirements

= (Ash Pond Volume, acre-ft) ÷ 12 ft depth + 3, if ash ponds are used.

= (Settling Basin Area, ft^2) ÷ 43,560 ft^2/acre + 3, if settling basins are used.

L_1 = Cost of labor for ash pond (per pond)

= $13.85/hr x (Labor Requirement, worker-hours), where

Labor Requirement = 41.2 x (Volume, acre-ft)$^{0.5}$, for Volume of 10 to 700 acre-ft.

L_2 = Cost of labor for settling basin (per compartment)

= $13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-6.

L_3 = Cost of Labor for ash hopper overflow bin pump

= $13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-7.

Table 11-12 (continued)

L_4 = Cost of Labor for ash pond recirculation pump

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-7.

L_5 = Cost of labor for settling basin recirculation pump

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirement, see Figure 11-7.

N_1 = Cost of maintenance materials for settling basin (per compartment)

= 1.35 x 1.93 x (Settling Tank Area, $ft^2)^{0.77}$, for Settling Tank Area of 400 to 100,000 ft^2.

N_2 = Cost of maintenance materials for ash hopper overflow bin pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_3 = Cost of maintenance materials for ash pond recirculation pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_4 = Cost of maintenance materials for settling basin recirculation pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

S_1 = Cost of electricity for ash settling basin (per compartment)

= \$0.035/kWh x 3200, for Settling Basin Area of 100 to 4000 ft^2

= \$0.035/kWh x 12.3 x (Settling Tank Area, $ft^2)^{0.67}$, for Settling Basin Area of 4000 to 13,000 ft^2.

S_2 = Cost of electricity for ash hopper overflow bin pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd$)^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_3 = Cost of electricity for ash pond recirculation pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd$)^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_4 = Cost of electricity for settling basin recirculation pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd$)^{0.9}$, for Flow Rate of 7 to 700 mgd.

W_1 = Labor requirements for chemical analyses

= 1000 hr/yr for Plant Size of 1000 MW or less

= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

Table 11-12 (continued)

†† Assumptions:

1. Three plant sizes are considered--200, 500, and 1500 MW. The 1500-MW plant is assumed to be three 500-MW units.
2. Plant lifetime is 30 yr.
3. Power unit input heat requirement is 9000 Btu/kWh.
4. Coal heating value is 10,500 Btu/lb.
5. Coal analysis (wt%): 3.5% sulfur (S), dry; 16.0% ash.
6. Fly ash is removed from flue gas separately from SO_2.
7. Coal ash is 80% fly ash, 20% bottom ash.
8. Density of ash is assumed to be 2 g/cm^3.
9. Two ash ponds are considered necessary for continuous operation.
10. Ash pond depth is 12 ft; no liners or internal erosion protection are necessary.
11. A single ash pond inlet and a single overflow weir box are included in the cost.
12. Embankments for ash ponds are based on a top width of 15 ft, an external slope of 3:1, and an internal slope of 2:1.
13. Embankment material is obtained on-site. No off-site borrow is included.
14. Labor for ash ponds is required for piping and earthwork enclosing the lagoon cell, and for cleanup of the lagoon at 5-yr intervals.
15. A two-compartment settling basin is considered necessary for continuous operation.
16. Sidewall depth for settling basin is 12 ft.
17. Excavation costs for one compartment of the settling basin are based on a Class 3 material (fine sand, silt with no more than 25% clay) and use of a 3/4-yd^3 Bucyrus Erie 20-H Backhoe. A 1.5-in. diameter pipe handrail is included in the steel costs.
18. A single settling basin inlet and a single overflow weir box are included in the cost of a two-compartment unit.
19. On-site capital cost for pumps includes underground structure housing and piping.
20. Power used for pumping is based on 10 minutes of pumping per hour.
21. One pump serves two ash ponds.

Table 11-12 (continued)

22. One pump serves two compartments in the settling basin.

23. Maintenance materials and power requirements for ash ponds are considered negligible.

Table 11-13

COST ESTIMATING EQUATIONS: DEWATERING - PRIMARY/SECONDARY[††]
(Including Subvariable Calculations[†] and System Assumptions[††])

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10}$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Included in E
CAF	1.0193	Construction period equals 2 years
G	0	Not applicable
H	$0.02 \times TPI^* + 1/12\ (FOM + VOM)$	
I	1/12 (N + W)	
J	0	Not applicable
K	$5500/acre x K_1	
LAFCR	0.18	Life span equals 30 years
L	$L_1 + L_2 + L_3 + L_4 + L_5$	
M	0	Included in L
N	$N_1 + N_2 + N_3 + N_4 + N_5$	
P	0.3 x L	
Q	0	Not applicable
R	0	Not applicable
S	$S_1 + S_2 + S_3 + S_4 + S_5$	
T	0	Not applicable
U	0	Not applicable

Table 11-13 (continued)

Variable	Cost Equation	Remarks
V	0	No additional costs incurred
W	$17/hr x W_1	
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products at some sites
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of gravity thickening equipment, concrete, steel, and installation labor

= 7940 x (Thickener Area, $ft^2)^{0.38}$, for Thickener Area of 300 to 4000 ft^2.

A_2 = Cost of vacuum filtration equipment, installation labor, housing, piping, and valves

= 11,220 x (Filter Area, $ft^2)^{0.62}$, for Filter Area of 100 to 800 ft^2.

A_3 = Cost of thickener overflow tank, concrete, steel, and installation labor

= 7760 x (Tank Volume, $ft^3)^{0.82}$, for Tank Volume of 1.5×10^4 to 4×10^6 ft^3.

A_4 = Cost of secondary dewatering underflow tank concrete, steel, and installation labor

= 7760 x (Tank Volume, $ft^3)^{0.82}$, for Tank Volume of 1.5×10^4 to 4×10^6 ft^3.

A_5 = Cost of thickener overflow tank pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd$)^{0.67}$, for Pumping Capacity of 5×10^6 to 5×10^8 gpd.

A_6 = Cost of secondary dewatering underflow tank pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd$)^{0.67}$, for Pumping Capacity of 5×10^6 to 5×10^8 gpd.

Table 11-13 (continued)

A_7 = Cost of thickener sludge pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 7590 x (Pumping Capacity, gpm)$^{0.51}$, for Pumping Capacity of 50 to 5000 gpm.

A_8 = Cost of electricity during construction period

= $(0.15 \times A_1) + 0.20\ (A_2 + A_5 + A_6 + A_7)$.

A_9 = Cost of miscellaneous items for construction and installation

= $0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8)$.

A_{10} = Cost of piping

= $0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9)$.

K_1 = Acre requirements

= $\leq$4 acres for Plant Size of 200 MW or less

= 4 to 5 acres for Plant Size of 200 to 500 MW

= 5 to 8 acres for Plant Size of 500 to 1500 MW.

L_1 = Cost of labor for O&M of gravity thickeners

= \$13.85/hr x Labor Requirement (worker-hours); for Labor Requirement, see Figure 11-9.

L_2 = Cost of labor for O&M of vacuum filters

= \$13.85/hr x Labor Requirement (worker-hours), where Labor Requirement = 100 x (Filter Area, ft^2)$^{0.66}$, for Filter Area of 50 to 6000 ft^2.

L_3 = Cost of labor for O&M of thickener overflow tank pump

= \$13.85/hr x Labor Requirement (worker-hours); for Labor Requirement, see Figure 11-7.

L_4 = Cost of labor for O&M of secondary dewatering underflow tank pump

= \$13.85/hr x Labor Requirement (worker-hours); for Labor Requirement, see Figure 11-7.

L_5 = Cost of labor for O&M thickener sludge pump

= \$13.85/hr x Labor Requirement (worker-hours), where Labor Requirement = 220 x (Pumping Capacity, gpm)$^{0.42}$, for Pumping Capacity of 20 to 5000 gpm.

N_1 = Cost of maintenance materials for gravity thickening

= 3.11 x (Thickener Area, ft^2)$^{0.74}$, for Thickener Area of 400 to 3500 ft^2.

Table 11-13 (continued)

N_2 = Cost of maintenance materials for vacuum filtration

= 797 x (Filter Area, $ft^2)^{0.7}$, for Filter Area of 10 to 4000 ft^2.

N_3 = Cost of maintenance materials for thickener overflow tank pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_4 = Cost of maintenance materials for secondary dewatering underflow tank pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_5 = Cost of maintenance materials for thickener sludge pump

= 162 x (Pumping Capacity, gpm$)^{0.66}$, for Pumping Capacity of 20 to 4000 gpm.

S_1 = Cost of electricity for gravity thickening

= $0.035/kWh x 7.2 x (Thickener Area, $ft^2)^{0.94}$, for Thickener Area of 200 to 40,000 ft^2.

S_2 = Cost of electricity for vacuum filtration

= $0.035/kWh x 5430 x (Filter Area, $ft^2)^{0.64}$, for Filter Area of 20 to 150 ft^2

= $0.035/kWh x 1350 x (Filter Area, $ft^2)^{0.92}$, for Filter Area of 150 to 4000 ft^2.

S_3 = Cost of electricity for thickener overflow tank pumping

= $0.035/kWh x 83,200 x (Flow Rate, mgd$)^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_4 = Cost of electricity for secondary dewatering underflow tank pump

= $0.035/kWh x 83,200 x (Flow Rate, mgd$)^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_5 = Cost of electricity for thickener sludge pump

= $0.035/kWh x 23.9 x (Flow Rate, gpm$)^{0.98}$, for Flow Rate of 20 to 2500 gpm.

W_1 = Labor requirements for chemical analyses

= 1000 hr/yr for Plant Size of 1000 MW or less

= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

†† Assumptions:

1. Effluent from the FGD system contains 10% solids.
2. Loading of thickener is 800 gpd/ft^2 of FGD sludge.
3. Thickener underflow contains 30% solids.

Table 11-13 (continued)

4. Thickener overflow tank storage time is 8 hr.
5. Loading of vacuum filter is 50 $lb/ft^2/hr$.
6. Cake solids content is 50%.
7. Vacuum filters operate 20 hr/day, 7 days/week.
8. Standby pumping is included.
9. Secondary dewatering underflow tank storage time is 8 hr.
10. On-site capital cost for pumps includes underground structure housing and piping.
11. Power used for pumping is based on 10 minutes of pumping per hour.
12. Plant lifetime is 30 yr.
13. Fly ash is removed from flue gas prior to scrubbing.

Table 11-14

COST ESTIMATING EQUATIONS: DIKES
(With Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5$	
B	0	Included in A
C	0.15 x A	
D	0	Included in A
E	0.20 (A + C)	
F	0.15 (A + C + E)	
CAF	1.00249	Construction period equals 4 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.23	Lifespan equals 10 years
L	$13.85/hr x 40 hr	Yearly repairs due to storm damage
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

TABLE 11-14 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of clay material

= ($0.32/ft^3) x (4 ft wide) x (Length of dike, ft) x (Height of dike, ft).

A_2 = Cost of offsite clay excavation and hauling

= [1.6 x (Cost of off-site excavation, $1/yd^3) + (Cost of off-site hauling, $/yd^3)] (4 ft wide) x (Length of dike, ft) x (Height of dike, ft) ÷ (27 ft^3/yd^3) where 1.6 = factor adjusting for difficulty of excavating clay, see Figure 11-5 for cost of off-site hauling.

A_3 = Cost of on-site borrow excavation and hauling

= (Unit Cost, $/yd^3) x (Length of dike, ft) x $(6h + 3h^2)$ ÷ (27 ft^3/yd^3), where h = finished height of dike, ft, and $(6h + 3h^2)$ = cross sectional area of dike consisting of borrow; for Unit Cost, see Figure 11-2.

A_4 = Cost of clearing and grubbing site

= ($3.85/100 ft^2) x (Area to be Cleared, ft^2).

A_5 = Cost of dike placement and compaction

= ($1.25/yd^3) x $(10h + 3h^2)$ x (Length of dike, ft), where h = finished height of dike, ft, and $(10h + 3h^2)$ = total cross sectional area of dike, ft^2.

†† Assumptions:

1. Dike consists of a 4 ft wide clay core surrounded by granular borrow. Slopes are 3:1, and top is 10 ft across.
2. Borrow is available on-site, while clay is purchased off-site.
3. Soil is compacted to 8-in. lifts.
4. Material amounts to be purchased are calculated as installed and compacted volumes.

Table 11-15

COST ESTIMATING EQUATIONS: DITCHES
(Including Subvariable Calculations[T])

Variable	Cost Equation	Remarks
A	$A_1 + A_2$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.2 (A + C)	
F	0.15 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 40 hr	Assume ditch needs to be repaired once per year due to storm damage
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-15 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of ditch

= (\$2.30/yd^3) x (Cross Sectional Area of Ditch, ft^2) x (Length of Ditch, ft) ÷ 27 ft^3/yd^3.

A_2 = Cost of concrete liner

= (\$2.56/ft^2) x (Area Lined with Concrete, ft^2).

Table 11-16

COST ESTIMATING EQUATIONS: DRAINS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Not applicable
C	0	Included in A
D	0	Included in A
E	0.25 x A	
F	0.20 (A + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 96 hr	Cost for monitoring 12 times per year
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-16 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of trench excavation

= ($2.30/yd^3) x (Trench Depth, ft) x (Trench Width, ft) x (Length of Trench, ft) ÷ 27 ft^3/yd^3.

A_2 = Cost of pipe

= (Unit Cost, $/linear foot) x (Trench Length, ft); for Unit Cost, see Table 11-48.

A_3 = Cost of sand or gravel fill

= (Cost of Fill, $/yd^3) x (Trench Length, ft) x (Trench Width, ft) x (Depth to be Filled, ft) ÷ 27 ft^3/yd^3, where

Cost of Fill = $6.64, for sand
= $6.87, for gravel (1 to 1.5 in)
= $7.67, for crushed stone.

A_4 = Cost of backfilling

= ($0.80/yd^3) x (Trench Length, ft) x (Width of Backfill Area, ft) x (Depth of Backfill Area, ft) ÷ 27 ft^3/yd^3.

†† Assumptions:

1. Monitoring is done 12 times per year.
2. Submersible pumping system costs are not included.

Table 11-17

COST ESTIMATING EQUATIONS: FIXATION - DRAVO PROCESS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5$	
B	0	Included in A
C	$C_1 + 0.096 \times (A_1 + A_2 + A_3)^{0.76}$	
D	0	Included in A
E	0.20 (A + C)	
F	0	Included in E
CAF	1.02442	Construction period equals 2.5 years
G	0	Not applicable
H	$0.10 (A + C + E - A_3)$	
I	1/12 (N + T + W)	
J	0	Included in H
K	$\$5500/acre \times (K_1 + K_2)$	
LAFCR	0.18	Life span equals 30 years
L	$\$13.85/hr \times L_1$	
M	0.04 x A	
N	$0.06 \times TPI^*$	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	$\$0.035\ kWh \times S_1$	
T	$T_1 + T_2$	Not applicable
U	0	No additional costs incurred
V	0	Not applicable

Table 11-17 (continued)

Variable	Cost Equation	Remarks
W	\$17/hr x W_1	
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products at some sites
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = On-site construction cost, excluding pond

= $1.97 \times 10^6 \times (\text{Plant Size, MW})^{0.204}$, for Plant Size of 200 to 1500 MW.

A_2 = Cost of services, utilities, and miscellaneous items

= $0.015 \times A_1$.

A_3 = Cost of pond construction

= $5.5 \times 10^4 \times (\text{Plant Size, MW})^{0.80}$, for Plant Size of 200 to 1500 MW.

A_4 = Cost of engineering, design, and supervision

= $1.93 \times 10^5 \times (\text{Plant Size, MW})^{0.25}$, for Plant Size of 200 to 1500 MW.

A_5 = Construction expenses

= $0.25 \times (A_1 + A_2)^{0.83} + 0.13 \times (A_3)^{0.83}$, where A_1, A_2, A_3, and A_5 are in millions of dollars.

C_1 = Architect and engineering contractor expenses

= $78.5 \times 10^3 \times (\text{Plant Size, MW})^{0.13}$, for Plant Size of 200 to 500 MW

= $43.8 \times 10^5 \times (\text{Plant Size, MW})^{0.22}$, for Plant Size of 500 to 1500 MW.

K_1 = Acre requirements for settling pond

= See Figure 11-10.

Table 11-17 (continued)

K_2 = Acre requirements for Dravo system, excluding pond
= $\leq$3 acres for Plant Size of 200 MW or less
= 3 to 4 acres for Plant Size of 200 to 500 MW
= 4 to 7 acres for Plant Size of 500 to 1500 MW.

L_1 = Labor requirements for O&M (worker-hours)
= $4980 \times (MW)^{0.314}$, for Plant Size of 200 to 500 MW
= $9920 \times (MW)^{0.203}$, for Plant Size of 500 to 1500 MW.

S_1 = Electricity consumed (kWh/yr)
= $1.33 \times 10^5 \times$ (Plant Size, MW)$^{0.566}$, for Plant Size of 200 to 500 MW
= $2.88 \times 10^4 \times$ (Plant Size, MW)$^{0.812}$, for Plant Size of 500 to 1500 MW.

T_1 = Annual cost of lime
= ($38/ton lime) x (10.15 tons lime/MW) x (Plant Size, MW).

T_2 = Annual cost of Calcilox
= ($58/ton Calcilox) x (70.96 tons Calcilox/MW) x (Plant Size, MW).

W_1 = Labor requirements for chemical analyses
= 1000 hr/yr for Plant Size of 1000 MW or less
= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

†† Assumptions:

1. Plant lifetime is 30 yr.
2. Three plant sizes are considered--200, 500, and 1500 MW. The 1500-MW plant is assumed to be three 500-MW units.
3. Total operating life is 127,500 hours, with average annual capacity of 4250 hr.
4. Power unit input heat requirement is 9000 Btu/kWh.
5. Coal heating value is 10,500 Btu/lb.
6. Coal analysis (wt%): 3.5% sulfur (S), dry; 16.0% ash.
7. Limestone scrubbing process with 1.5 stoichiometry based on SO_2 removed.

Table 11-17 (continued)

8. SO_2 removed to meet New Source Performance Standards (NSPS).

9. Coal ash is 80% fly ash.

10. Ninety-five percent of the S in the coal is emitted as SO_2.

11. Sludge is assumed to be primarily calcium sulfite hemihydrate, with 15% of the total SO_2 removed being oxidized to gypsum.

12. Fly ash and SO_2 are removed simultaneously in the scrubber system.

13. Effluent from the FGD system is 15% solids.

14. Thickened sludge (35% solids) is treated with Dravo additives: Calcilox (7% of dry sludge) and Thiosorbic lime (1% of dry solids).

15. A gravity thickener is used for dewatering the sludge.

16. Treated sludge is pumped to a clay-lined pond located 1 mile from the scrubber facilities.

17. The ponded sludge settles in the pond to 50% solids, and excess water is recycled to the scrubber system.

18. The treated, settled sludge fixes as a soil-like material in the pond.

Table 11-18

COST ESTIMATING EQUATIONS: FIXATION - IUCS PROCESS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Included in A
C	$0.25 \times A_3 + 0.096 \times (A_1 + A_2)^{0.76}$	
D	0	Included in A
E	0.20 (A + C)	
F	0	Included in E
CAF	1.0193	Construction period equals 2 years
G	0	Not applicable
H	0.10 (A + C + E)	
I	1/12 (N + T + W)	
J	0	Included in H
K	\$5500/acre x K_1	
LAFCR	0.18	Life span equals 30 years
L	\$13.85/hr x L_1	
M	0.04 x A	
N	0.06 x TPI*	
P	0.3 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	\$0.035/kWh x S_1	
T	(\$38/ton lime) x (40.88 tons lime/MW) x (Plant Size, MW)	
U	0	No additional costs incurred
V	0	Not applicable

Table 11-18 (continued)

Variable	Cost Equation	Remarks
W	\$17/hr x W_1	
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products at some sites
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = On-site construction cost for IUCS process

= $2.4 \times 10^5 \times (\text{Plant Size, MW})^{0.51}$, for Plant Size of 200 to 1500 MW.

A_2 = Cost of services, utilities, and miscellaneous items

= $0.015 \times A_1$

A_3 = Cost of engineering, design, and supervision

= $97{,}720 \times (\text{Plant Size, MW})^{0.233}$, for Plant Size of 200 to 1500 MW.

A_4 = Construction expenses

= $0.25 \times (A_1 + A_2)^{0.83}$

K_1 = Acre requirements

= $\leq$4 acres for Plant Size of 200 or less MW

= 4 to 5 acres for Plant Size of 200 to 500 MW

= 5 to 8 acres for Plant Size of 500 to 1500 MW.

L_1 = Labor requirements (worker-hours)

= $4980 \times (\text{Plant Size, MW})^{0.314}$ for Plant Size of 200 to 500 MW

= $9920 \times (\text{Plant Size, MW})^{0.203}$ for Plant Size of 500 to 1500 MW.

S_1 = Electricity consumed (kWh/yr)

= $1.15 \times 10^5 \times (\text{Plant Size, MW})^{0.59}$, for Plant Size of 200 to 500 MW

= $2.84 \times 10^5 \times (\text{Plant Size, MW})^{0.82}$, for Plant Size of 500 to 1500 MW.

Table 11-18 (continued)

W_1 = Labor requirements for chemical analyses
= 1000 hr/yr for Plant Size of 1000 MW or less
= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

†† Assumptions:

1. Plant lifetime is 30 yr.
2. Three plant sizes are considered--200, 500, and 1500 MW. The 1500-MW plant is assumed to be three 500-MW units.
3. Total operating life is 127,500 hours, with average annual capacity of 4250 hr.
4. Power unit input heat requirement is 9000 Btu/kWh.
5. Coal heating value is 10,500 Btu/lb.
6. Coal analysis (wt%): 3.5% sulfur (S), dry; 16.0% ash.
7. Limestone scrubbing process with 1.5 stoichiometry based on SO_2 removed.
8. SO_2 removed to meet New Source Performance Standards (NSPS).
9. Coal ash is 80% fly ash.
10. Ninety-five percent of the S in the coal is emitted as SO_2.
11. Sludge is assumed to be primarily calcium sulfite hemihydrate, with 15% of the total SO_2 removed being oxidized to gypsum.
12. Fly ash and SO_2 are removed simultaneously in the scrubber system.
13. Effluent from the FGD system is 15% solids.
14. Effluent from the scrubber system is dewatered (60% solids) using a thickener and rotary drum filter.
15. The dewatered sludge is fixed by mixing with lime (4% of dry sludge).

Table 11-19

COST ESTIMATING EQUATIONS: FLY ASH HANDLING - PNEUMATIC CONVEYORS AND CONCRETE SILOS (Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Included in A
C	0	Included in A
D	$0.06 (A_1 + A_2 + A_3 + A_4)$	
E	0.20 (A + D)	
F	0.10 (A + D + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	$5500/acre x K_1	
LAFCR	0.19	Life span equals 20 years
L	$13.85/hr x L_1	
M	0	Included in L
N	0.06 x TPI*	
P	0.30 x L	
Q	0	Not applicable
R	0	Not applicable
S	$0.035/kWh x S_1	
T	0	Not applicable
U	0	Not applicable

Table 11-19 (continued)

Variable	Cost Equation	Remarks
V	0	No additional cost incurred
W	0	Not applicable
(X)	0	Not applicable
CF	0.69	Implemented when system is new
LF	1.629	

† Subvariable Calculations:

A_1 = Cost of silo concrete, design, and installation labor

= 2215 x (Silo Capacity, tons)$^{0.504}$, for Silo Capacity of 200 to 1000 tons

= 295 x (Silo Capacity, tons)$^{0.796}$, for Silo Capacity of 1000 to 2000 tons.

A_2 = Cost of silo foundation excavation and construction

= \$15/ft^3 x 2 ft thick x ([Silo Diameter, ft] + 8)^2

A_3 = Cost of pneumatic conveyor equipment, including piping

If Pipe Length is 2000 ft or less:

= \$12,000 for Fly Ash Transportation Rate of 10 to 30 tons per hour
= \$17,000 for Fly Ash Transportation Rate of 40 to 100 tons per hour

If Pipe Length is over 2000 ft:

= \$22,000 for Fly Ash Transportation Rate of 10 to 30 tons per hour
= \$27,000 for Fly Ash Transportation Rate of 40 to 100 tons per hour.

A_4 = Cost of installing pneumatic conveyor

= \$4/ft x (Conveyor Length, ft), for Conveyor Length of 200 ft or more.

K_1 = Acre requirements

= 1/2 acre or less.

L_1 = Labor requirements for pneumatic conveyor operation and maintenance
= 150 Worker-Hours/yr for Conveyor Length of 100 ft or less
= 200 Worker-Hours/yr for Conveyor Length of 110 to 500 ft
= 250 Worker-Hours/yr for Conveyor Length of 510 to 1000 ft
= 300 Worker-Hours/yr for Conveyor Length of 1100 to 2000 ft.

Table 11-19 (continued)

S_1 = Total electricity (kWh/yr) required to run pneumatic conveyor

= 8760 hr/yr x 0.7457 kW/HP x ([HP Requirements of Pump] + [HP Requirements of Compressor] + [Total HP Requirements of Motors]).

†† Assumptions:

1. Concrete silos are precast, with discharge through a 45-degree cone.

2. Silo storage capacity is based on a density of 100 lb/ft^3 for the stored material.

Table 11-20

COST ESTIMATING EQUATIONS: FORCED OXIDATION
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11} + A_{12} + A_{13}$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Included in E
CAF	1.0193	Construction period equals 2 years
G	0	Not applicable
H	$0.02 \times TPI^* + 1/12\ (FOM + VOM)$	
I	1/12 (N + W)	
J	0	Not applicable
K	$\$5500/acre \times K_1$	
LAFCR	0.18	Life span equals 30 years
L	$L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7$	
M	0	Included in L
N	$N_1 + N_2 + N_3 + N_4 + N_5 + N_6 + N_7$	
P	0.30 x L	
Q	0	Not applicable
R	0	Not applicable
S	$S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7$	
T	0	Not applicable
U	0	Not applicable

Table 11-20 (continued)

Variable	Cost Equation	Remarks
V	0	No additional costs incurred
W	\$17/hr x W_1	
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products for some sites
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of forced oxidation basin (concrete, steel, and installation labor)

= 72 x (Basin Volume, $ft^3)^{0.74}$, for Basin Volume of 1.5×10^4 to 3×10^5 ft^3

= 7.5 x (Basin Volume, $ft^3)^{0.92}$, for Basin Volume of 3×10^5 to 4×10^6 ft^3.

A_2 = Cost of forced oxidation equipment

= 422 x (Basin Volume, $ft^3)^{0.53}$, for Basin Volume of 10^5 to 5×10^7 ft^3

= 57.4 x (Basin Volume, $ft^3)^{0.68}$, for Basin Volume of 5×10^5 to 10^7 ft^3.

A_3 = Cost of gravity thickening equipment (concrete, steel, and installation labor)

= 7940 x (Thickener Area, $ft^2)^{0.38}$, for Thickener Area of 300 to 4000 ft^2.

A_4 = Cost of thickener overflow tank (concrete, steel, and installation labor)

= 7760 x (Tank Volume, $ft^3)^{0.82}$, for Tank Volume of 1.5×10^4 to 4×10^6 ft^3.

A_5 = Cost of vacuum filtration equipment, installation labor, housing, piping, and valves

= 11,220 x (Filter Area, $ft^2)^{0.62}$, for Filter Area of 100 to 800 ft^2.

A_6 = Cost of filtrate sump/tank concrete, steel, and installation labor

= 7760 x (Tank Volume, $ft^3)^{0.82}$, for Tank Volume of 1.5×10^4 to 4×10^6 ft^3.

Table 11-20 (continued)

A_7 = Cost of forced oxidation tank pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_8 = Cost of thickener overflow tank pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_9 = Cost of filtrate sump/tank pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 4.5 x (Pumping Capacity, gpd)$^{0.67}$, for Pumping Capacity of 5 x 10^6 to 5 x 10^8 gpd.

A_{10} = Cost of thickener sludge pump, concrete, steel, installation labor, housing, metal pipes, and valves

= 7590 x (Pumping Capacity, gpm)$^{0.51}$, for Pumping Capacity of 50 to 5000 gpm.

A_{11} = Cost of electricity during construction and installation period

$= 0.15\ (A_2 + A_3) + 0.20\ (A_5 + A_7 + A_8 + A_9 + A_{10}).$

A_{12} = Cost of miscellaneous items for construction and installation

$= 0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11}).$

A_{13} = Cost of piping

$= 0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11} + A_{12}).$

K_1 = Acre requirements

= $\leq$4 acres for Plant Size of 200 MW or less

= 4 to 5 acres for Plant Size of 200 to 500 MW

= 5 to 8 acres for Plant Size of 500 to 1500 MW.

L_1 = Labor cost for O&M of forced oxidation

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirements, see Figure 11-11.

L_2 = Labor cost for O&M of gravity thickeners

= \$13.85/hr x (Labor Requirement, worker-hours); for Labor Requirements, see Figure 11-9.

Table 11-20 (continued)

L_3 = Labor cost for O&M of vacuum filters

= $13.85/hr x (Labor Requirement, worker-hours), where

Labor Requirements = 100 x (Filter Area, $ft^2)^{0.66}$, for Filter Area of 50 to 6000 ft^2.

L_4 = Labor cost for O&M of forced oxidation tank pump

= $13.85/hr x (Labor Requirement, worker-hours); for Labor Requirements, see Figure 11-7.

L_5 = Labor cost for O&M of thickener overflow tank pump

= $13.85/hr x (Labor Requirement, worker-hours); for Labor Requirements, see Figure 11-7.

L_6 = Labor cost for O&M of filtrate sump/tank pump

= $13.85/hr x (Labor Requirement, worker-hours); for Labor Requirements, see Figure 11-7.

L_7 = Labor cost for O&M of thickener sludge pump

= $13.85/hr x (Labor Requirement, worker-hours), where

Labor Requirement = 220 x (Pumping Capacity, $gpm)^{0.42}$, for Pumping Capacity of 20 to 5000 gpm.

N_1 = Cost of maintenance materials for forced oxidation

= 999 x (Power Requirement, $HP)^{0.42}$, for Power Requirement of 30 to 5000 HP.

N_2 = Cost of maintenance materials for gravity thickening

= 3.11 x (Thickener Area, $ft^2)^{0.74}$, for Thickener Area of 400 to 35,000 ft^2.

N_3 = Cost of maintenance materials for vacuum filtration

= 797 x (Filter Area, $ft^2)^{0.7}$, for Filter Area of 10 to 4000 ft^2.

N_4 = Cost of maintenance materials for forced oxidation tank pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_5 = Cost of maintenance materials for thickener overflow tank pump

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

N_6 = Cost of maintenance materials for filtrate sump/tank pumping

= 1.35 x (Material Cost); for Material Cost, see Figure 11-8.

Table 11-20 (continued)

N_7 = Cost of maintenance materials for thickener sludge pumping

= 162 x (Pumping Capacity, gpm)$^{0.66}$, for Pumping Capacity of 20 to 4000 gpm.

S_1 = Cost of electricity for forced oxidation

= \$0.035/kWh x 5.0 x (Power Requirement, HP)$^{1.01}$, for Power Requirements of 30 to 5000 HP.

S_2 = Cost of electricity for gravity thickening

= \$0.035/kWh x 7.2 x (Thickener Area, ft^2)$^{0.94}$, for Thickener Area of 200 to 40,000 ft^2.

S_3 = Cost of electricity for vacuum filtration

= \$0.035/kWh x 5430 x (Filter Area, ft^2)$^{0.64}$, for Filter Area of 20 to 150 ft^2.

= \$0.035/kWh x 1350 x (Filter Area, ft^2)$^{0.92}$, for Filter Area of 150 to 4000 ft^2.

S_4 = Cost of electricity for forced oxidation tank pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd)$^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_5 = Cost of electricity for thickener overflow tank pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd)$^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_6 = Cost of electricity for filtrate sump/tank pump

= \$0.035/kWh x 83,200 x (Flow Rate, mgd)$^{0.9}$, for Flow Rate of 7 to 700 mgd.

S_7 = Cost of electricity for thickener sludge pump

= \$0.035/kWh x 23.9 x (Flow Rate, gpm)$^{0.98}$, for Flow Rate of 20 to 2500 gpm.

W_1 = Labor requirements for chemical analyses

= 1000 hr/yr for Plant Size of 1000 MW or less

= 1500 hr/yr for Plant Size of 1100 to 1500 MW.

†† Assumptions:

1. Effluent from the FGD system contains 10% solids.
2. Stoichiometry for forced oxidation is 1.5, i.e., 0.2 lb O_2 per lb $CaSO_3$.
3. Three pounds of O_2 transferred per HP-hr by air compressor.

Table 11-20 (continued)

4. Sulfite/sulfate ratio in the feed is 50/50.
5. One hour of detention time in forced oxidation tank.
6. No pH control is required in forced oxidation.
7. Loading of thickener is 1600 gpd/ft^2 of oxidized sludge.
8. Thickener underflow contains 50% solids.
9. Thickener overflow tank storage time is 8 hr.
10. Loading of vacuum filter is 150 lb/ft^2/hr.
11. Cake solids content is 80%.
12. Vacuum filters operate 20 hr/day for 7 days/week.
13. Secondary dewatering underflow tank storage time is 8 hr.
14. On-site capital cost for pumps includes underground structure housing and piping.
15. Power used for pumping is based on 10 minutes of pumping per hour.
16. Plant lifetime is 30 yr.
17. Fly ash is removed from flue gas prior to scrubbing.

Table 11-21

COST ESTIMATING EQUATIONS: GRADING
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	A_1	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.15 (A + C)	
F	0.10 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	0	Not applicable
J	0	Not applicable
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-21 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of grading

= (Unit Cost, $\$/yd^2$) x (Area to be Graded, yd^2), where

Unit Cost = $\$0.52/yd^2$ when area is <1 acre
= $\$0.44/yd^2$ when area is 1 to 5 acres
= $\$0.36/yd^2$ when area is >5 acres.

†† Assumptions:

1. Overall grading is done to achieve approximate grade, with cut and fill limited to 6 in.

2. Soil cover has already been added.

Table 11-22

COST ESTIMATING EQUATIONS: GROUNDWATER MONITORING
(With Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2$	
B	0	Included in A
C	0.15 x A	
D	0	Included in A
E	0.15 (A + C)	
F	0.10 (A + C + E)	
CAF	1.0	Construction period equals 1 month.
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x W	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.18	Lifespan equals 30 years
L	0	Not applicable
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	$W_1 + W_2$	

TABLE 11-22 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of well materials and installation

= (Number of Wells) x ($32/ft of well depth) x (Depth of Well, ft), where Number of Wells = [(1 well/50 ac) x (Acres in Facility to be Monitored)] + 5 wells.

A_2 = Cost of pump and portable generator for sampling

= $1700.

W_1 = Cost of sample collection

= [$17/hr x (3 hr/well) x (Number of Wells) + $50] x (Samples/yr), where Number of Wells is defined under A_1
and Samples/yr = 4 for first year
= 2 for hazardous sites in subsequent years;
= 1 for nonhazardous sites in subsequent years.

W_2 = Cost of sample analyses

= ($/sample) x (1 sample/well) x (Number of Wells), where Number of Wells is defined under A_1,
and $/sample = $115 for nonhazardous materials
= $180 for hazardous materials.

†† Assumptions

1. Wells are equipped with protective casings and locking caps.
2. Wells are installed in hollow stem auger borings.
3. Wells do not exceed 100 ft depth.

Table 11-23

COST ESTIMATING EQUATIONS: GROUNDWATER PUMPING
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.3 (A + C)	
F	0.2 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.34	Life span equals 5 years (interim measure)
L	$13.85/hr x 96 hr	Monitoring cost per year
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	($0.035/kWh) x S_1	
T	0	Not applicable
U	0	Not applicable

Table 11-23 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.182	

† Subvariable Calculations:

A_1 = Cost of drilling and casing of injection wells

= ($7/linear foot) x (Number of Linear Feet).

A_2 = Cost of trench excavation for header line

= ($\$2.30/yd^3$) x (Trench Length, ft) x (Trench Width, ft) x (Trench Depth, ft) ÷ 27 ft^3/yd^3.

A_3 = Cost of header line

= (Unit Cost, $/linear foot) x (Length of Header Line); for Unit Cost, see Table 11-49.

A_4 = Cost of submersible pumps

= ($430/pump) x (Number of Pumps), where Number of Pumps is site-specific.

A_5 = Cost of pipe bedding

= ($\$5.20/yd^3$) x (Pipe Bedding Depth, ft) x (Pipe Bedding Width, ft) x (Length of Trench, ft) ÷ 27 ft^3/yd^3.

A_6 = Cost of backfilling trench

= ($\$0.80/yd^3$) x (Length of Trench, ft) x ([Trench Depth, ft] - [Bedding Depth, ft]) x (Trench Width, ft) ÷ 27 ft^3/yd^3.

S_1 = Electricity consumed (kWh/yr)

= (0.75 kWh/hour of operation) x (Hours of Operation/pump/yr) x (Number of Pumps).

†† Assumptions:

1. A 1-HP pump is used.
2. Electrical service is available.

Table 11-24

COST ESTIMATING EQUATIONS: GROUT CURTAIN
(Including Subvariable Calculations†)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.3 (A + C)	
F	0.25 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 96 hr	Cost per year of monitoring
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Cost included in A_2
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-24 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of drilling and casing

= (\$7/linear foot) x (Number of Linear Feet)

A_2 = Cost of grout curtain

= (Unit Cost, \$/yd^3) x (0.25) x (Grout Curtain Length, ft) x (Grout Curtain Depth, ft) x (Grout Curtain Width, ft) ÷ 27 ft^3/yd^3, where 0.25 equals the average fraction of grouted subsurface material filled with grout; for Unit Cost, see Table 11-47.

A_3 = Cost of grout injection

= (\$100/yd^3) x (0.25) x (Grout Curtain Length, ft) x (Grout Curtain Depth, ft) x (Grout Curtain Width, ft) ÷ 27 ft^3/yd^3, where 0.25 equals the average fraction of grouted subsurface material filled with grout.

Table 11-25

COST ESTIMATING EQUATIONS: INJECTION WELLS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.3 (A + C)	
F	0.2 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.34	Life span equals 5 years
L	$13.85/hr x 96 hr	Monitoring cost per year
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	($0.45/1000 gal) x (12,000 gal/hr) x (hours of operation/yr)	
S	($0.035/kWh) x S_1	
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-25 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.182	

† Subvariable Calculations:

A_1 = Cost of drilling and casing injection wells

= ($7/linear foot) x (Number of Linear Feet).

A_2 = Cost of trench excavation for header line

= ($\$2.30/yd^3$) x (Trench Length, ft) x (Trench Width, ft) x (Trench Depth, ft) ÷ 27 ft^3/yd^3.

A_3 = Cost of header line

= (Unit Cost, $/linear foot) x (Length of Header Line); for Unit Cost, see Table 11-49.

A_4 = Cost of pump station

= $35,000.

A_5 = Cost of pipe bedding

= ($\$5.20/yd^3$) x (Pipe Bedding Depth, ft) x (Pipe Bedding Width, ft) x (Length of Trench, ft) ÷ 27 ft^3/yd^3.

A_6 = Cost of backfilling trench

= ($\$0.80/yd^3$) x (Length of Trench, ft) x ([Trench Depth, ft] - [Bedding Depth, ft]) x (Trench Width, ft) ÷ 27 ft^3/yd^3.

S_1 = Electricity consumed (kWh/yr)

= (15 kWh/hr of pump operation) x (Hours of Operation/yr).

†† Assumptions:

1. Water supply is on site.
2. Electrical service is available.

Table 11-25 (continued)

3. Pump station has a 40-hp pump and a 200-gpm capacity.

4. Hours of pump station operation per year depend on the characteristics of the site.

Table 11-26

COST ESTIMATING EQUATIONS: LEVEES
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.2 (A + C)	
F	0.15 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 40 hr	Assumes levee needs work once per year, due to storm damage
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-26 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of excavation and hauling of on-site materials

= (Unit Cost, $\$/yd^3$) x (Volume of On-Site Material, yd^3); for Unit Cost, see Figure 11-2.

A_2 = Cost of off-site excavation

= (Unit Cost, $\$/yd^3$) x (Volume of Off-Site Material, yd^3), where Unit Cost = $\$1.24/yd^3$ (earth); $\$1.75/yd^3$ (clay).

A_3 = Cost of hauling off-site material

= (Unit Cost, $\$/yd^3$) x (Volume of Off-Site Material, yd^3); for Unit Cost, see Figure 11-5.

A_4 = Cost of compaction

= ($\$1.68/yd^3$) x (Cross Section of Levee, ft^2) x (Length of Levee, ft) ÷ 27 ft^3/yd^3.

A_5 = Cost of spreading

= ($\$0.76/yd^3$) x (Volume of Material, yd^3).

†† Assumptions:

1. Ninety-five percent compaction achieved with sheepsfoot compactor.
2. Grading and vegetation costs are presented elsewhere.

Table 11-27

COST ESTIMATING EQUATIONS: LINER AND/OR LEACHATE COLLECTION SYSTEMS
(With Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0.15 (A + E)	
CAF	1.00166	Construction period equals 3 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.18	Lifespan equals 30 years
L	0	Not applicable
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable

TABLE 11-27 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of granular blanket material

= ($/yd^3) x (Acres of System) x (4840 yd^2/ac) x (1/3 yd thick),
where $/yd^3 = $5.25 for washed masonry sand
= $2.75 for bank sand.

A_2 = Cost of hauling granular blanket material

= (Unit Cost, $/yd^3) x (Volume of material, yd^3); for Unit Cost, see Figure 11-5.

A_3 = Cost of piping material and installation

= (Unit Cost, $/ft piping) x (1200 ft piping/ac) x (Acres of System), if piping is desired; for Unit Cost, see Table 11-48.

A_4 = Cost of granular blanket placement

= ($3/yd^3) x (Acres of System) x (4840 yd^2/ac) x (1/3 yd thick).

A_5 = Cost of upper and/or lower liners

= see Table 11-30 for cost of clay liner

= see Table 11-31 for costs of synthetic liner.

†† Assumptions:

1. System is used in conjunction with one or more liners. For liner cost estimates, see liner sections.

2. Based on a fishbone design with 50 ft centers, 1200 ft of piping is needed per acre.

3. See sketches of liner systems, Figure 11-12, for typical installations.

Table 11-28

COST ESTIMATING EQUATIONS: PIPELINES
(With Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Included in A
C	0.15 x A	
D	0	Included in A
E	0.20 (A + C)	
F	0.15 (A + C + E)	
CAF	1.00249	Construction period equals 4 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.23	Lifespan equals 10 years
L	0	Not applicable
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 x M	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable

TABLE 11-28 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of trench excavation

= ($2.17/ft) x (Length of Trench, ft), if pipeline is underground.

A_2 = Cost of piping material and installation

= (Unit Cost, $/ft) x (Length of Piping, ft), for Unit Cost, see Table 11-50.

A_3 = Cost of sand bedding material and installation

= ($1.06/linear ft of trench) x (Length of Trench, ft), if pipeline is underground.

A_4 = Cost of backfill and compaction (using 8 in. lifts)

= ($1.81/linear ft of trench) x (Length of Trench, ft), if pipeline is underground.

†† Assumptions:

1. Trench has a 4 ft wide bottom and is 5 ft deep; banks are sloped 1:2.
2. Excavation is done with a tractor backhoe.
3. Every 5 linear feet of trench require 1 yd^3 of sand bedding.
4. Possible charges for installing pipeline on private property are not considered.

Table 11-29

COST ESTIMATING EQUATIONS: POND EXCAVATION
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Not applicable
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0	Not applicable
I	0	Not applicable
J	0	Not applicable
K	0	No new land required
LAFCR	0.23	Booklife equals 10 years
L	0	Not applicable
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable

Table 11-29 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of pumping water off surface, assuming a capacity of 1 million gallons per acre of lagoon

= ($0.10/yd^3 Sludge) x (Sludge Volume, yd^3), for Sludge Volume of 100,000 yd^3 or more.

A_2 = Cost of removing and loading sludge, using a dragline for removal

= ($1.10/yd^3 Sludge) x (Sludge Volume, yd^3), for Sludge Volume of 100,000 yd^3 or more.

A_3 = Cost of hauling sludge by dump truck, assuming a distance of 0.5 mile, a truck capacity of 10 yd^3, and a rate of $45/hr

= ($1.30/yd^3 Sludge) x (Sludge Volume, yd^3), for Sludge Volume of at least 100,000 yd^3.

A_4 = Cost of equipment preparation and usage and administrative overhead

= ($0.15/yd^3 Sludge) x (Sludge Volume, yd^3), for Sludge Volume of at least 100,000 yd^3.

A_5 = Cost of supervision

$= 0.05\ (A_1 + A_2 + A_3 + A_4)$.

†† Assumptions:

1. Dragline is used.
2. Sludge is hauled by dump truck.
3. Sludge volume $\geq$100,000 yd^3.
4. This disposal method occurs once only to dispose of leftover liquid sludge.

Table 11-30

COST ESTIMATING EQUATIONS: POND LINING -
CLAY LINER (BENTONITE)
(Including Subvariable Calculations[†] and System Assumptions[††])

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11}$	
B	0	Not applicable
C	0.15 x A	Liner design and specifications
D	0	Included in A
E	0.15 (A + C)	
F	0.10 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	0	Not applicable
J	0	Not applicable
K	0	No new land required
LAFCR	0.18	Life span equals 30 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable

Table 11-30 (continued)

Variable	Cost Equation	Remarks
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.68	Implemented when plant is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of stripping and grubbing

= (\$240/acre) x (Number of Acres).

A_2 = Cost of filling and compacting

= (Unit Cost, \$/yd^3) x (Amount of Site Material, yd^3), where

Unit Cost = \$0.90 to \$1.37 for Class 1 site material - sandy gravel
= \$0.97 to \$1.48 for Class 2 site material - sandy topsoil
= \$1.05 to \$1.62 for Class 3 site material - sandy loam
= \$1.11 to \$1.69 for Class 4 site material - sandy clay.

A_3 = Cost of rolling area with steel roller

= (\$0.48/yd^2) x (Surface Area of Pond, yd^2).

A_4 = Cost to dump and spread cover

= (\$0.68/yd^2) x (Area Using Cover Material, yd^2).

A_5 = Cost for trenching

= (Unit Cost, \$/linear foot) x (Linear Feet of Trench), where Unit Cost = \$0.30 to \$0.60/linear foot using ditcher and backhoe.

A_6 = Cost of soil sterilization

= (Unit Cost, \$/ft^2) x (Area to be Lined, ft^2), where Unit Cost = \$0.02 to \$0.03/ft^2.

A_7 = Cost of clay liner material

= (\$0.20/ft^2) x (Area to be Lined with Clay, ft^2), assuming a density of 4 lb/ft^2.

Table 11-30 (continued)

A_8 = Cost of transportation

= (Unit Cost, \$/ton) x (Tons of Clay Needed), where

Unit Cost = \$40 to \$50 for shipment to West Coast from Wyoming
= \$95 to \$100 for shipment to East Coast from Wyoming
= \$75 to \$80 for shipment to the South from Wyoming.

A_9 = Cost of installation

= (\$0.06/ft^2) x (Area to be Lined, ft^2).

A_{10} = Cost of 6-in. earth cover

= (\$0.06/ft^2) x (Area to be Lined, ft^2), assuming on-site availability.

A_{11} = Cost of subgrade preparation for clay liners

= (\$0.06/ft^2) x (Area to be Lined, ft^2).

†† Assumptions:

1. Pond surface area is greater than 4 acres.
2. Disposal facility is average in type and location. Numbers will vary widely depending on the site and the nature of the proposed pond.
3. Costs do not include (a) hydrogeological investigation, (b) permit application, (c) site clearing and excavation, (d) groundwater monitoring, (e) closure and post-closure activities (final cover, revegetation, monitoring), and (f) transportation. These costs are so highly variable and site-specific that general estimates would be misleading.

Table 11-31

COST ESTIMATING EQUATIONS: POND LINING - MEMBRANE LINER[†]
(Including Subvariable Calculations[†] and System Assumptions[††])

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10}$	
B	0	Not applicable
C	0.15 x A	Liner design and specifications
D	0	Included in A
E	0.15 (A + C)	
F	0.10 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	$0.02 \times TPI^{*} + 1/12\ (FOM + VOM)$	
I	0	Not applicable
J	0	Not applicable
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-31 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of stripping and grubbing

= (\$240/acre) x (Number of Acres).

A_2 = Cost of filling and compacting

= (Unit cost, $\$/yd^3$) x (Amount of Site Material, yd^3), where

Unit Cost = \$0.90 to \$1.37 for Class 1 site material - sandy gravel
= \$0.97 to \$1.48 for Class 2 site material - sandy topsoil
= \$1.05 to \$1.62 for Class 3 site material - sandy loam
= \$1.11 to \$1.69 for Class 4 site material - sandy clay.

A_3 = Cost of rolling area with steel roller

= ($\$0.48/yd^2$) x (Surface Area of Pond, yd^2).

A_4 = Cost to dump and spread cover

= ($\$0.68/yd^2$) x (Area Using Cover Material, yd^2).

A_5 = Cost for trenching

= (Unit Cost, \$/linear foot) x (Linear Feet of Trench), where Unit Cost = \$0.30 to \$0.60/linear foot using ditcher and backhoe.

A_6 = Cost of soil sterilization

= (Unit Cost, $\$/ft^2$) x (Area to be Lined, ft^2), where Unit Cost = \$0.02 to $\$0.03/ft^2$.

Table 11-31 (continued)

A_7 = Cost of installation for underliner and liner

= [(Underliner Cost, $/yd^2 ÷ 9 ft^2/yd^2) + (Liner Cost, $/ft^2)] x (Area to be Lined, ft^2), where

Underliner Cost = $0.09 to $0.18 for geotextile underliner

Liner Cost = $0.03 to $0.08 for PVC liner
= $0.05 to $0.15 for hypalon/CPE liner
= $0.09 to $0.18 for high-density polyethylene.

A_8 = Cost of subgrade preparation for membrane liner

= ($0.12/ft^2) x (Area to be Lined, ft^2).

A_9 = Cost of additional, site-specific requirements

= ($0.05/ft^2) x (Area of Pond, ft^2).

A_{10} = Cost of underliner and liner material

= [(Underliner Cost, $/yd^2 ÷ 9 ft^2/yd^2) + (Liner Cost, $/ft^2)]

x (Area to be Lined, ft^2), where

Underliner Cost = $1.33 to $1.60 for geotextile, 400 gm/m
= $1.01 to $1.20 for geotextile, 300 gm/m
= $0.69 to $0.86 for geotextile, 200 gm/m

Liner Cost = $0.16 to $0.19 for PVC, 20 mil
= $0.20 to $0.25 for PVC, 30 mil
= $0.26 to $0.33 for PVC, 30 mil, oil-resistant

= $0.46 to $0.59 for hypalon, 36 mil (6 x 6)
= $0.48 to $0.61 for hypalon, 36 mil (10 x 10)

= $0.44 to $0.57 for chlorinated polyethylene, 36 mil (6 x 6)
= $0.46 to $0.59 for chlorinated polyethylene, 36 mil (10 x 10)

= $0.25 to $0.30 for high-density polyethylene, 20 mil
= $0.33 to $0.38 for high-density polyethylene, 30 mil
= $0.40 to $0.45 for high-density polyethylene, 40 mil
= $0.55 to $0.60 for high-density polyethylene, 60 mil.

†† Assumptions:

1. Pond surface area is greater than 4 acres.

2. Disposal facility is average in type and location. Numbers will vary widely depending on the site and the nature of the proposed pond.

Table 11-31 (continued)

3. Costs do not include (a) hydrogeological investigation, (b) permit application, (c) site clearing and excavation, (d) groundwater monitoring, (e) closure and post-closure activities (final cover, revegetation, monitoring), and (f) transportation. These items are so highly variable and site-specific that general estimates would be misleading.

Table 11-32

COST ESTIMATING EQUATIONS: PUMP STATION
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7$	
B	0	Included in A
C	$0.15\ (A_4 + A_5 + A_6 + A_7)$	Other subvariable costs include overhead
D	0	Included in A
E	$0.30\ (A + C)$	
F	$0.25\ (A + C + E)$	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	$0.02 \times TPI^* + 1/12\ (FOM + VOM)$	
I	$1/12 \times N$	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.18	Life span equals 30 years
L	0	Not applicable
M	$0.04 \times TPI^*$	
N	$0.06 \times TPI^*$	
P	$0.03 \times M$	
Q	0	Not applicable
R	0	Not applicable
S	S_1	
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-32 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.68	Implemented when plant is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of clearing and grubbing

= (\$85/100 ft) x (Area to be cleared, ft^2).

A_2 = Cost of pumping station (excluding wetwell)

= \$35,000 for 200 gpm station of prefabricated concrete.

A_3 = Cost of wetwell

= \$6500.

A_4 = Cost of transporting pumping station and wetwell to site

= $0.10\ (A_2 + A_3)$.

A_5 = Cost of excavation and backfill (using backhoe)

= (\$1.80/yd^3) x (Volume Excavated, yd^3), if station is installed below ground level.

A_6 = Miscellaneous costs (e.g., piping, concrete slabs)

= $0.50\ (A_2 + A_3 + A_4 + A_5)$.

A_7 Cost of connecting electricity to system

= \$20,000.

S_1 = Electrical requirements for operation

= see Figure 11-13.

†† Assumptions:

1. Pump station is purchased as package system.
2. A power supply exists sufficiently close to the site so that only electrical connections need to be established.
3. Piping to sewer lines is not included. For piping costs see Table 11-50.

Table 11-33

COST ESTIMATING EQUATIONS: ROAD CONSTRUCTION
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6$	
B	0	Included in A
C	0.25 x A	
D	0	Included in A
E	0.30 x (A + C)	
F	0.25 (A + C + E)	
CAF	1.00249	Construction period equals 4 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.18	Life span equals 30 years
L	0	Not applicable
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.03 x M	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable

Table 11-33 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.68	Implemented when plant is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of clearing and grubbing
= ($154/100 ft road) x (Road Length, ft).

A_2 = Cost of rolling and preparing subbase
= ($160/100 ft road) x (Road Length, ft).

A_3 = Cost of culvert material and installation
= ($977/culvert) x (Number of Culverts).

A_4 = Cost of base material and installation
= ($587/100 ft road) x (Road Length, ft), for 12-in. base.

A_5 = Cost of wear course material and installation
= ($183/100 ft road) x (Road Length, ft), for 4-in. deep crushed stone
= ($751/100 ft road) x (Road Length, ft), for 3-in. thick bituminous paving.

A_6 = Cost of final grading and cleanup
= ($60/100 ft road) x (Road Length, ft).

†† Assumptions:

1. Road is 20 ft wide, sufficient for two lanes.
2. Shoulders are each 8 ft wide, covered with the base layer, and graded. They are not paved with the wear course material.
3. Base layer uses bank run gravel.
4. Culvert costs are for 24-in. equivalent ovals of coated and paved corrugated steel, each 54 ft long.
5. Possible charges for road construction through private property are not considered.

Table 11-34

COST ESTIMATING EQUATIONS: SAND DRYING BEDS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.15 x A	
F	0	Included in E
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 (N + T + W)	
J	0	Included in H
K	$5500 x K_1	
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x L_1	
M	0	Included in L
N	1.35 x N_1	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Negligible
T	0	Not applicable
U	0	Not applicable
V	0	No additional costs incurred

Table 11-34 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	However, waste quantities, characteristics, and local markets may allow sale of by-products at some sites
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of concrete, steel, metal piping and valves, clay piping, and media

= 1.645 x (Sand Drying Bed Area, $ft^2)^{0.96}$, for Sand Drying Bed Area of 10,000 to 100,000 ft^2.

A_2 = Cost of construction labor

= \$13.85 x 0.507 x (Sand Drying Bed Area, $ft^2)^{0.91}$, for Sand Drying Bed Area of 10,000 to 100,000 ft^2.

A_3 = Miscellaneous items

= 0.15 $(A_1 + A_2)$.

K_1 = Acre requirements

= (Sand Drying Bed Area, $ft^2 \div 43{,}560\ ft^2$/acre) + 0.5 acre.

L_1 = Cost of Labor for O&M

= (\$13.85/worker-hour) x (Labor Requirement, worker-hours); for Labor Requirements, see Figure 11-14.

N_1 = Cost of solids disposal (1976 \$)

= 3.520 x (Weight of Dry Solids Applied, tons/yr$)^{0.996}$, for Weight of Dry Solids Applied between 50 and 8000 tons/yr.

†† Assumptions:

1. Sludge drying beds are open, with underdrains and sludge inlet piping and valves.

2. O&M labor costs include loading sludge, removing weeds from the beds, maintaining sludge inlets, drains, and bed partitions, and replacing sand. Costs of hauling sludge are not included.

Table 11-35

COST ESTIMATING EQUATIONS: SEDIMENTATION BASINS
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.2 (A + C)	
F	0.15 (A + C + E)	
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 40 hr	Assume basins need work once per year due to storm damage
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-35 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of on-site excavation and hauling

= (Unit Cost, $\$/yd^3$) x (Volume of On-Site Material, yd^3); for Unit Cost, see Figure 11-2.

A_2 = Cost of spreading

= ($\$0.76/yd^3$) x (Volume of On-Site Material, yd^3).

A_3 = Cost of compaction

= (Unit Cost, $\$/yd^3$) x (Depth of Basin, ft) x (Width of Basin, ft) x (Length of Basin, ft) ÷ 27 ft^3/yd^3; for Unit Cost, see Table 11-45.

†† Assumptions:

1. Grading costs are developed separately.
2. Vegetation costs are developed separately.
3. No off-site materials are needed.
4. Outlet and inlet structures are not included because their costs vary widely depending on the design of the basin.

Table 11-36

COST ESTIMATING EQUATIONS: SITE SECURITY - FENCING
(Including Subvariable Calculations[†] and System Assumptions[††])

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3$	
B	0	Included in A
C	0	
D	0	Included in A
E	0.15 (A + C)	
F	0	Included in E
CAF	1.0	Construction period equals 1 month
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Not applicable
LAFCR	0.18	Life span equals 30 years
L	0	Not applicable
M	0.01 x TPI*	
N	0.01 x TPI*	
P	0.30 x M	
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable
W	0	Not applicable

Table 11-36 (continued)

Variable	Cost Equation	Remarks
(X)	0	Not applicable
CF	0.68	Implemented when system is new
LF	1.886	

† Subvariable Calculations:

A_1 = Cost of fencing material and installation

= [($7.37/ft) x (Length, ft)] + [($100/cornerpost) x (4 cornerposts)].

A_2 = Cost of gate material and installation

= ($34/ft of gate) x (Length of Gate, ft) x (Number of Gates).

A_3 = Cost of signs

= ($25/sign) x (Number of Signs).

†† Assumptions:

1. Fencing is 6 ft high chain link with 3 strands of barbed wire along the top.
2. Gates stand 6 ft high with galvanized steel frames.

Table 11-37

COST ESTIMATING EQUATIONS: SLUDGE LANDFILLING - AREA FILL/DIKED CONTAINMENT METHOD (Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Not applicable
CAF	1.0075	Construction period equals 10 months
G	0	Not applicable
H	0	Not applicable
I	0	Not applicable
J	0	Not applicable
K	\$5500/acre x K_1	
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-37 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0	Not applicable
LF	0	Not applicable

† Subvariable Calculations:

(y) x (z) = Average dimensions (ft^2) of dike interior = (Sludge Volume, yd^3) x 27 ft^3/yd^3 ÷ 24 ft. Determination of y and z separately is done through consideration of the dimensions of the available land. If no land constraints exist, choose y = z to minimize volume of earth required for dike.

CE = Total volume of earth (yd^3) required for a 3-ft cover layer

= 3 ft x (y + 60 ft) x (z + 60 ft) ÷ 27 ft^3/yd^3.

DC = Total area (ft^2) of land required for diked containment

= (y + 210 ft) x (z + 210 ft).

DE = Total volume of earth (yd^3) required for finished dike

= 2 x (y + 75 ft + z + 75 ft) x (92 yd^3 earth/linear foot of dike) x 1.1.

IC = Volume of earth (yd^3) required for four layers (each 2 ft thick) of interim cover

= 8 ft x (y) x (z) ÷ 27 ft^3/yd^3.

A_1 = Cost of clearing material from land providing borrow earth for dike construction and cover, and from land chosen for the diked containment

= \$480/acre x K_1.

A_2 = Cost of loading cleared material

= (\$0.75/yd^3) x (500 yd^3 material/acre) x K_1.

A_3 = Cost of hauling cleared material

= (\$2/acre) x (500 yd^3 material/acre) x K_1.

A_4 = Cost of earthwork required for dike construction

= \$1.85/yd^3 x DE.

Table 11-37 (continued)

A_5 = Cost of accumulating earth required for interim and final covers
= $0.95/yd^3 \times (IC + CE)$.

A_6 = Cost of placement for cover layers
= $1.25/yd^3 \times (IC + CE)$.

A_7 = Miscellaneous expenses
= $0.15 (A_1 + A_2 + A_3 + A_4 + A_5 + A_6)$.

A_8 = Cost of equipment preparation and usage, and administrative overhead
= $0.20/yd^3 \times$ (Sludge Volume, yd^3), for Sludge Volume of 25,000 yd^3 or more.

A_9 = Cost of engineering design and supervision
= $0.15 (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8)$.

K_1 = Acre requirements for mound area fill site and area providing cover soil
= $([(DE + CE) \times 27\ ft^3/yd^3 \div 10\ ft] + DC) \div 43{,}560\ ft^2/acre$.

†† Assumptions:

1. Dikes are 30 ft high with 2:1 slopes and a top width of 15 ft.
2. Dikes are built entirely above natural grade with borrow material.
3. Borrow material suitable for scraper pickup down to 10 ft is available nearby ($\leq$2000 ft from site).
4. Containment area will be filled with sludge to 24 ft, using 4 interim cover layers, each with a thickness of 2 ft. Top cover layer will be 3 ft thick.
5. Excavation will be done by a scraper, and covers will be laid by a dragline and dozer.
6. Sludge volume $\geq$25,000 yd^3.
7. This disposal method occurs once only to dispose of leftover liquid sludge.

Table 11-38

COST ESTIMATING EQUATIONS: SLUDGE LANDFILLING - AREA FILL/LAYER METHOD
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11}$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Not applicable
CAF	1.00416	Construction period equals 6 months
G	0	Not applicable
H	0	Not applicable
I	0	Not applicable
J	0	Not applicable
K	$5500/acre x K_1	
LAFCR	0.23	Life span equals 10 years
L	0	Not applicable
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-38 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of clearing material from land to be used
= \$480/acre x K_1.

A_2 = Cost of loading cleared material
= (\$0.75/yd^3) x (500 yd^3/acre) x K_1.

A_3 = Cost of hauling cleared material
= (\$2/yd^3) x (500 yd^3/acre) x K_1.

A_4 = Cost of constructing gravel pad(s) for mixing sludge and soil
= (\$10/ton gravel) x (130 tons gravel/pad) x Number of Pads, where
Number of Pads = 1 for 35,000-60,000 yd^3 of sludge
= 2 for 61,000-120,000 yd^3 of sludge
= 3 for 121,000-180,000 yd^3 of sludge.

A_5 = Cost of accumulating borrow and stockpile earth for cover
= (\$0.95/yd^3) x $(y + 12\ ft)^2$ x 2 ft ÷ (27 ft^3/yd^3).

A_6 = Cost of placing cover on area fill
= (\$1.25/yd^3) x $(y + 12\ ft)^2$ x 2 ft ÷ (27 ft^3/yd^3).

A_7 = Cost of accumulating borrow and stockpile earth for mixing material
= \$0.95/yd^3 x 2 x (Sludge Volume, yd^3), for Sludge Volume $\geq$35,000 yd^3.

A_8 = Cost of mixing and placing sludge/soil mixture
= \$2.10/yd^3 x 3 x (Sludge Volume, yd^3), for Sludge Volume $\geq$35,000 yd^3.

A_9 = Miscellaneous expenses
= 0.15 $(A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8)$.

Table 11-38 (continued)

A_{10} = Cost of equipment preparation and use, plus administrative overhead

= $0.51/yd^3 x (Sludge Volume, yd^3), for Sludge Volume ≥35,000 yd^3.

A_{11} = Cost of engineering design and supervision

$= 0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10})$.

K_1 = Acre requirements

$$= \frac{[(y + 12\ ft)^2 + (2 \times [\text{Sludge Volume, } yd^3] \times 27\ ft^3/yd^3 \div 10\ ft)]}{43{,}560\ ft^2/acre}$$

y = Length (ft) of side of uncapped area fill

$$= \left(\frac{(\text{Sludge Volume, } yd^3) \times 27\ ft^3/yd^3}{0.33 \times 28\ ft} - 7056\right)^{0.5} + 84$$

†† Assumptions:

1. Suitable site exists.
2. Area fill height with cap equals 30 ft.
3. Slope of sides is 3:1.
4. Sludge will be mixed 1:2 with stockpiled soil.
5. Borrow soil is available nearby (≤2000 ft from site) to a depth of 10 ft.
6. Mixture is placed in layers 10 ft wide and 3 ft thick.
7. No interim covers are applied.
8. Final cover applied is 2 ft thick.
9. Sludge volume ≥35,000 yd^3.
10. This disposal method occurs once only to dispose of leftover liquid sludge.
11. Disposal site has a post-closure lifetime of 10 yr.

Table 11-39

COST ESTIMATING EQUATIONS: SLUDGE LANDFILLING - AREA FILL/MOUND METHOD
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10} + A_{11}$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Not applicable
CAF	1.00416	Construction period equals 6 months
G	0	Not applicable
H	0	Not applicable
I	0	Not applicable
J	0	Not applicable
K	\$5500/acre x K_1	
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-39 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of clearing land for mound area fill site and for area chosen to provide cover soil

= \$480/acre x K_1.

A_2 = Cost of loading cleared material

= \$0.75/acre x K_1.

A_3 = Cost of hauling cleared material

= \$2/acre x K_1.

A_4 = Cost of constructing gravel pad(s) for mixing sludge and sand

= (\$10/ton gravel) x (130 tons gravel/pad) x Number of Pads, where Number of Pads = 1 for 35,000-90,000 yd^3 sludge
= 2 for 91,000-180,000 yd^3 sludge
= 3 for 181,000-270,000 yd^3 sludge.

A_5 = Cost of purchasing low-grade sand for mixing

= \$2/ton x 1.5 ton/yd^3 x (Sludge Volume, yd^3), for Sludge Volume of 35,000 yd^3 or more.

A_6 = Cost of accumulating and stockpiling cover soil

= \$0.95/yd^3 x (Sludge Volume, yd^3) x 2 x (2 parts cover/5 parts fill), for Sludge Volume of 35,000 yd^3 or more.

A_7 = Cost of placing interim and final covers over fill

= \$1.25/yd^3 x (Sludge Volume, yd^3) x 2 x (2 parts cover/5 parts fill), for Sludge Volume of 35,000 yd^3 or more.

A_8 = Cost of mixing and placement of sludge/sand mixture

= \$1.95/yd^3 x (Sludge Volume, yd^3) x 2, for Sludge Volume of 35,000 yd^3 or more.

Table 11-39 (continued)

A_9 = Miscellaneous expenses

$= 0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8)$.

A_{10} = Cost of equipment preparation and use, plus administrative overhead

= $0.10/yd^3 x (Sludge Volume, yd^3), for Sludge Volume of 35,000 yd^3 or more.

A_{11} = Cost of engineering design and supervision

$= 0.15\ (A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10})$.

K_1 = Acre requirements for mound area fill site, and area providing cover soil

$= (y^2 + [\text{Sludge Volume, yd}^3] \times 2 \times 2/5 \div 10\ \text{ft} \times 27\ \text{ft}^3/\text{yd}^3) \div 43{,}560\ \text{ft}^2/\text{acre}$, where

y = length of side of mound at base, ft

$$= \left(\frac{(\text{Sludge Vol, yd}^3) \times 27\ \text{ft}^3/\text{yd}^3}{28 \times 0.50 \times 5/7} - 12{,}544\right)^{0.5} + 112$$

†† Assumptions:

1. Suitable storage area (e.g., pit or depression) exists.
2. Final fill height, including cover, equals 28 ft.
3. Bottom of storage area is shaped to provide a level pad.
4. Sludge will be mixed 1:1 with imported low-grade sand, using a loader on a gravel pad.
5. Sludge/sand mixture is mounded into 20-yd^3 piles, each 5 ft high.
6. Mounds are covered with a 2-ft layer of earth before the next layer of sludge is placed.
7. Slopes of sides are 4:1.
8. Gravel mixing pad is 30 ft by 40 ft, with a thickness of 2 ft.
9. Borrow soil is available nearby ($\leq$2000 ft from site) to a depth of 10 ft.
10. Sludge volume $\geq$35,000 yd^3.
11. This disposal method occurs once only to dispose of leftover liquid sludge.
12. No O&M costs are needed during the 10-yr life span.

Table 11-40

COST ESTIMATING EQUATIONS: SLUDGE LANDFILLING – NARROW TRENCH METHOD
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Not applicable
CAF	1.00332	Construction period equals 5 months
G	0	Not applicable
H	0	Not applicable
I	0	Not applicable
J	0	Not applicable
K	$5500/acre x K_1	
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-40 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Clearing cost
= (\$480/acre cleared) x K_1.

A_2 = Cost of loading cleared material
= (\$0.75/yd^3 material loaded) x (500 yd^3 cleared material/acre cleared) x K_1.

A_3 = Cost of hauling cleared material
= (\$2/yd^3 material hauled) x (500 yd^3 cleared material/acre cleared) x K_1.

A_4 = Cost for excavation and stockpiling of earth, using a backhoe
= (\$1.70/yd^3 earth) x (1800 yd^3 earth/0.7 acres) x K_1.

A_5 = Miscellaneous costs
= 0.10 ($A_1 + A_2 + A_3 + A_4$).

A_6 = Costs for equipment preparation and use, plus administrative overhead
= (\$6000/5320 yd^3 storage) x (Sludge Volume, yd^3).

A_7 = Cost for replacing soil over filled trench, without compaction
= (\$1/yd^3 earth) x (1800 yd^3 earth/0.7 acres) x K_1.

A_8 = Cost of engineering design and supervision
= 0.15 ($A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7$).

K_1 = Acre requirements, assuming trench is 6 ft wide and 8 ft deep
= (0.7 acres/1330 yd^3 storage) x (Sludge Volume, yd^3).

Table 11-40 (continued)

†† Assumptions:

1. Trench is 6 ft wide and 8 ft deep.
2. Trench is excavated with a backhoe.
3. Excavated earth is stored next to trench.
4. Trench is filled with sludge to within 2 ft of surface. Sludge is allowed to sit for 1 week, then is covered with excavated material.
5. This disposal method occurs once only to dispose of leftover liquid sludge.

Table 11-41

COST ESTIMATING EQUATIONS: SLUDGE LANDFILLING - WIDE TRENCH METHOD
(Including Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8$	
B	0	Included in A
C	0	Included in A
D	0	Included in A
E	0.20 x A	
F	0	Not applicable
CAF	1.00332	Construction period equals 5 months
G	0	Not applicable
H	0	Not applicable
I	0	Not applicable
J	0	Not applicable
K	\$5500/acre x K_1	
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

Table 11-41 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Clearing cost

= ($480/acre cleared) x K_1.

A_2 = Cost of loading cleared material

= ($0.75/$yd^3$ material loaded) x (500 yd^3 cleared material/acre cleared) x K_1.

A_3 = Cost of hauling cleared material

= ($2/$yd^3$ material hauled) x (500 yd^3 cleared material/acre cleared) x K_1.

A_4 = Cost for excavation and stockpiling of earth, using a bulldozer and wheel loader

= ($0.80/$yd^3$ earth) x (11,900 yd^3 earth/1.4 acres cleared) x K_1.

A_5 = Miscellaneous costs

= 0.10 ($A_1 + A_2 + A_3 + A_4$).

A_6 = Costs for equipment preparation and use, plus administrative overhead

= ($8000/35,600 yd^3 storage) x (Sludge Volume, yd^3).

A_7 = Cost for covering filled trench with 5 ft of soil, without compaction

= ($1.10/$yd^3$ earth) x (11,900 yd^3/1000 ft of Trench Length) x (Trench Length, ft).

A_8 = Cost of engineering planning and supervision

= 0.15 ($A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7$).

K_1 = Acre requirements, assuming trench is 40 ft wide and 8 ft deep

= (1.4 acres/8900 yd^3 storage) x (Sludge Volume, yd^3).

Table 11-41 (continued)

†† Assumptions:

1. Trench is 40 ft wide and 8 ft deep.
2. Trench is excavated with dozer and wheel loader.
3. Excavated earth is stored alongside trench for later use as cover.
4. Trench is filled by dumping. Sludge is allowed to sit 1 week, then is covered with 5 ft of soil.
5. This disposal method occurs once only to dispose of leftover liquid sludge.

Table 11-42

COST ESTIMATING EQUATIONS: SHEET PILING
(Including Subvariable Calculations†)

Variable	Cost Equation	Remarks
A	A_1	
B	0	Not applicable
C	0	Included in A
D	0	Included in A
E	0.25 x A	
F	0.20 (A + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	0	Not applicable
J	0	Included in A
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	0	No maintenance required
M	0	Not applicable
N	0	Not applicable
P	0	Not applicable
Q	0	Not applicable
R	0	Not applicable
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-42 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when plant is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of sheet piling

= (Unit Cost, $/ft^2) x (Length of Wall, ft) x (Depth of Wall, ft); for Unit Cost, see Table 11-51.

Table 11-43

COST ESTIMATING EQUATIONS: SLURRY TRENCH
(Including Subvariable Calculations[T])

Variable	Cost Equation	Remarks
A	$A_1 + A_2 + A_3 + A_4$	
B	0	Not applicable
C	0.15 x A	
D	0	Included in A
E	0.30 (A + C)	
F	0.20 (A + C + E)	
CAF	1.00083	Construction period equals 2 months
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Included in A
K	0	No new land required
LAFCR	0.23	Life span equals 10 years
L	$13.85/hr x 96 hr	Cost per year of monitoring
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Cost included in A_4
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable
V	0	Not applicable

Table 11-43 (continued)

Variable	Cost Equation	Remarks
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of trench excavation

= ($2.30/yd^3) x (Trench Depth, ft) x (Trench Length, ft) x (3 ft wide) ÷ 27 ft^3/yd^3.

A_2 = Cost of bentonite slurry injection

= ($100/yd^3) x (Trench Depth, ft) x (Trench Length, ft) x (3 ft wide) x (0.25) ÷ 27 ft^3/yd^3, where 0.25 equals the average fraction of grouted subsurface material filled with grout.

A_3 = Cost of backfill

= ($0.80/yd^3) x (Trench Depth, ft) x (Trench Length, ft) x (3 ft wide) ÷ 27 ft^3/yd^3.

A_4 = Cost of bentonite slurry

= ($35/yd^3) x (Trench Depth, ft) x (Trench Length, ft) x (3 ft wide) x (0.25) ÷ 27 ft^3/yd^3, where 0.25 equals the average fraction of grouted subsurface material filled with grout.

Table 11-44

COST ESTIMATING EQUATIONS: VEGETATION
(with Subvariable Calculations† and System Assumptions††)

Variable	Cost Equation	Remarks
A	$A_1 + A_2$	
B	0	Not applicable
C	0.10 x A	
D	0	Not applicable
E	0.10 (A + C)	
F	0.50 x E	
CAF	1.0	Construction period equals 2 weeks
G	0	Not applicable
H	0.02 x TPI* + 1/12 (FOM + VOM)	
I	1/12 x N	
J	0	Not applicable
K	0	Revegetation requires no new land
LAFCR	0.23	Lifespan equals 10 years
L	$13.80 hr x 56 hr	8 hr refertilization + 48 hr mowing/year
M	0.04 x TPI*	
N	0.06 x TPI*	
P	0.30 (L + M)	
Q	0	Not applicable
R	0	Watering not included
S	0	Not applicable
T	0	Not applicable
U	0	Not applicable

TABLE 11-44 (continued)

Variable	Cost Equation	Remarks
V	0	Not applicable
W	0	Not applicable
(X)	0	Not applicable
CF	0.70	Implemented when system is new
LF	1.335	

† Subvariable Calculations:

A_1 = Cost of stabilizing soil with hay mulch, including materials, equipment, and labor

= ($142.70/acre) x (Land area, acres).

A_2 = Cost of seeding and sodding, including materials, equipment and labor

= (Unit Cost, $\$/yd^2$) x (Land area, acres) x (4840 yd^2/acre); for Unit Cost, see Table 11-52.

†† Assumptions:

1. Grading and site preparation are costed elsewhere.
2. Hydraulic seeding is used; cost includes lime, fertilizer, and seed.
3. Watering is not included in O&M costs.

Table 11-45

UNIT COST FOR COMPACTION
(Using Sheepsfoot Compactor)

Description	$/yd^3
Common fill - 8" lifts	1.29
Select fill - 8" lifts	1.08
Common fill - 12" lifts (95% compaction)	1.68

Table 11-46

UNIT COSTS FOR BORROW

Material	$/yd^3
Bank run gravel	2.50
Common borrow	1.00
Crushed stone 1-1/2 in.	5.25
3/4 in.	5.50
1/2 in.	6.25
3/8 in.	6.50
Sand, washed	5.25
Sand, dead or bank	2.75
Select structural fill	4.50
Screened loam	7.00
Topsoil, weed free	4.75

Table 11-47

UNIT COST OF GROUTS

Type of Grout	$\$/yd^3$ Diluted
Portland cement	26
Bentonite (1:10)*	35
Silicate - 15%	35
Lignin	44
Phenoplast	53
Silicate - 30%	59
Silicate - 40%	79
Urea formaldehyde (1:2)* resin	147
Acrylamide	188

* Grout to water ratio.

Table 11-48

UNIT COST FOR POROUS PIPE MATERIAL* ($/linear foot)

Pipe Material	Pipe Diameter								
	3"	4"	5"	6"	8"	10"	12"	15"	18"
Asbestos cement, class 4000, perforated	-	3.00	-	4.03	6.00	6.85	9.15	-	-
Bituminous fiber, perforated	1.72	1.88	2.42	3.36	-	-	-	-	-
Corrugated steel, perforated, asphalt coated	-	-	-	3.75	5.00	6.20	7.70	-	10.65
Porous wall concrete	-	2.61	-	2.76	3.96	-	5.65	7.00	10.15
Vitrified clay C-211, perforated	-	2.64	-	3.70	5.10	-	8.80	-	-

* Cost applies to pipe laid in trench, excluding excavation and backfill.

Source: Mechanical & Electrical Cost Data, 1980. Kingston, Massachusetts: Robert Snow Means Co., 1980, p. 263.

Table 11-49

UNIT COST FOR HEADER LINE* ($/linear ft)

Pipe Material	Pipe Diameter						
	4"	6"	8"	10"	12"	16"	18"
Asbestos cement, 150 psi	4.55	5.90	8.20	11.10	13.60	22	24
Ductile iron, class 350, mechanical joint	8.35	9.45	13.40	16.85	21.00	32	40
Ductile iron, class 350, tyton joint	8.15	8.95	12.95	16.30	21.00	30	37
Polyvinyl chloride, class 150, SDR 18	5.85	7.95	12.20	14.55	18.60	-	-
Gate valves and boxes, cast iron (each)	335.00	415.00	615.00	900.00	1150.00	2750	-
Butterfly valves and boxes, cast iron (each)	265.00	390.00	590.00	845.00	1025.00	2075	-

* Cost includes material, labor, equipment, and overhead.

Source: Mechanical & Electrical Cost Data, 1980. Kingston, Massachusetts: Robert Snow Means Co., 1980, p. 263.

Table 11-50

UNIT COST FOR PIPING* ($/ft)

	Pipe Diameter										
Pipe Material	2"	3"	4"	6"	8"	10"	12"	14"	16"	18"	24"
Asbestos cement, 150 psi, C.L. lots	-	-	3.79	5.03	7.02	9.64	11.88	15.35	19.11	21.14	-
Ductile iron, class 250 water piping, 18 ft lengths, mechanical joint	-	-	6.89	7.79	11.06	14.00	17.65	22.65	26.50	32.85	42.65
Copper tubing, type K, 20 ft joints	6.29	11.84	-	-	-	-	-	-	-	-	-
PVC, class 150, S.D.R.-18	-	-	4.79	6.64	10.34	12.36	15.70	-	-	-	-

* Cost includes material and installation in trench, excluding excavation and backfill.

Source: Building Construction Cost Data, 1980. Kingston, Massachusetts: Robert Snow Means Co., 1979. pp. 34-35.

Table 11-51

UNIT COST FOR SHEET PILING

Description of Piling		Unit Cost ($/ft^2)
Depth (ft)	Type	
15	22 psf (90.9 ft^2/ton)	8.14
20	27 psf (74.0 ft^2/ton)	9.55
25	38 psf (52.6 ft^2/ton)	12.35

Table 11-52

UNIT COSTS FOR SEEDING AND SODDING

Description	$/yd^2
Seeding	
Less than 480 yd^2 (0.1 acres)	0.44
More than 480 yd^2	0.53
Sodding	
Less than 480 yd^2 - level surface	2.38
- sloped surface	2.63
More than 480 yd^2 - level surface	1.83
- sloped surface	2.02

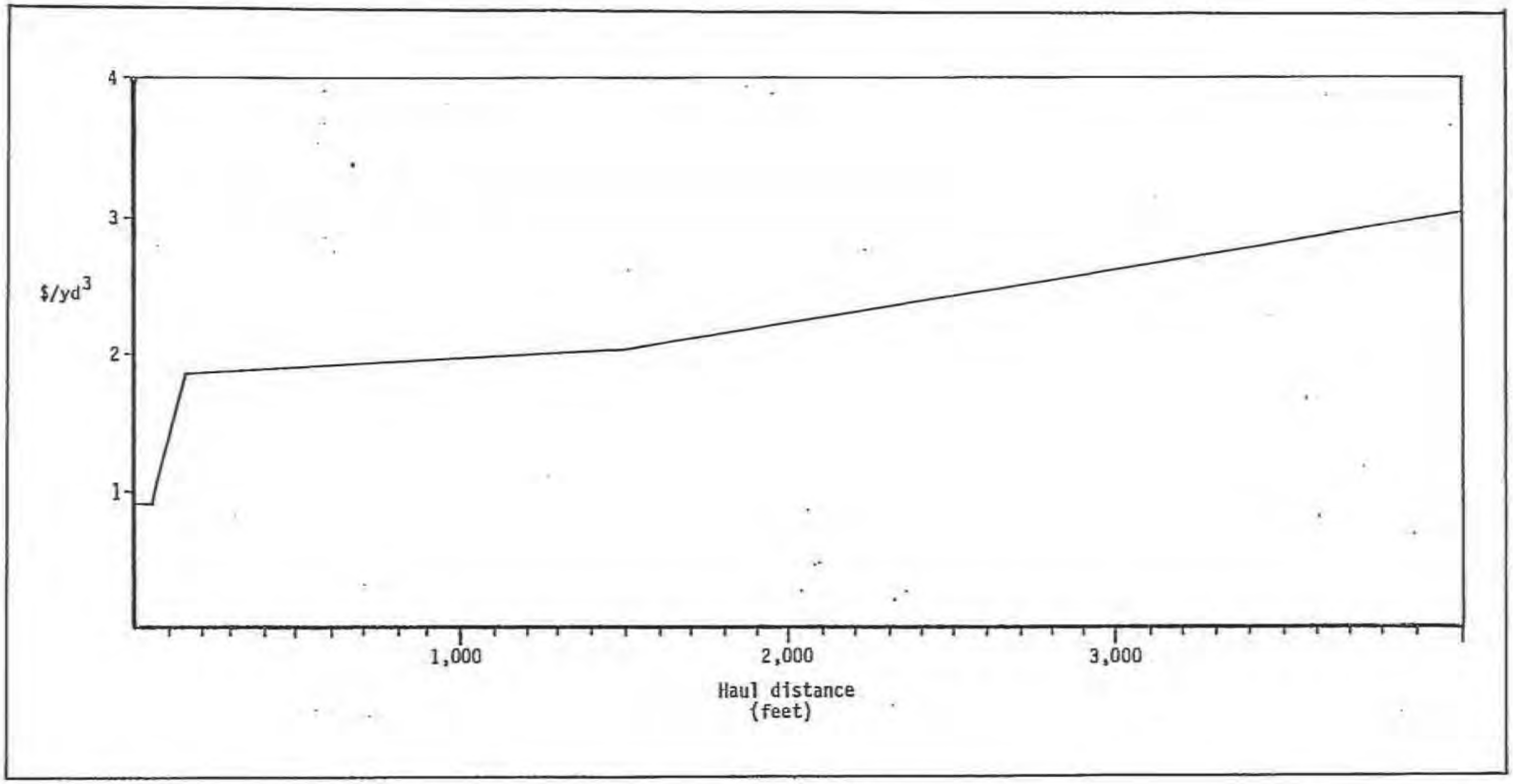


Figure 11-2. Unit costs for on-site excavation and hauling.

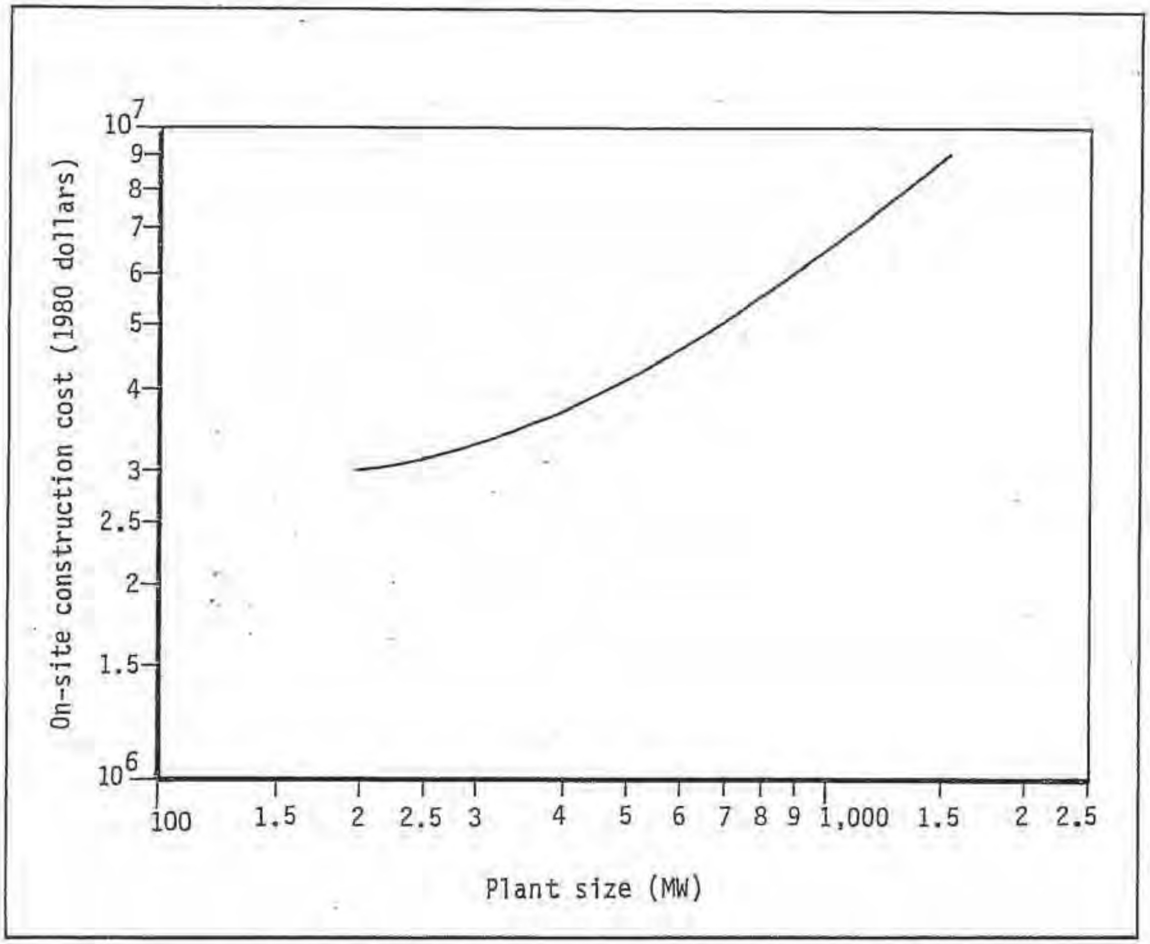


Figure 11-3. On-site construction cost for sludge/fly ash blending.

Source: Adapted from Barrier, J.W., H.L. Faucett, and L.J. Henson, Tennessee Valley Authority. Economics of Disposal of Lime/Limestone Scrubbing Wastes: Sludge/Fly Ash Blending and Gypsum Systems. EPA-600/7-79-069. February 1979.

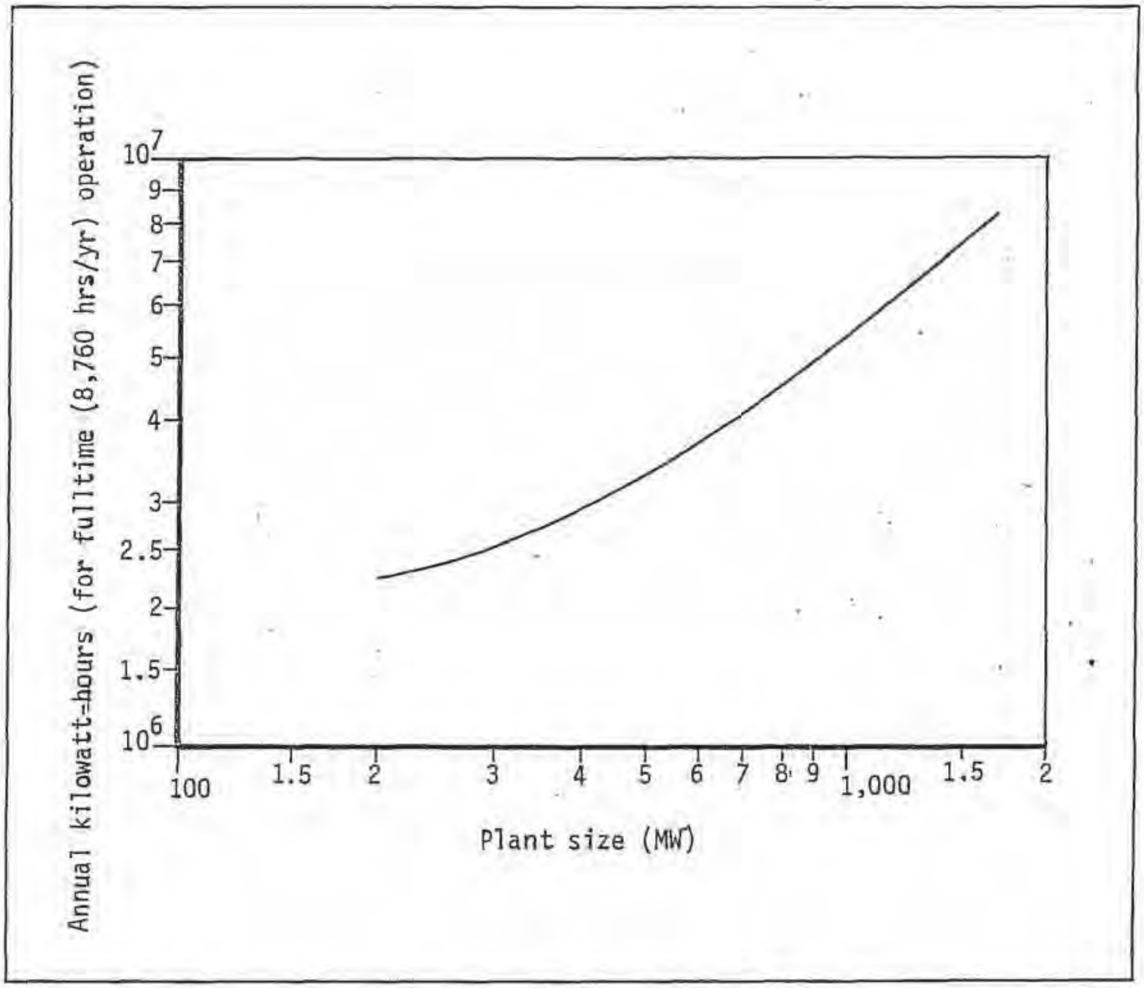


Figure 11-4. Power requirements for sludge/fly ash blending.

Source: Adapted from Barrier, J.W., H.L. Faucett, and L.J. Henson, Tennessee Valley Authority. Economics of Disposal of Lime/Limestone Scrubbing Wastes: Sludge/Fly Ash Blending and Gypsum Systems. EPA-600/7-79-069. February 1979.

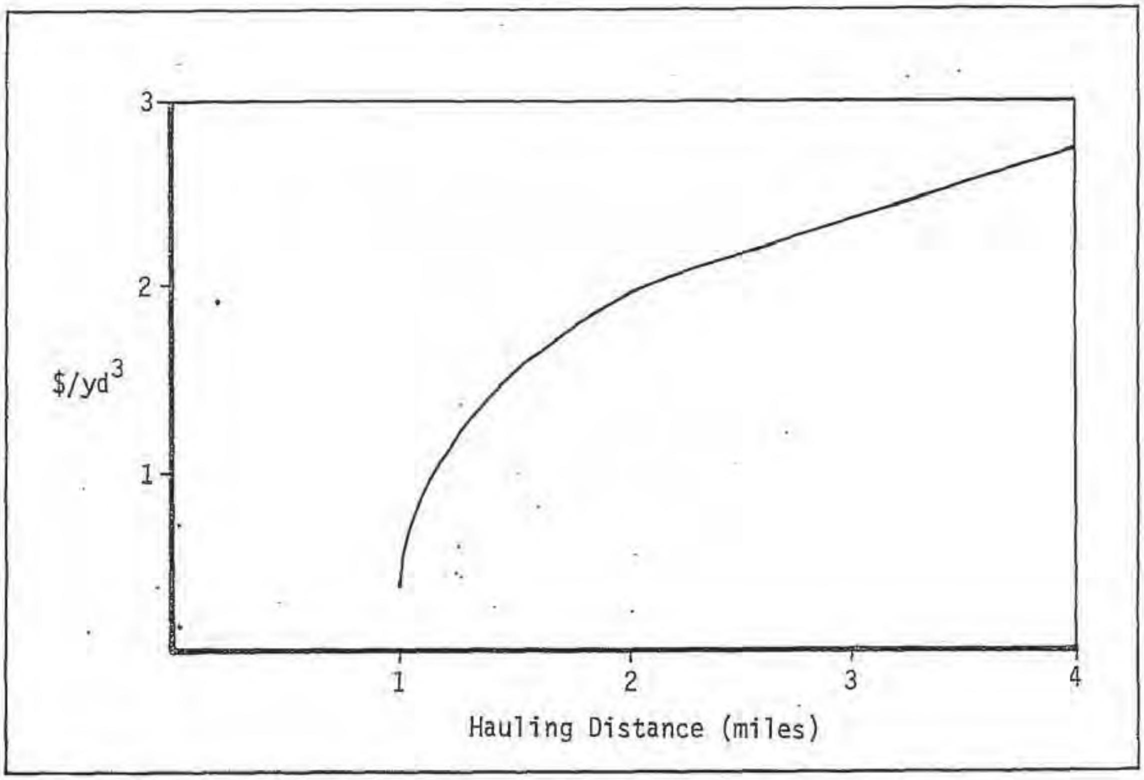


Figure 11-5. Unit costs for off-site hauling.

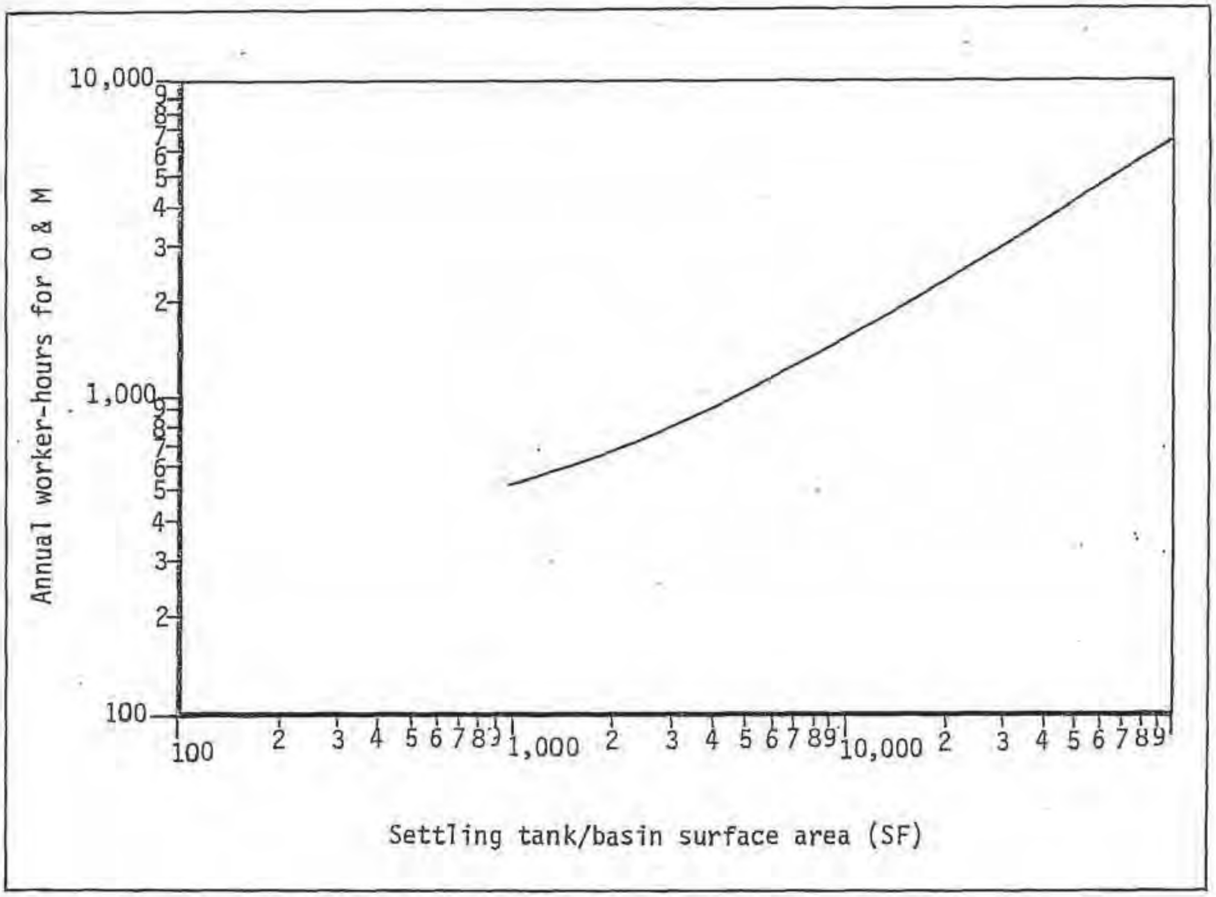


Figure 11-6. Labor requirements for settling tank/basin.

Source: Culp, Wesner, Culp, Clean Water Consultants. Costs of Chemical Clarification of Wastewater, Draft Report, EPA Task Order Contract No. 68-03-2186, Task Order No. 2, January 1976.

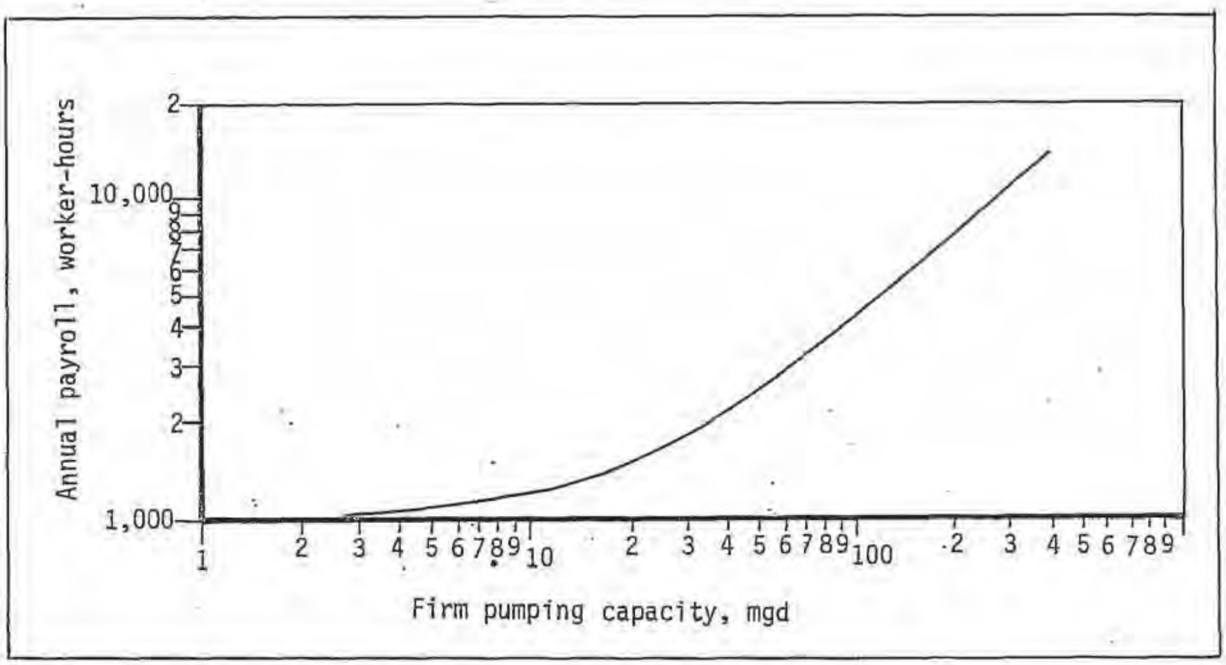


Figure 11-7. Labor requirements for wastewater pumping.

Source: Benjes, H.H., Jr., Culp, Wesner, Culp, Consulting Engineers. Attached Growth Biological Wastewater Treatment Estimating Performance and Construction Costs and Operating and Maintenance Requirements. Draft Report, EPA Contract No. 68-03-2186, January 1977.

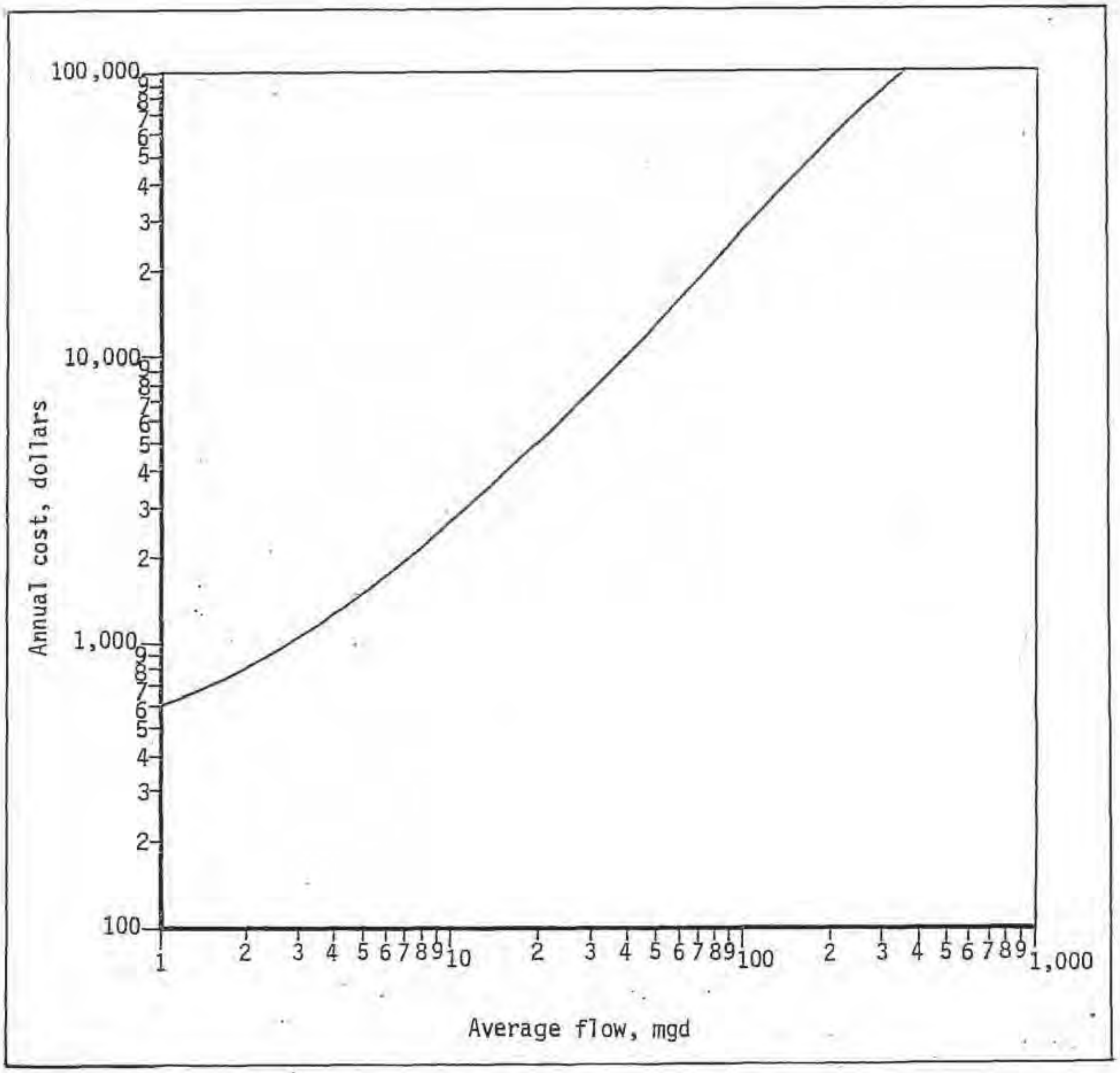


Figure 11-8. Maintenance materials cost for wastewater pumping.

Source: Benjes, H.H., Jr., Culp, Wesner, Culp, Consulting Engineers. Attached Growth Biological Wastewater Treatment Estimating Performance and Construction Costs and Operating and Maintenance Requirements. Draft Report, EPA Contract No. 68-03-2186, January 1977.

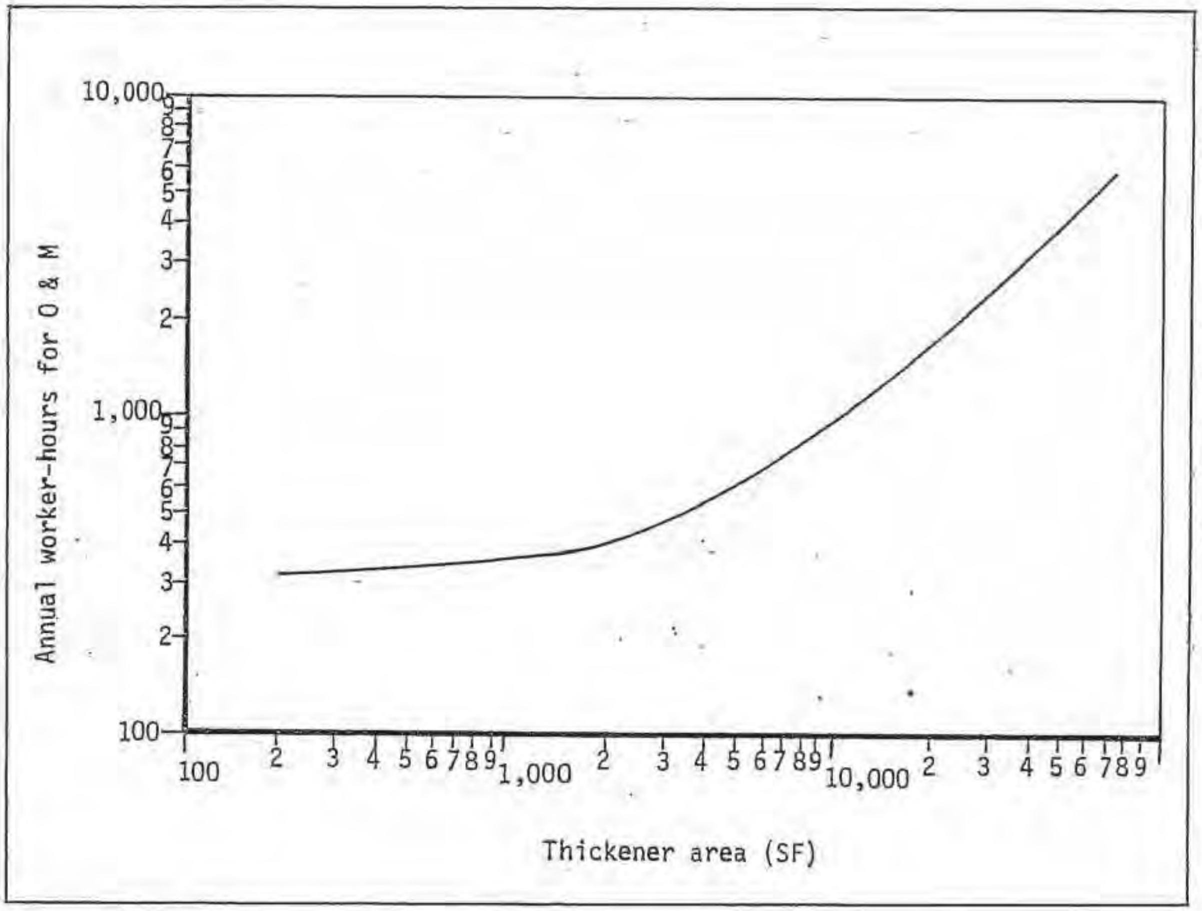


Figure 11-9. Labor requirements for gravity thickening.

Source: Culp, Wesner, Culp, Clean Water Consultants. Costs of Chemical Clarification of Wastewater, Draft Report, EPA Task Order Contract No. 68-03-2186, Task Order No. 2, January 1976.

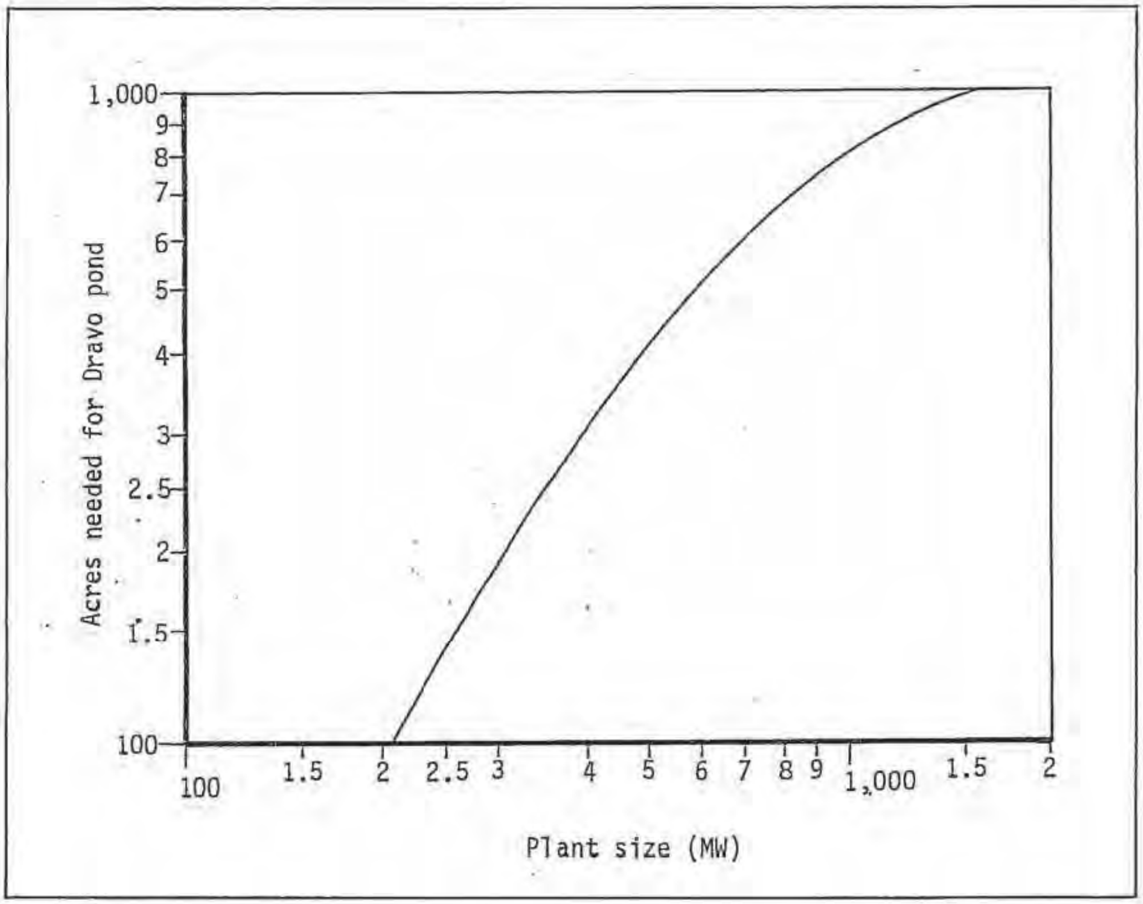


Figure 11-10. Acre requirements for Dravo pond.

Source: Adapted from Barrier, J.W., and Faucett, H.L., Tennessee Valley Authority. Economics of Disposal of Lime/Limestone Scrubbing Wastes: Untreated and Chemically Treated Wastes. EPA - 600/7-78-023a. February 1978.

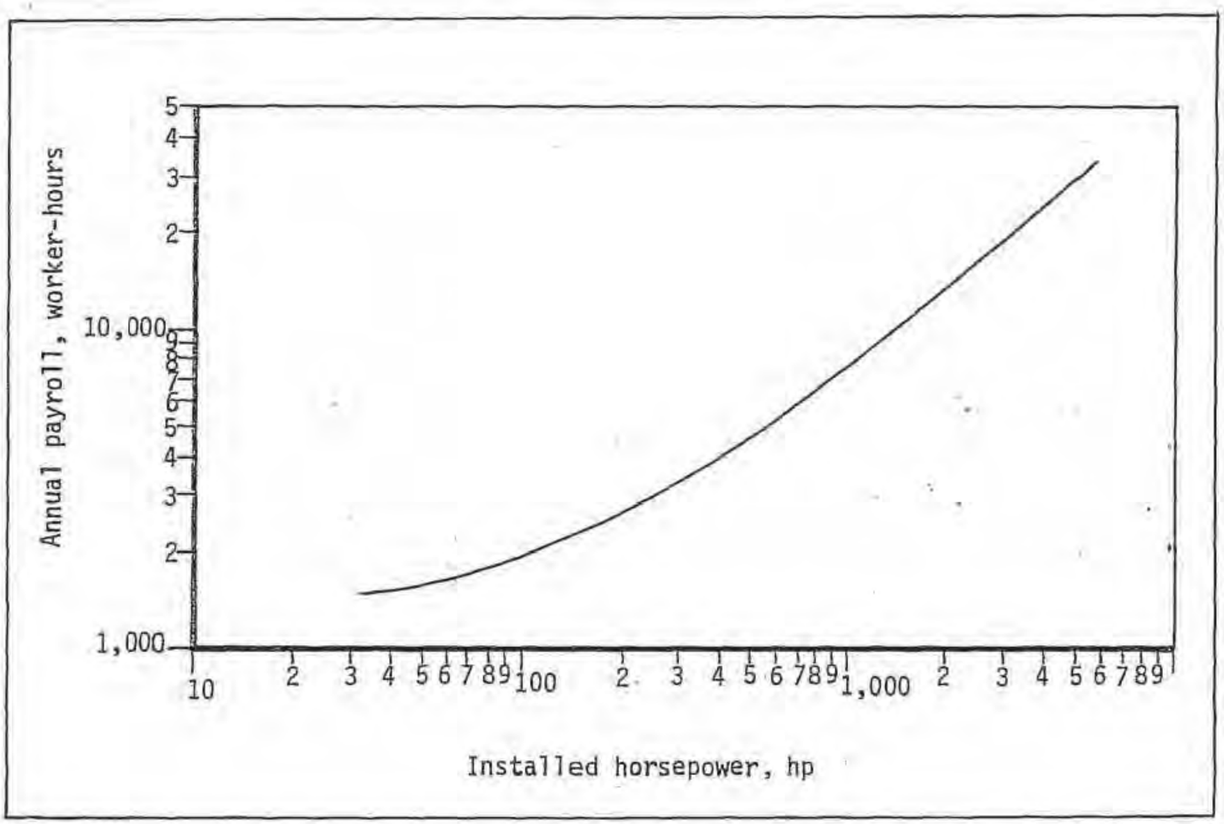
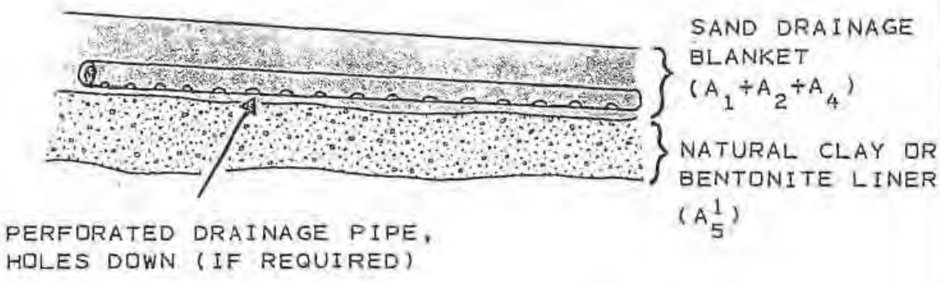


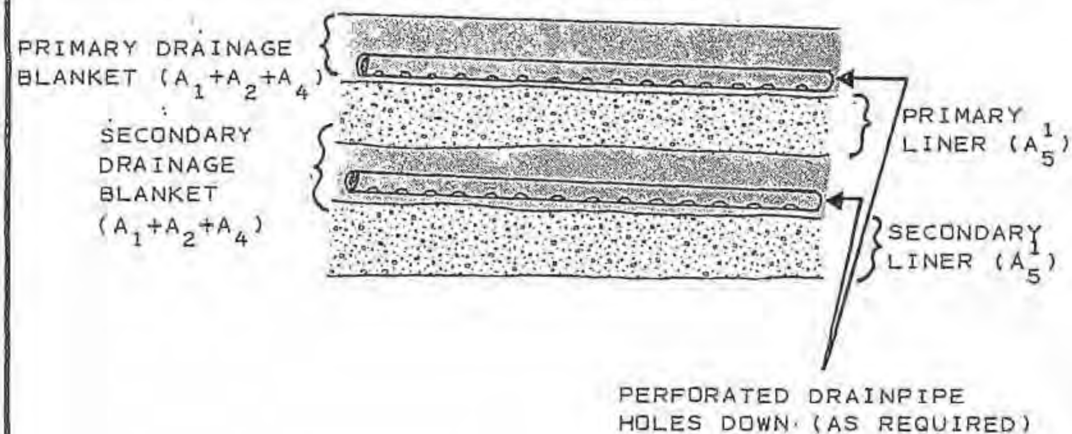
Figure 11-11. Labor requirements for forced oxidation.

Source: Benjes, H.H., Jr. Culp, Wesner, Culp, Consulting Engineers. Attached Growth Biological Wastewater Treatment Estimating Performance and Construction Costs and Operating and Maintenance Requirements. Draft Report, EPA Contract No. 68-03-2186, January 1977.

EXAMPLE 1. CONVENTIONAL SOIL LINER WITH DRAINAGE BLANKET (DRAIN PIPES OPTIONAL).



EXAMPLE 2. REDUNDANT LINER WITH LEACHATE COLLECTION (DRAIN PIPES OPTIONAL).



NOTES:

1. FIGURE NOT TO SCALE.
2. SOIL/ADMIXTURE LINER MAY BE REPLACED WITH SYNTHETIC MEMBRANE.
3. BOTTOM LINER MAY ALSO BE COMPRISED OF NATURAL IN-PLACE CLAYS (IN WHICH CASE, USE FT^2 COMPACTION COSTS FOR CLAY MATERIALS ONLY).

Figure 11-12. Liner and/or leachate collection systems.

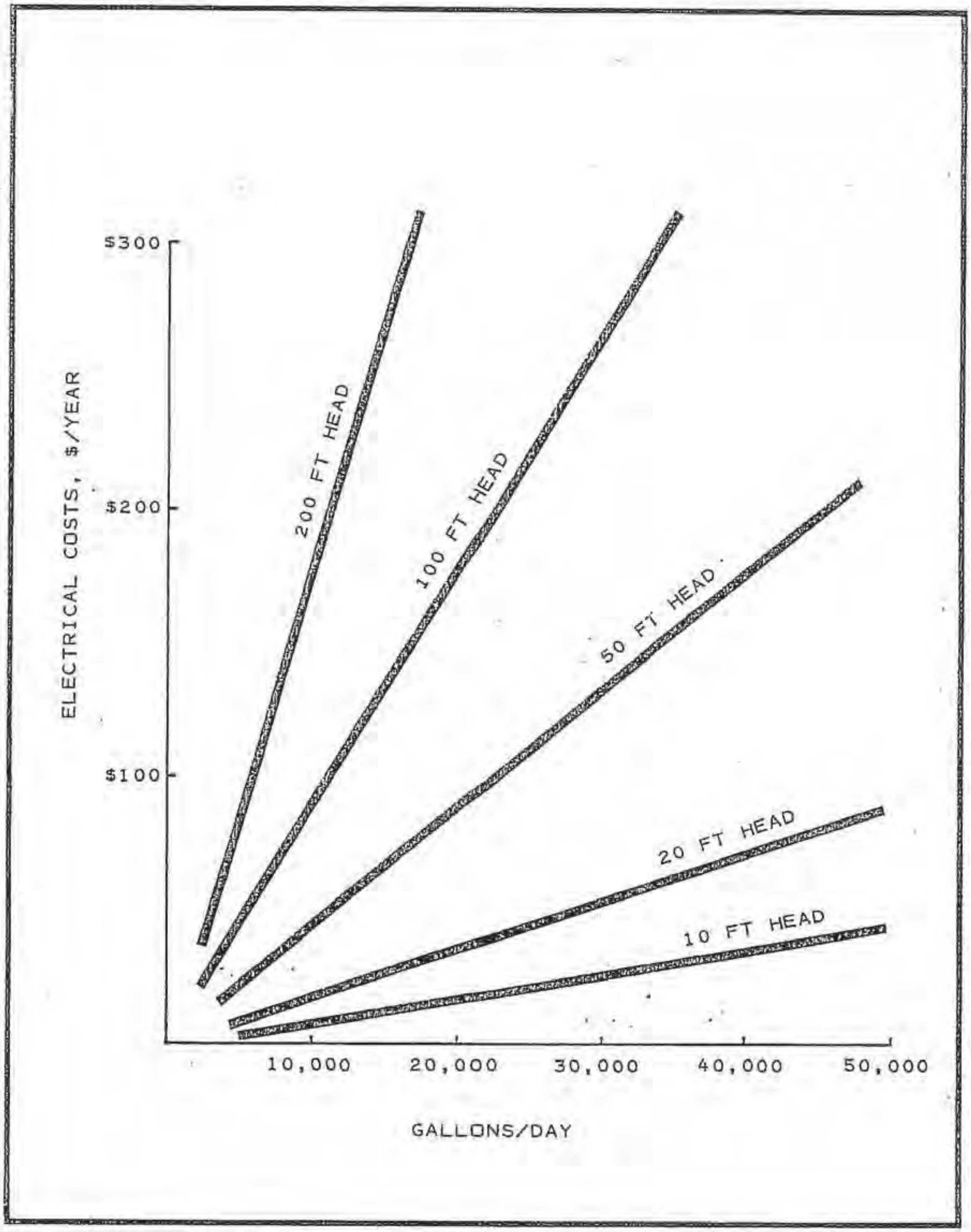


Figure 11-13. Electrical requirements for pump station as a function of flow rate and head.

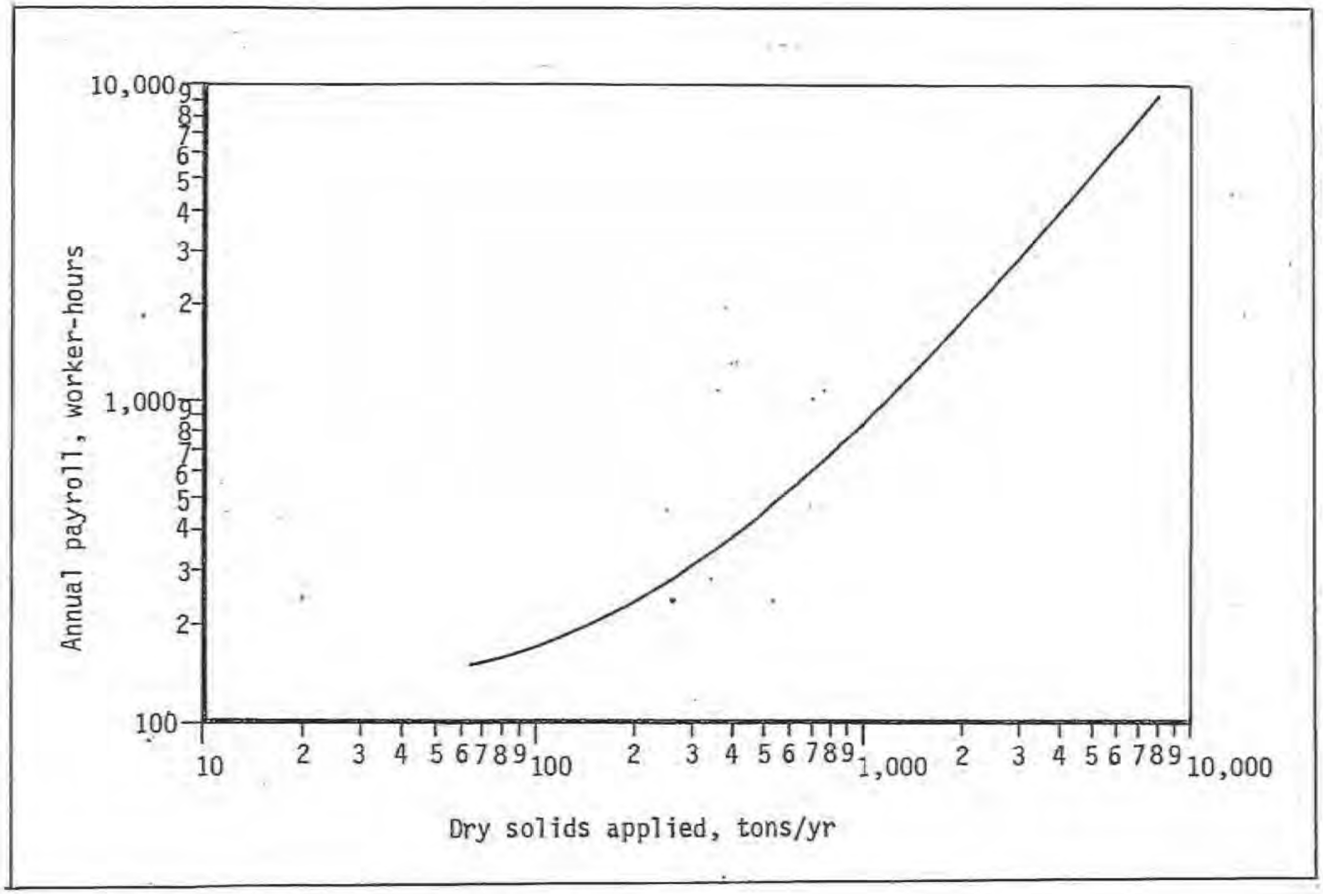


Figure 11-14. Labor requirements for sand drying beds.

Source: Benjes, H.H., Jr. Culp, Wesner, Culp, Consulting Engineers. Attached Growth Biological Wastewater Treatment Estimating Performance and Construction Costs and Operating and Maintenance Requirements. Draft Report EPA Contract No. 68-03-2186, January 1977.

Appendix A

CASE STUDIES

SITE 1

Site Description

Site 1 is in a rural setting on the eastern seaboard and belongs to a medium size power generating plant.* Approximately 4000 t (3630 mt) of fly ash and 80,000 t (72,600 mt) of bottom ash are produced annually at the site.

Waste Disposal Practice

The disposal facility, a fly ash and bottom ash settling pond of less than one acre (0.41 ha) in size, is located on a peninsula, bordered by an estuary on one side and wetland on the other two sides. Soil formation in the area is sandy and local groundwater lies within a few feet from the pond's bottom. Groundwater is not used domestically.

The pond is unlined and has no berms. It is partioned by three earthen dikes which extend more than halfway across the pond width, forming a baffle to lengthen flow path of the sluiced ashes. This design could increase the ash retention time by as much as three times.

The sluiced fly ash is intermittently discharged to this pond since dry fly ash is collected and reburned in the plant's cyclone boilers. After the waste settled, supernatant water is discharged via a weir to the wetlands.

Every two years, approximately 6000 yd^3 (4600 m^3) of settled waste is dredged and removed by an outside contractor to a permitted landfill in the state. A commercial caustic (pH ≈ 13 to 14) is injected into the sluiceway to offset the acidity of the fly ash (pH ≈ 3.5). The wastewater is slightly acidic, when entering the pond.

* The site of a generating facility is indicated according to the following scale: "large" plants are those whose nameplate capacity exceeds 1000 MW; "medium" plants fall in the 200 to 1000 MW range; and "small" plants have capacity of less than 200 MW.

Existing Pollution Control Effort

All constituents of concern (contaminants) which are present in bottom ash and fly ash have been analyzed, using EPA-approved extraction procedure. Concentration of the contaminants were claimed to be low.

Supernatant water is regularly monitored at the discharge outlet according to NPDES specification. Groundwater, however, is not monitored.

The plant plans to close the fly ash pond in 1982. Settled waste will be dredged and reburied at an approved landfill. The pond will then be filled with gravel and uncontaminated soil. Future fly ash will be collected dried and reburned. The process of reburning fly ash is not clear to the project team.

Identified Deficiencies/Potential Problems

Using the current federal standards for non-hazardous waste disposal facilities, two deficiencies.are identified from site 1:

- No groundwater monitoring system.
- No leachage monitoring system.

Due to the design and construction features of the pond, potential washout and groundwater degration may exist at Site 1. However, the site operator believes that the site is well maintained and no environmental problems would be expected to occur.

SITE 2

Site Description

Site 2, located on a river bank in the southern reaches of the Appalachian highland, is a large size coal-fired power plant equipped with electrostatic precipitators. On the average, 537,000 t (487,000 mt) of fly ash and 134,000 t (122,000 mt) of bottom ash are generated annually.

Waste Disposal Practice

Site 2 disposal facility is a 280-ac (113-ha) unlined pond and accepts both fly ash and bottom ash slurries on a continuous basis.

The pond lies about 150 yd (136 m) from the river. The terrain is relatively flat, with a slope of about 5% or less toward the pond. Soils in the area vary from sandy to silty clay. Information on groundwater is not documented. However, local residents believe that a shallow aquifer exists at about 15 to 20 ft (4.6 to 6.1 m) below ground surface, while drinkable groundwater is found deeper, at a depth of about 80 ft (24.4 m).

Existing Pollution Control Effort

Effluent from the settling pond is regularly monitored according to the NPDES requirements. Effluent pH and temperature are monitored continually; oil and grease and TSS are checked bi-monthly. Recirculation of supernatant water is also considered as an effort to control water pollution.

Identified Deficiencies/Potential Problems

Based on current federal standards, a number of design and operation deficiencies in waste disposal practice at Site 2 are identified, including:

- No groundwater monitoring system.
- No leachate monitoring system.
- Site access is not controlled.
- No record of waste quantity and quality.
- No closure/postclosure plans.

In addition, there is a potential for leachate generation and migration to groundwater due to the constant hydraulic head in the pond. The potential for contamination of the potable groundwater supply is, however, greatly reduced due to the depth (80 ft) of this aquifer and the attenuation capability of underlying silty clay soil. Regardless of the hydrogeologic conditions, monitoring of water from perched water tables and deep aquifers is still needed for environmental protection.

SITE 3

Site Description

The plant is a medium size generator which lies along the bank of a major midwestern river in a rural community. Approximately 80,000 t (73,000 mt) of fly ash and 34,000 t (31,000 mt) of bottom ash are generated annually at this site.

The site is located in a flood plain. Record of soil exploration indicates that surface and subsurface materials (to 100 ft or 31 m) are primarily silty sand. Water was encountered at 12 to 20 ft (4 to 6 m) during drilling. Water level of the site well where drinking water is pumped is at 125 ft (38 m). Actual depth to usable groundwater is not known.

Waste Disposal Practice

Two unlined ponds constitute the present disposal system at Site 3. Each is about 250 ac (101 ha), with Pond No. 1 being slightly smaller than Pond No. 2. Ponds are about 10 ft (3 m) deep. Berms were constructed around the ponds to protect them from the 100-yr flood.

Pond No. 1 receives bottom ash and wastewaters from the plant, while Pond No. 2 receives both bottom ash and fly ash. Bottom ash is sluiced to both ponds; fly ash is hauled dry and disposed of at Pond No. 2. In the past, fly ash was trucked to one side of the pond and blown through a 4-in (10-cm) pipe to the receiving water of the pond. It was a failure. Presently, fly ash is dumped near the pond edge, or in the pond and graded evenly. About 10 to 25 percent of fly ash is sold.

Runoff in the area of the plant is directed to several small catch basins and to a retention pond. Discharge is to a small creek which drains into the river. Supernatant waters from the ash ponds are recirculated for sluice water.

Existing Pollution Control Effort

Effluent discharged to the river is regularly monitored according to the NPDES requirements. Water is sampled monthly for pH, TSS, and oil and grease.

Identified Deficiencies/Potential Problems

With reference to current federal standards, design, and operation deficiencies of Site 3 are identified as follows:

- Lack of groundwater monitoring system.
- Lack of leachate monitoring system.
- Lack of dust control measures at Pond No. 2.
- Lack of record on waste quantity and quality.
- Lack of closure/postclosure plans.

Although the site operator believes that fly ash will seal the bottom of the pond eventually, there still exists a potential for groundwater and surface water contamination due to the silty sand material and shallow groundwater table. In fact, the ponds may lie within or slightly above the shallow groundwater table. Thus, there is a need for groundwater monitoring, particularly in the deep aquifer.

SITE 4

Site Description

Site 4, situated in a rural setting on the bank of a major midwestern river, accommodates a large electric generator which produces 490,000 t/yr (445,000 mt/yr) of fly ash and 29,000 t/yr (26,000 mt/yr) of bottom ash. The ash disposal sites are constructed on the recharge zone of the river and are probably in a 100-yr floodplain.

Groundwater in the area lies at about 10 ft (3 m) below the ground surface. Underlying soils are alluvium and relatively permeable. Soil permeability is about 10^{-4} cm/sec.

Waste Disposal Practice

The disposal facilities at this site consist of a 0.5-ac (0.2-ha) metal cleaning waste pond, a 3-ac (1.2-ha) bottom ash settling pond, and a 40-ac (16-ha) fly ash pond. Only the metal cleaning waste pond is lined (with 3-mil Hypalon® liner).

Metal cleaning waste are discharged to the first pond, where the pH is raised from 2 or 3 to 12.5. The metals precipitate and the supernatant is discharged to the bottom ash pond. Bottom ash is slurried, using river water, and piped to the bottom ash pond. The supernatant from the bottom ash pond is pumped, by way of a recirculating pond, to the fly ash pond. Fly ash is sluiced, also using river water, to join the bottom ash supernatant stream, and thus to the fly ash pond. Supernatant from the fly ash pond is discharged to a small stream, which flows to the river. Sludge from the bottom ash pond is dredged weekly and landfilled.

Existing Pollution Control Effort

The bottom ash pond and metal cleaning waste ponds are reportedly diked above the level of a 100-yr flood. Effluent discharged to the river is regularly monitored, in compliance with the NPDES permit requirements.

Identified Deficiencies/Potential Problems

Using the current federal standards as a guide, the design and operation dificiencies identified at Site 4 include:

- Lack of groundwater monitoring system.
- Lack of leachate monitoring system.
- No safety manual for site operator.
- No record of waste quantity and quality.
- No closure/postclosure plan.

Based on available data on hydrogeology and construction of the pond, groundwater contamination appears to be a potential environmental problem at Site 4. A detailed subsurface investigation is needed to reveal the water quality status.

SITE 5

Site Description

Site 5 is in a valley farming community in the Great Plains area. The plant is a medium size generator equipped with FGD scrubbers. The disposal site lies at a lower elevation than the plant itself.

On the average, fly ash, bottom ash, and FGD sludge are generated at 300 t/d (272 mt/d), 90 t/d (82 mt/d) and 70 t/d (64 mt/d) respectively. About 60 percent of the fly ash is landfilled.

Site soils consist of silty clay with low compressibility and permeability. Several perched water tables have been identified around the site. Depth to usable groundwater, however, is not known. Earthquakes with intensities ranging from VI to VIII (MM) have occurred in the past and are expected to recur in the future.

Waste Disposal Practice

The disposal site consists of a 25-ac (10-ha) fly ash landfill and a 300-ac (122-ha) sludge pond (or dam), which also holds bottom ash leachate. It is claimed that both of these facilities are lined with in-situ clay.

Dry fly ash is hauled from the ash silos to the landfill where it is spread by a scraper. Water is applied occasionally for dust control. Bottom ash is sluiced to the higher part of the dam and its leachate drained down hill to the dam. FGD sludge slurry, on the other hand, is pumped to underground drain and later allowed to flow by gravity to the dam. Surface runoff from the landfill is also drained to the dam.

Existing Pollution Control Effort

Wells have been installed around the dam to check leakage. One groundwater monitoring well located downgradient from the dam is sampled semi-annually and analyzed for pH, EC, alkalinity, hardness, Cl^-, SO_4^{2-}, PO_4^{3-}, Na, Fe, Pb, Cd, As, Cr, Hg, and Ni.

Idenfified Deficiencies/Potential Problems

The power plant is only three years old and the dam appears to be carefully designed, constructed, and managed. It is, however, uncertain that the structure will withstand a strong earthquake.

Among the operation deficiencies of this site are:

- No safety manual for site operator.
- Groundwater monitoring network not adequate.
- No closure/postclosure plans.

No potential environmental problems are anticipated from the results of site visit. Additional monitoring wells are needed to ensure adequate protection of the water resources.

SITE 6

Site Description

Site 6 is a medium size power generating plant located in the rolling hills of the northern Great Plains. Wastes generated at this site include 93,600 t/yr (85,000 mt/yr) of fly ash, 218,000 t/yr (197,000 mt/yr) of bottom ash and 130,000 t/yr (118,000 mt/yr) of FGD sludge. Fly ash quantity is relatively small because the majority of it is used in the FGD scrubber system as a SO_2 absorbent.

Glacial sediment (till) veneers much of the disposal area. The disposal site is in a mine pit of a groundwater recharge area. The hydrologic units of major interest in the waste disposal area include the spoil materials and unruined units below the base of the spoils.

Waste Disposal Practice

The wastes (FGD sludge, fly ash, and bottom ash) are disposed of at either the base of a mine pit or at the V-notch between spoil ridges. The latter, however, usually encountered some difficulties during wet seasons due to poor access roads. Two unlined storage ponds, 120 ac-ft (15 ha-m) each, have been constructed and used. Each pond is designed to store up to 6 months of waste. Waste material in the storage ponds is periodically excavated and disposed of in the mine pit.

Existing Pollution Control Effort

Small runoff collection ponds have been built in the disposal area. The site has no surface/groundwater monitoring network. Five wells were installed around the new sludge ponds for leak detection. These wells, however, are not suitable or meant for groundwater monitoring.

Under a federal contract, a major university and the U.S. Geological Survey in the state have installed a network of 150 piezometers within the waste-disposal area and its surroundings. One of the contract objectives is to study effect of waste disposal on underlying groundwater. Preliminary findings show that fly ash and scrubber sludge have caused groundwater to acquire exceptionally high concentrations of sulfate and TDS. Furthermore, fly ash has the potential to cause severe degradation of groundwater in reclaimed land due to high solubility of arsenic, selenium and molybdenum.

Identified Deficiencies/Potential Problems

As indicated by findings from the research group, mine pit disposal is prone to groundwater contamination. Structures for diverting groundwater from contact with wastes are unavailable. Even the newly constructed ponds are unlined.

Other design and operation deficiencies identified include:

- No groundwater monitoring network.
- Lack of access control.
- Lack of daily covering.
- No safety manual for site operator.
- No closure/postclosure plans.

SITE 7

Site Description

Site 7 is a small generator located in the rural western U.S. which produces approximately 80,000 t/yr (73,000 mt/yr) of fly ash and bottom ash.

The disposal facility is situated on a bedrock of dark black, very thinly bedded shale of Cretaceous age. Soils are typical of weathered siltstone or claystone and are predominately composed of silty clays to a depth of approximately 10 ft (3.0 m) below the natural ground surface.

Groundwater is normally present at greater than 20 ft (6.1 m), although the water table fluctuates during the year. A perched water table has been found at depths of less than 7 ft (2.1 m) near the power plant.

Waste Disposal Practice

The disposal site consists of an inactive ash pond, a 28-ac (11-ha) active ash pond, and a small refuse landfill. The ash pond receives fly ash and bottom ash slurry every day. The refuse landfill, which receives garbage and trash from the power plant is operated only one day per week. Only the active ash pond is discussed.

The active ash pond is unlined, and is underlain by clayey soil. The pond supernatant is discharged to a small creek. Some of the ash is reclaimed for a variety of uses, but reclamation is not practiced on a regular basis.

Existing Pollution Control Effort

Effluent discharged is regularly monitored according to the NPDES requirements. Effluent is sampled at 2 sampling points. Monitoring parameters and frequencies are as follows:

- Weekly monitoring - flow rate, pH, temperature, and total residual chlorine.
- Monthly monitoring - TDS, TSS.
- Quarterly monitoring - Cu, Fe, and oil and grease.

Identified Deficiencies/Potential Problems

Based on current federal standards, the design and operation deficiencies identified at Site 7 include:

- Lack of a runoff diversion system.
- No groundwater monitoring system.
- No leachate monitoring system.
- Public access to the disposal site is not restricted.
- No safety manual available for site operator.
- No record of waste quality maintained at the site.
- No closure/postclosure plans.

In addition, the active ash pond appears to provide inadequate freeboard to prevent overflow in the event of heavy rain or spring snowmelt. Judged on the waste quantity and hydrologeolic conditions at Site 7, potential for groundwater contamination from the active pond appears to be low. However, periodic monitoring of the groundwater is needed for environmental protection.

SITE 8

Site Description

Site 8A and 8B are owned and operated by the same utility company. They are medium size power generating plants which are located in the Rocky Mountains. Site 8A, situated 14 miles (22.4 km) west of site 8B, generates 500 t/d (454 mt/d), 100 t/d (91 mt/d), and 200 t/d (182 mt/d) of fly ash, bottom ash, and FGD sludge, respectively. Site 8B produces only fly ash and bottom ash, at approximately 476 t/d (432 mt/d) and 119 t/d (108 mt/d), respectively.

Only hydrogeology of disposal area in site 8A was available and is summarized here. Bedrock beneath the disposal area is a Cretaceous-age marine formation, consisting of thin- to medium-bedded silty claystones, with a few thin interbeds of siltstone. The upper 5 to 10 ft (1.5 to 3.0 m) of bedrock is slightly to moderately weathered and the bedrock is impervious. No evidence of faulting within the disposal area is found.

Natural clays in the disposal area are impervious to semi-impervious. Groundwater is at about 700 to 1500 ft (200 to 460 m) deep.

Waste Disposal Practices

Utility wastes in Site 8A are disposed of in a well-designed landfill, while the disposal practice at Site 8B is simply a mine pit dumping operation.

Site 8A. The disposal area consists of a single 45-ac (18-ha) clay-lined landfill, which receives bottom ash, fly ash, and scrubber sludge. Fly ash is collected dry and wetted to control dust. Bottom ash and scrubber sludge are hauled wet (20% and 40% solids, respectively) and piled temporarily at the upper end of a sump within the landfill to drain excess water. The dewatered sludge and bottom ash are then mixed with the fly ash, spread in loose lifts ($\leq$1 ft), and compacted. Soil cover is applied periodically and the sump water is sprayed over the lift to control dust. Fly ash and bottom ash are generally hauled 5 days/week; scrubber sludge is hauled 7 days/week.

Site 8B. The disposal site consists of mined-out areas that were stripmined in the early 1960s, before mandatory reclamation requirements were in force.

Fly ash, collected by electrostatic precipitators, is mixed with water to 20% moisture and transferred to a hopper for truck loading. Saturated bottom ash is transported hydraulically to storage silos where excess water is drained. Trucks are loaded separately from the fly ash and bottom ash hoppers and driven to the fill area, approximately 5 miles (8 km) from the power plant.

The disposal operation is a "valley fill" with the work normally proceeding downhill from the top. Trucks back to the edge of the fill area and dump their loads. Plans call for the fill to be spread toward and over the edge by a bulldozer, but this is not a daily or even a common practice. On the contrary, open heaps of ash were left where they were dumped.

The fill is compacted only by the weight of the trucks working over it. Plans call for 33 to 43 ft (10 to 13 m) of fill to be covered by 3 to 6 ft (1 to 2 m) of mine spoil. Again, it has been observed that this is not the common practice. Instead, ash piles are commonly left uncovered, causing extreme dust and runoff (erosion) problems.

Operations are slowed and hampered in wet weather, which is quite common. When the primary fill site is inaccessible, another area down the hill is used. Since ash storage capacity at the plant is limited, disposal cannot be curtailed for any significant period. Records are kept of the number of loads hauled per day and the waste quantities are calculated from these figures.

Existing Pollution Control Effort

It appears that there is no existing pollution control effort for Site 8B. At Site 8A, six monitoring wells and three piezometers were installed within its limits. The piezometers are used for monitoring water levels and the wells for obtaining water samples for water quality analyses.

Surface runoff from higher ground at Site 8A is routed around the disposal area in interceptor ditches and into natural drainages. These ditches also handle the runoff from the exterior pile slopes during construction and operation and from the top of the pile as well after reclamation. The ditches will be located adjacent to the landfill area and moved in stages as the outer limits of the storage area increase.

Site closure plan for site 8A includes grading the overall exterior slope of 3-1/4:1 (horizontal to vertical) with 2-1/2:1 slopes between benches. The benches would be 15 ft (4.6 m) in width spaced at 20-ft (6.1-m) intervals vertically. The benches would reduce runoff velocities and associated erosion and accommodate vehicular traffic for maintenance of the slope. Slope erosion would be further reduced by sloping the benches toward the pile interior and directing the runoff along the benches to the pile perimeter. Soil cover would be provided on the outside to minimize runoff contact with waste in the fill and to facilitate reclamation of the fill. The soil cover would be brought up periodically with pile raises but not exceeding about 3 or 4 lifts.

Identified Deficiencies/Potential Problems

For Site 8A, the site location and design are generally good. Groundwater monitoring activity, however, is not functioning up to expectation. Only one sampling/analysis has been done in the past two years. Other deficiencies identified at Site 8A include:

- The waste covering is not as frequent as required.
- Safety manual is not available for site operator.
- Record of waste quality is not maintained.
- No postclosure care plan prepared.

Site 8B requires more upgrading attention. Among the design/operation deficiencies identified at Site 8B are:

- No runoff control structures.
- No groundwater monitoring system.
- No leachate monitoring system.
- Access to the disposal site is not restricted.
- Wastes are not covered.
- No effort to control dust.
- No safety manual available to site operator.
- Record of waste quality is not maintained.
- No closure/postclosure plans.

There was evidence of dust problems at Site 8B. In hot weather, fugitive dust from spillage and ash tracked onto haul roads has attracted the states authority's attention. An incident of surface water contamination was also reported by a neighbor after erosion by surface runoff contaminated a pond on his property. Potential for groundwater contamination at Site 8B cannot be assessed due to lack of site hydrogeologic and construction data.

SITE 9

Site Description

Site 9 is a large power generator located in the desert southwest. It produces 520,000 t/yr (472,000 mt/yr) and 128,000 t/yr (116,000 mt/yr) fly ash and bottom ash, respectively.

The disposal canyons are formed by naturally eroded sandstone and stand about 100 ft (31 m) high; the permeability is estimated to range between 5×10^{-5} to 1.5×10^{-4} cm/sec. The canyon bottoms are filled with variable thickness of dune sand deposits. The dune sands are generally loose near the surface and become denser with depth. Groundwater is at about 1000 ft (305 m) below the soil surface and is claimed to be of good quality. The site area, in general, is located in an inactive fault zone.

Waste Disposal Practice

The disposal site of this large coal-fired generating station consists of a 580-ac (235-ha) ash disposal landfill and a series of 33 evaporation ponds which receive boiler blowdown and maintenance wastewater. The ponds, designed to collect and contain surface runoff from a 100-yr flood, are 3 to 40 ft (1 to 12 m) deep and have a combined surface area of 180 ac (73 ha). Approximately half of the ponds are lined with 30-mil CPE or Hypalon®.

Fifty percent of the dry fly ash is sold. The remaining fly ash is conveyed to the ash bin by pneumatic line and mixed with water prior to hauling to the disposal site. Bottom ash is conveyed from the boiler by water and is dewatered prior to hauling (by truck) to the disposal site.

The ash landfill is located approximately two miles (3.2 km from the power plant. It is designed to be filled with ash that is placed in 2 ft (0.6 m) layers and compacted by machine tracking. The compacted fly ash has a permeability of 1.6×10^{-5} cm/sec. Fill side slopes are maintained at a 3 horizontal to 1 vertical slope. As areas within the disposal areas are completed, they are covered with 2 ft (0.6 m) of sandy soil and revegetated with native plant species.

Existing Pollution Control

A system of 46 leachate monitoring wells (40 to 150 ft deep) and one 1000-ft (305-m) groundwater well allows regular monitoring of both leachate and groundwater. Water samaples are collected monthly to monitor pH, EC, and selected trace elements. Storm runoff is directed to the evaporation ponds, preventing it from entering nearby surface waters.

Identified Deficiencies/Potential Problems

There are no identifable design or operation deficiencies at the fly ash disposal area. The landfill is well operated and maintained. However, groundwater monitoring with a single well appears to be inadequate.

SITE 10

Site Description

Site 10, located in the desert west of the U.S., is a medium size generating plant which produces 63,000 t/yr (57,000 mt/yr), 21,000 t/yr (19,000 mt/yr), and 15,000 t/yr (14,000 mt/yr) of fly ash, bottom ash, and FGD sludge, respectively.

The disposal area lies over alkaline clay soils and near a small river. Information on thickness and permeability of the clay layer is not available. Groundwater is at 5 to 6 ft (1.5 to 1.8 m) below the ground surface and is high in alkalinity.

Waste Disposal Practice

The disposal site consists of a 7-ac (2.8-ha) FGD sludge settling pond, a 45-ac (18-ha) evaporation pond, and a 20-ac (8.1-ha) ash landfill. All of these facilities are unlined, but a bentonite slurry barrier has been installed between the evaporation pond and the river to prevent lateral seepage from the pond.

The sludge pond receives sludge continuously from the wet FGD system. The supernatant from this pond is piped to the evaporation pond; the sediment is dredged annually and disposed in the landfill along with bottom ash and fly ash. A portion of the fly ash is sold.

Existing Pollution Control Effort

Groundwater is sampled semi-annually and analyzed for pH, alkalinity, cloride, and sulfate. The river is sampled annually and analyzed for total hardness, calcium hardness, chlorides, silicon, sodium, pH, total alkalinity, sulfates, phosphates, and TDS.

Identified Deficiencies/Potential Problems

The design and operation deficiencies identified at Site 10 include:

- No leachate monitoring system.
- Access to the disposal facilities is not restricted.
- Wastes disposed of at the landfill are not covered.
- Safety manual is not available for site operator.
- Closure/postclosure plans are not prepared.

In addition, chemical composition of wastes generated at Site 10 has not been determined. As a result, the site monitoring program appears insufficient in terms of checking appropriate parameters of concern. Certain heavy metals (i.e., Cd, Pb, Cu, etc.) and anion contaminants (i.e., Mo, As, Se, etc.) should be included.

Although groundwater in the area is thought to be undrinkable because of its alkalinity and high TDS, the aquifer is not classified as an exempted aquifer under federal standards.

Appendix B

GROUND WATER QUALITY CRITERIA*

Ground water is considered contaminated if the introduction of a substance would cause:

- The concentration of the substance in the ground water to exceed the maximum contaminant level specified herein, or
- An increase in the concentration of that substance in the ground water where the existing concentration of that substance exceeds the maximum contaminant level specified herein.

1. MAXIMUM CONTAMINANT LEVELS FOR INORGANIC CHEMICALS

The following are the maximum levels of inorganic chemicals other than fluoride:

Contaminant	Level (milligrams per liter)
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

The maximum contaminant levels for fluoride are:

Temperature[1] Degrees Fahrenheit	Degrees Celsius	Level (milligrams per liter)
53.7 and below	12 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

[1] Annual average of the maximum daily air temperature.

2. MAXIMUM CONTAMINANT LEVELS FOR ORGANIC CHEMICALS

The following are the maximum contaminant levels for organic chemicals:

	Level (milligrams per liter)
(a) Chlorinated hydrocarbons:	
Endrin (1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8-dimethano naphthalene)	0.0002
Lindane (1,2,3,4,5,6-Hexachlorocyclohexane, gamma isomer)	0.004
Methoxychlor (1,1,1-Trichloro-2,2-bis (p-methoxyphenyl) ethane)	0.1
Toxaphene ($C_{10}H_{10}Cl_8$-Technical chlorinated camphene, 67 to 69% chlorine)	0.005
(b) Chlorophenoxys:	
2,4-D (2,4-Dichlorophenoxy-acetic acid)	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	0.01

3. MAXIMUM MICROBIOLOGICAL CONTAMINANT LEVELS

The maximum contaminant level for coliform bacteria from any one well is as follows:

(a) Using the membrane filter technique:

(1) Four coliform bacteria per 100 milliliters if one sample is taken, or

(2) Four coliform bacteria per 100 milliliters in more than one sample of all the samples analyzed in one month.

(b) Using the five tube most probable number procedure (the fermentation tube method) in accordance with the analytical recommendations set forth in "Standard Methods for Examination of Water and Waste Water", American Public Health Association, 13 Ed. pp. 662-688, and using a Standard sample, each portion being one fifth of the sample.

(1) If the standard portion is 10 milliliters, coliform in any five consecutive samples from a well shall not be present in three or more of the 25 portions, or

(2) If the standard portion is 100 milliliters, coliform in any five consecutive samples from a well shall not be present in five portions in any of five samples or in more than fifteen of the 25 portions.

4. MAXIMUM CONTAMINANT LEVELS FOR RADIUM-226, RADIUM-228, AND GROSS ALPHA PARTICLE RADIOACTIVITY

The following are the maximum contaminant levels for radium-226, radium-228, and gross alpha particle radioactivity:

(a) Combined radium-226 and radium-228 - 5 pCi/l;

(b) Gross alpha particle activity (including radium-226 but excluding radon and uranium) - 15 pCi/l.

* Criteria for Classification of Solid Waste Disposal Facilities and Practices; Final, Interim Final, and Proposed Regulations, Federal Register, Vol. 44, No. 179, September 13, 1979.

APPENDIX C

PARTIAL LISTING OF LINED UTILITY WASTE DISPOSAL SITES

Appendix C

PARTIAL LISTING OF LINED UTILITY WASTE DISPOSAL SITES

Utility	Location	Material	Size(ft^2)	Application	Date Installed
Colorado Public Service Co.	Arapahoe Station	Clay		Bottom & fly ash	1979
Colorado Public Service Co.	Cherokee Station	Clay		Bottom & fly ash	1979
Colorado Public Service Co.	Comanche Station	Clay		Bottom & fly ash	1980
Colorado-Ute Electric Assoc.	Craig Station	Clay		Boiler/metal wastes	1979
Colorado Springs Utilities	Martin Drake	Clay		Bottom & fly ash	1979
Colorado Public Service Co.	Pawnee Station	Clay		Fly ash	1980
Colorado Springs Utilities	Ray D. Nixon	Clay		Bottom ash	1979
Colorado Public Service Co.	Valmont	CSPE (inactive since 1973)		Stabilized sludge	
Springfield Water, Light & Power Co.	Dallman #33	Clay		Bottom & fly ash	1979
Central Illinois Light Co.,	Duck Creek	Clay		Bottom & fly ash	1979
Kansas Power & Light Co.	Jeffney Station	Compacted soils		Bottom & fly ash	1979
Kansas Power & Light Co.	Lawrence Station	Clay		Bottom & fly ash	1979
Kansas Power & Light Co.	Tecumseh Station	Clay		Bottom & fly ash	1979
Kentucky Power Co.	Big Sandy Station	Clay		Bottom & fly ash	1979
Commonwealth Edison	Waukegan	CSPE (Hypalon®)	1,100,000		1977
California Pacific	Winnemucca	CSPE	18,000		1977
Pennsylvania Power & Light	Harrisburg	CSPE	1,000,000		1977
Virginia Electric	Portsmouth	CSPE	151,000		1977
Detroit Edison	Avoca	8140	18,000		1978

Appendix C (continued)

Utility	Location	Material	Size(ft^2)	Application	Date Installed
Colorado Public Utilities	Brush	HDPE	2,000,000		1979
Commonwealth Edison	Argonne	Pos-A-Pak	1,000,000		1979
Florida Power & Light	Cape Canaveral	HDPE		Neutralization	1977
Florida Power & Light	Hollywood	HDPE		Neutralization	1977
Florida Power & Light	Martin	HDPE		Neutralization	1975
Rochester Gas & Electric	Stations 7 & 9	HDPE			1978
Cleveland Electric Illum.	Astabula	HDPE			1979
El Paso Electric	Newman	PVC			1974,197
Penn Power Co.	Bruce Mansfield	Stabilized sludge		Fly ash, stabilized sludge	1979
Penn Electric Co.	Front Street	PVC		Bottom & fly ash	1980
Penn Power & Light Co.	Martins Creek	Not specified		Fly ash	1979
Penn Power & Light Co.	Holtwood	Clay		Fly ash	1980
Metro Edison	Titus	Clay		Bottom ash	1979
Texas Power & Light Co.	Big Brown	Clay		Bottom & fly ash	1979
Colorado River Authority	Fayette #1	Clay		Bottom & fly ash	1979
Southwest Public Service Co.	Harrington	Clay		Bottom ash	1979
San Antonio Public Service	J. T. Deely	Clay		Fly ash	1979
Texas Power & Light Co.	Monticello	Clay		Bottom & fly ash	
El Paso Electric Co.	Newman	PVC		Cooling/boiler blowdown	1980
Houston Power & Light	Parish	Clay		Bottom & fly ash	1979
Centra OP&G Co.	Clay			Bottom & fly ash	

Appendix C (continued)

Utility	Location	Material	Size(ft^2)	Application	Date Installed
Arizona Power Coop.	Apache Station	CSPE		Fly ash	1980
Louisville Gas & Electric	Cane Run Station	Clay		Bottom & fly ash	1979
Kentucky Utilities Co.	Green River Station	Clay		Not specified	1980
Big Rivers Electric Corp.	Kenneth Coleman Sta.	Clay		Bottom & fly ash	1979
Louisville Gas & Electric	Millcreek Station	Clay		Bottom & fly ash	1979
Louisville Gas & Electric	Paddy's Run Station	Clay		Bottom & fly ash	1979
Big River Electric Corp.	Robert Green Station	Clay		Bottom & fly ash	1979
E. Kentucky Power Coop.	Spurlock Station	Clay		Bottom & fly ash	1979
Mississippi Power Co.	V.J.Daniels Jr. Sta.	CSPE		Boiler cleaning wastes	1980
Springfield Cities Utilities	SW Power Station	Fly ash/soil admixture		Bottom & fly ash	1979
Detroit Edison Co.	St. Clair Station	Clay		Bottom & fly ash	1979
Lansing Board of Water & Light	Lake Lansing	Compacted soil		Bottom & fly ash	1980
Northern States Power Co.	Sherburn Co.	Clay		Bottom & fly ash	1980
Minnesota Power & Light Co.	C. Boswell Station	Clay		Bottom & fly ash	
Montana Power Co.	Colstrip Station	Clay/CSPE		Bottom & fly ash	1980
Nevada Power Co.	Reid Gardner Station	Clay Slurry		Fly ash	1979
New Hampshire Public Service	Merrimack Station	Clay/ore fines		Fly ash	
Duke Power Co.	Allen Steam Station	Soil/clay admixture		Bottom & fly ash	1980
Coop Power Assoc.	Coal Creek #1	Clay		Bottom & fly ash	1979
Dayton Power & Light Co.	J.M. Stuart Station	Clay		Bottom & fly ash	1979

Appendix C (continued)

Utility	Location	Material	Size(ft^2)	Application	Date Installed
Cincinnati Gas & Electric	Miami Fort Station	Compacted soil		Bottom ash	1980
Cincinnati Gas & Electric	W.C. Beckjord Sta.	Compacted soils		Bottom & fly ash	
Pacific Gas & Electric	Moss Landing	CSPE	29,000		1974
Pacific Gas & Electric	Albany	CSPE			1975,1978
Pacific Gas & Electric	Antioch	CSPE	15,000		1978
Pacific Gas & Electric	Contra Costa	CSPE	15,000		1976
Pacific Gas & Electric	Eureka	CSPE	17,000		1977
Pacific Gas & Electric	Morro Bay	CSPE	12,000		1978
Pacific Gas & Electric	Pittsburgh	CSPE	22,000		1976
Pacific Gas & Electric	San Francisco	CSPE	60,000		1978
Magma Electric	Holtsville	CPE			
Southern California Edison	San Clemente	CSPE	60,000		1976
Southern California Edison	San Onofre	CSPE	15,000		1978
Salt River Authority	Phoenix	CPE	2,000,000		1979
United Illuminating Co.	Bridgeport	CSPE	64,000		1973
Colorado Public Service Co.	Platteville	CPE	150,000		1972
Windsor Power House	Power	CSPE	23,000		1973
Commonwealth Edison	Cordova	PVC	2,000,000		1973
Metropolitan Utilities	Omaha	Butyl rubber	174,000		1974
Montana Power Co.	Colstrip	CSPE	164,000		1975
Louisville Gas & Electric	Louisville	CSPE	13,000		1976
Pacific Gas & Electric	Albany	CSPE	36,000		1976

APPENDIX D

CASE STUDY EXAMPLE OF UPGRADING COST ESTIMATION

Section 11 of this manual presents detailed guidance and information for estimating the cost of disposal site upgrading alternatives. While the information is presented in a systematic fashion, it is still useful to work through an actual example applying the methodology. One such case study was selected for illustration here.

The cost estimation examples presented in this appendix are based on a case study described in Volume II, Section 6, of Engineering Evaluation of Projected Solid Waste Disposal Practices, a report prepared for EPRI by Michael Baker Jr., Inc. The study involves the upgrading two large flyash and bottom ash disposal ponds to conform to RCRA requirements.

The case study site receives 185,600 tons per year of fly ash and bottom ash from three coal-burning power plants with a combined generating capacity of 805 MW. Currently, ash produced at the plants is either sluiced or trucked dry to the ponds for disposal. The ponds, as currently constructed, meet the criteria established under Subtitle D of RCRA, but fail to meet the guidelines proposed under RCRA Section 1008 becuase the unlined pond bottoms are at an elevation near the ground water table and are surrounded by moderately permeable soil.

Cost estimates for two sets of scenarios are developed in the following examples. Each set considers both hazardous and nonhazardous waste disposal in delineating measures necessary to comply with RCRA. The "wet" disposal scenarios involves upgrading the disposal site to allow continued operation as a ponding facility, with ash either sluiced in or washed from trucks for disposal. The "dry" disposal scenarios involve draining and dewatering the ponds, converting the disposal site to a landfill for dry and dewatered ash.

- Raise bottom of each pond 10 ft using natural soils.
- Raise dikes 10 ft around each pond.
- Construct liner in each pond
  - For nonhazardous wastes, a single 12-in. thick liner with a maximum permeability of 10^{-7} cm/sec should be installed.
  - For hazardous wastes, the liner should consist of a 6-in. thick top liner and 1-ft thick bottom liner, each of 10^{-7} cm/sec permeability. A gravity-flow leachate detection/ collection system consisting of a 1-ft thick layer of sand should be placed between the liners.
- Add appropriate piping
  - For hazardous wastes, install lined sumps within dikes to collect leachate from drainage layer. Install pumps and piping to return leachate to ponds.
  - For nonhazardous wastes, construct a pipeline to tie the north pond into the existing water recycle line.
- Provide an on-site source of clean water, an emergency communications system, and other emergency provisions.
- Secure site against unauthorized and/or accidental entry.
  - For nonhazardous wastes, construct a gate across the main road entering the site.
  - For hazardous wastes, construct a fence around the entire disposal area, post warning signs, and gate all entrances.
- Install 12 ground water monitoring wells and implement an appropriate monitoring program.
- Implement closure activities when site is closed
  - Construct a soil cover over the entire site consisting of 6 in. of liner-quality fill beneath 18 in. of soil capable of supporting vegetation.
  - Landscape the final cover on the site.

Tasks for the dry disposal scenarios are as follows:

- Drain ponds and dewater existing waste ash.
- Shift wastes from one pond to the other. (Each pond is upgraded in turn.)
- Raise bottom of disposal areas 10 ft using natural soils.
- Construct a liner over the entire disposal area.
  - For nonhazardous wastes, a single 12-in. thick liner with a permeability of 10^{-7} cm/sec should be installed.

- For hazardous wastes, a 1-ft thick liner with a permeability of 10^{-7} cm/sec should be covered with a 1-ft pervious drainage layer sized to prevent clogging. This layer must be graded to allow drainage to a collection sump.

- Provide diversion and storage for surface water runoff from disposal area, consisting of sedimentation ponds, dikes and pumps, and treatment if needed. For the hazardous scenario, this will allow collection of leachate from liner drainage.

- Construct and maintain dewatering system for bottom ash brought to the site.

- Construct a silo for storage of fly ash.

- Install 12 ground water monitoring wells and implement an appropriate monitoring program.

- Provide an on-site source of clean water, an emergency communications system, and other emergency provisions.

- Secure site against unauthorized and/or accidental entry

  - For nonhazardous wastes, construct a gate across the main road entering the site.

  - For hazardous wastes, construct a fence barrier around the entire disposal area, post warning signs, and gate all entrances.

- Construct a soil cover over the site as sections are completed. Cover consists of 6 in. of liner-quality fill beneath 18 in. of soil capable of supporting vegetation.

Tables D-1 and D-2 present cost estimates for the dry and wet disposal upgrading scenarios. Sizing information, design criteria, and source tables are presented in the tables to allow the reader to follow the Section 11 calculations.

TABLE D-1

LEVELIZED COSTS FOR DRY DISPOSAL SCHEME

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Construct drain pipe from ponds to sewer	11-28		4000 ft			System requires 4000 ft of 4-ft diameter reinforced concrete pipe
On-site capital		A		$260,000	$260,000	Municipal sewer line is located at or immediately adjacent to power plant for wastewater disposal
Engineering overhead and fees		C		39,000	39,000	
Project contingency		E		59,800	59,800	
Process contingency		F		53,820	53,820	
Preproduction costs		H		16,201	16,201	
Inventory capital		I		3,447	3,447	
TOTAL LEVELIZED COST OF CAPITAL				77,993	77,993	
Maintenance labor		M		4,136	4,136	
Maintenance materials		N		4,136	4,136	
Overhead charges		P		1,241	1,241	
TOTAL LEVELIZED OPERATING COSTS				17,941	17,941	
TOTAL LEVELIZED REVENUE REQUIREMENT				95,935	95,935	
Pump supernatant water off pond and dispose of it	11-1		$2.64(10^8)$ gal			All costs are capital costs
On-site capital		A		1,178	1,178	A 15 MGPH centrifugal pump is rented at $70/week for one week (including down time)
Project contingency		E		236	236	Piping/hoses are provided with pump; drain is available
TOTAL LEVELIZED COST OF CAPITAL				254	254	Supernatant doesn't need treatment
TOTAL LEVELIZED REVENUE REQUIREMENT				254	254	Two operators work for one week at $13.85/hr

TABLE D-1 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Dewater waste in pond bottoms	11-1		405 acres			All costs are capital costs
On-site capital		A		$11,081	$11,081	Dewatering consists of disking, harrowing, and air drying
Engineering overhead and fees		C		1,662	1,662	
Project contingency		E		2,549	2,549	A 30,000 lb motorized grader is needed for 8 weeks (4 day/pond, 2 ponds, 4 times each over 2 months)
TOTAL LEVELIZED COST OF CAPITAL				15,292	15,292	
TOTAL LEVELIZED REVENUE REQUIREMENT				2,755	2,755	Ash left in pond bottoms after draining is roughly 5 or 6 in. deep
						One operator is needed for 260 hr
Shift twice the total volume of the existing waste ash the distance from north pond to south pond	11-7		549,926 yd^3			
On-site capital		A		1,440,806	1,440,806	
Engineering overhead and fees		C		360,202	360,202	
Project contingency		E		270,151	270,151	
Preproduction costs		H		41,458	41,458	
TOTAL LEVELIZED COST OF CAPITAL				380,580	380,580	
TOTAL LEVELIZED REVENUE REQUIREMENT				380,580	380,580	
Raise pond bottoms 10 feet	11-7		6,534,000 yd^3			Common borrow is obtained off-site; haul distance = 3 miles
On-site capital		A		32,996,700	32,996,700	
Engineering overhead and fees		C		8,249,175	8,249,175	
Project contingency		E		6,186,881	6,186,881	
Preproduction costs		H		948,655	948,655	
TOTAL LEVELIZED COST OF CAPITAL				11,127,725	11,127,725	
TOTAL LEVELIZED REVENUE REQUIREMENT				11,127,725	11,127,725	
Line pond bottoms	11-30		17,641,800 ft^2			Nonhazardous:
On-site capital		A		18,680,711	23,894,838	Bentonite ($25/ton) is hauled to mid-western site from Wyoming
Engineering overhead and fees		C		2,802,107	3,584,226	
Project contingency		E		3,222,423	4,121,860	

TABLE D-1 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total
Process contintency		F		$2,470,524	$3,160,092
Preproduction costs		H		543,966	695,797
TOTAL LEVELIZED COST OF CAPITAL				4,993,612	6,387,420
TOTAL LEVELIZED REVENUE REQUIREMENT				4,993,612	6,387,420
Construct dikes to form settling basins	11-14		1500 ft		
On-site capital		A		96,089	96,089
Engineering overload and fees		C		14,413	14,413
Project contingency		E		22,100	22,100
Process contingency		F		19,890	19,890
Preproduction costs		H		4,544	4,544
Inventory capital		I		764	764
TOTAL LEVELIZED COST OF CAPITAL				28,473	28,473
Operating labor		L		554	554
Maintenance labor		M		6,115	6,115
Maintenance materials		N		9,172	9,172
Overhead charges		P		2,001	2,001
TOTAL LEVELIZED OPERATING COSTS				33,650	33,650
TOTAL LEVELIZED REVENUE REQUIREMENT				62,123	62,123

Assumptions and Notes

Hazardous:
Bottom liner = 1-ft clay-soil liner topped by 1-ft pervious drainage layer
Cost of sandy topsoil for pervious layer is between the quoted unit costs for Class 2 material: $0.97 to $1.48/yd^3
Bentonite ($25/ton) is hauled to mid-western site from Wyoming

Dike will be 10-ft high
The settling basin for the north pond will have a capacity of 28.5 ac-ft of water and the south pond 12 ac-ft of water at maximum; both will be capable of maintaining at least 3 ft of freeboard at maximum capacity
This will require the addition of 910 ft of dike to the north pond and 590 ft of dike to the south pond to create 2 square ponds within the existing dikes that are capable of retaining the assumed maximums
Existing dikes will be used for 2 sides of each pond
On-site borrow must be hauled 2000 ft
Area will have newly raised and lined bottom, therefore will not have to be cleaned and grubbed
Assume transportation distances for clay is 4 miles

TABLE D-1 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Construct two pump stations	11-32					System requires two pump stations; each must overcome 20-ft head
On-site capital		A		$176,950	$176,950	
Engineering overhead and fees		C		14,092	14,092	
Project contingency		E		57,313	57,313	
Process contingency		F		62,089	62,089	
Preproduction costs		H		9,112	9,112	
Inventory capital		I		1,552	1,552	
TOTAL LEVELIZED COST OF CAPITAL				57,799	57,799	
Maintenance labor		M		12,418	12,418	
Maintenance materials		N		18,627	18,627	
Overhead charges		P		3,725	3,725	
Electricity		S		100	100	
TOTAL LEVELIZED OPERATING COSTS				65,704	65,704	
TOTAL LEVELIZED REVENUE REQUIREMENT				123,503	123,503	
Install and sample ground water monitoring well system	11-22					System requires 12 wells Wells average 60 ft deep
On-site capital		A		24,740	24,740	Samples are taken annually through 10-yr post-closure period for nonhazardous scenario; semi-annually through 30-yr post-closure period for hazardous scenario
Engineering overhead and fees		C		3,711	3,711	
Project contingency		E		4,268	4,268	
Process contingency		F		3,272	3,272	
Preproduction costs		H		8,037	8,037	
Inventory capital		I		7,317	7,317	
TOTAL LEVELIZED COST OF CAPITAL				9,242	9,242	
Variable maintenance costs		W		2,042	5,644	
TOTAL LEVELIZED OPERATING COSTS				2,619	7,238	
TOTAL LEVELIZED REVENUE REQUIREMENT				11,861	16,480	

TABLE D-1 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Install clean water pipeline to pond area	11-28		4000 ft			System requires 4000 ft of 4" diameter ductile iron pipe
On-site capital		A		$47,720	$47,720	Clean water source is at power plant
Engineering overhead and fees		C		7,158	7,158	
Project contingency		E		10,976	10,976	
Process contingency		F		9,878	9,878	
Preproduction costs		H		2,227	2,227	
Inventory capital		I		380	380	
TOTAL LEVELIZED COST OF CAPITAL				14,135	14,135	
Maintenance labor		M		759	759	
Maintenance materials		N		759	759	
Overhead charges		P		228	228	
TOTAL LEVELIZED OPERATING COSTS				3,293	3,293	
TOTAL LEVELIZED REVENUE REQUIREMENTS				17,428	17,428	
Construct silo for storage of fly ash from Units 2 and 3	11-19		19,640 ft^3			Silo shall have the capacity to store the amount of fly ash produced during 2 weeks (14 days) of Units 2 and 3 operation.
On-site capital		A		126,678	126,678	
Sales tax		D		7,601	7,601	
Project contingency		E		26,856	26,856	
Process contingency		F		16,113	16,113	Silo will be 30-ft tall (28.8 ft diameter)
Preproduction costs		H		6,715	6,715	
Inventory capital		I		887	887	Pneumatic conveyor equipment: pipe length <2000 ft, fly ash transportation rate = 10 to 30 tons/hr
Land costs		K		2,750	2,750	
TOTAL LEVELIZED COST OF CAPITAL				33,794	33,794	
Operating labor		L		3,462	3,462	System requires 600 ft of pneumatic conveyor
Maintenance materials		N		10,644	10,644	Power requirement of the pump, compressor, and motor is 100 hp
Overhead charges		P		1,039	1,039	
Electricity		S		22,863	22,863	
TOTAL LEVELIZED OPERATING COSTS				57,879	57,879	
TOTAL LEVELIZED REVENUE REQUIREMENT				91,674	91,674	

TABLE D-1 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Site security	11-36					Nonhazardous:
On-site capital		A		$ 510	$ 19,868	One 15-ft long gate is needed
Engineering overhead and fees		C		128	4,967	Hazardous:
Project contingency		E		128	4,967	Site requires 2400 ft of fence, and
Preproduction costs		H		17	653	three 15-ft gates, plus 10
Inventory capital		I		1	25	signs
TOTAL LEVELIZED COST OF CAPITAL				141	5,486	
Maintenance labor		M		8	298	
Maintenance materials		N		8	298	
Overhead charges		P		2	89	
TOTAL LEVELIZED OPERATING COSTS				33	1,293	
TOTAL LEVELIZED REVENUE REQUIREMENT				174	6,779	
Construct and maintain dewatering bin for bottom ash from all 3 units	11-11					System requires two 500 ton dewatering bins and one 5000 ft^2 settling basin to handle 37,120 tons of bottom ash/yr
On-site capital		A		1,000,778	1,000,778	
Sales tax		D		12,682	12,682	
Project contingency		E		202,692	202,692	
Preproduction costs		H		103,758	103,758	Storage tank = 100,000 gal ($13,333\ ft^3$)
Inventory capital		I		1,900	1,900	
Land costs		K		35,750	35,750	Pump capacity needed for water storage tank water return pump = 24,405 gpd (17 gpm)
TOTAL LEVELIZED COST OF CAPIRAL				248,586	248,586	Minimum pumping capacity = $5(10^6)$ gpd for A_5, A_6
Operating labor		L		685,437	685,437	
Maintenance materials		N		5,800	5,800	Minimum pumping capacity = 50 gpm for A_7, A_8
Overhead charges		P		205,631	205,631	
Electricity		S		33,722	33,722	Minimum pumping capacity = 22 gpm for L_4, L_5
Variable maintenance costs		W		17,000	17,000	Minimum flow rate = 7 MGPD for S_2, S_3
TOTAL LEVELIZED OPERATING COSTS				1,758,289	1,758,289	System requires 6-1/2 acres of land
TOTAL LEVELIZED REVENUE REQUIREMENT				2,006,874	2,006,874	

TABLE D-1 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Place 6" impermeable clay-soil cover topped by 18" of soil capable of supporting vegetation	11-30		17,641,800 ft^2			Soil for cover is available on-site
On-site capital		A		$7,674,186	$7,674,186	
Engineering overhead and fees		C		1,151,128	1,151,128	
Project contingency		E		1,323,797	1,323,797	
Process contingency		F		1,014,911	1,014,911	
Preproduction costs		H		223,466	223,466	
TOTAL LEVELIZED COST OF CAPITAL				2,051,416	2,051,416	
TOTAL LEVELIZED REVENUE REQUIREMENT				2,051,416	2,051,416	
Record keeing and other administrative duties	11-1					Three worker-years are required
Operating labor		L		2,881	2,881	
TOTAL LEVELIZED OPERATING COSTS				5,433	5,433	
TOTAL LEVELIZED REVENUE REQUIREMENT				5,433	5,433	
Landscape finished cover	11-44		405 acres*			
On-site capital		A		1,096,700	1,096,700	
Engineering overhead and fees		C		109,670	109,670	
Project contingency		E		120,637	120,637	
Process contingency		F		60,318	60,318	
Preproduction cost		H		40,779	40,779	
Inventory capital		I		6,937	6,937	
TOTAL LEVELIZED COST OF CAPITAL				258,307	258,307	
Operating labor		L		773	773	
Maintenance labor		M		55,493	55,493	
Maintenance materials		N		83,240	83,240	
Overhead charges		P		16,880	16,880	
TOTAL LEVELIZED OPERATING COSTS				208,774	208,774	
TOTAL LEVELIZED REVENUE REQUIREMENT				467,081	467,081	
GRAND TOTAL LEVELIZED REVENUE REQUIREMENT				21,438,428	22,843,460	

TABLE D-2

LEVELIZED COSTS FOR WET DISPOSAL SCHEME

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Construct drain pipe from ponds to sewer	11-28		4000 ft			System requires 4000 ft of 4-ft
On-site capital		A		$260,000	$260,000	diameter reinforced concrete pipe
Engineering overhead and fees		C		39,000	39,000	Municipal sewer line is located
Project contingency		E		59,800	59,800	at or immediately adjacent to
Process contingency		F		53,820	53,820	power plant for wastewater
Preproduction costs		H		16,201	16,201	disposal
Inventory capital		I		3,447	3,447	
TOTAL LEVELIZED COST OF CAPITAL				77,993	77,993	
Maintenance labor		M		4,136	4,136	
Maintenance materials		N		4,136	4,136	
Overhead charges		P		1,241	1,241	
TOTAL LEVELIZED OPERATING COSTS				17,941	17,941	
TOTAL LEVELIZED REVENUE REQUIREMENT				95,935	95,935	
Pump supernatant water off pond and dispose of it	11-1		$2.64(10^8)$ gal			All costs are capital costs
On-site capital		A		1,178	1,178	A 15 MGPH centrifugal pump is
Project contingency		E		236	236	rented at $70/week for one week (including down time)
TOTAL LEVELIZED COST OF CAPITAL				254	254	Piping/hoses are provided with pump; drain is available
TOTAL LEVELIZED REVENUE REQUIREMENT				254	254	Supernatant doesn't need treatment
						Two operators work for one week at $13.85/hr

TABLE D-2 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Dewater waste in pond bottoms	11-1		405 acres			All costs are capital costs
On-site capital		A		$ 11,081	$ 11,081	Dewatering consists of disking harrowing, and air drying
Engineering overhead and fees		C		1,662	1,662	
Project contingency		E		2,549	2,549	A 30,000 lb motorized grader is needed for 8 weeks (4 day/pond, 2 onds, 4 times over 2 months)
TOTAL LEVELIZED COST OF CAPITAL				15,292	15,292	Ash left in pond bottoms after draining is roughly 5 or 6 in. deep
TOTAL LEVELIZED REVENUE REQUIREMENT				2,755	2,755	One operator is needed for 260 hr
Shift twice the total volume of the existing waste ash the distance from north pond to south pond	11-7		549,926 yd^3			
On-site capital		A		1,440,806	1,440,806	
Engineering overhead and fees		C		360,202	360,202	
Project contingency		E		270,151	270,151	
Preproduction costs		H		41,458	41,458	
TOTAL LEVELIZED COST OF CAPITAL				380,580	380,580	
TOTAL LEVELIZED REVENUE REQUIREMENT				380,580	380,580	
Raise pond bottoms 10 feet	11-7		6,534,000 yd^3			Common borrow is obtained off-site; haul distance = 3 miles
On-site capital		A		32,996,700	32,996,700	
Engineering overhead and fees		C		8,249,175	8,249,175	
Project contingency		E		6,186,881	6,186,881	
Preproduction costs		H		948,655	948,655	
TOTAL LEVELIZED COST OF CAPITAL				11,127,725	11,127,725	
TOTAL LEVELIZED REVENUE REQUIREMENT				11,127,725	11,127,725	
Raise dike tops 10 ft around ponds	11-14		23,358 ft			North pond is 285 acres (3105 x 4000 ft); south pond is 120 acres (2287 ft square)
On-site capital		A		5,343,445	5,343,445	
Engineering overhead and fees		C		801,517	801,517	
Project contingency		E		1,228,992	1,228,992	Clay is hauled 4 miles
Process contingency		F		1,106,093	1,106,093	On-site borrow is hauled 4000 ft
Preproduction costs		H		249,427	249,427	Previous dike was built with a 4 ft wide clay core surrounded by granular burrow; slopes are 3:1 and top is 10 ft across
Inventory capital		I		42,506	42,506	
TOTAL LEVELIZED COST OF CAPITAL				1,582,757	1,582,757	

TABLE D-2 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Operating labor		L		$ 554	$ 554	
Maintenance labor		M		340,047	340,047	
Maintenance materials		N		510,070	510,070	
Overhead charges		P		102,180	102,180	
TOTAL LEVELIZED OPERATING COSTS				1,797,076	1,797,076	
TOTAL LEVELIZED REVENUE REQUIREMENT				3,379,833	3,379,833	
Line pond bottoms	11-30		17,641,800 ft^2			Nonhazardous:
On-site capital		A		18,680,711	33,781,706	Bentonite ($25/ton) is hauled to mid-western site from Wyoming
Engineering overhead and fees		C		2,802,107	5,067,256	Hazardous:
Project contingency		E		3,222,423	5,827,344	Bottom liner = 6 in. clay-soil layer + 1 ft sand + 1 ft clay-soil bottom layer
Process contingency		F		2,470,524	4,467,631	
Preproduction costs		H		543,966	983,695	
TOTAL LEVELIZED COST OF CAPITAL				4,993,612	9,030,316	Sandy topsoil is used for leachate detection drain
TOTAL LEVELIZED REVENUE REQUIREMENT				4,993,612	9,030,316	Unit cost for Class 2 material is $123/yd^3$; Bentonite ($25/ton) is hauled to mid-western site from Wyoming; Cost of installation roughly doubled because 2 distinct bentonite liners must be placed
Construct pipeline to tie the north pond into the existing recycle line	11-28		1500 ft			Recycle line from south pond can carry recycled water from both ponds
On-site capital		A		18,090		System required 1500 ft of 8" cement pipe
Engineering overhead and fees		C		2,714		
Project contingency		E		4,161		
Process contingency		F		3,745		
Preproduction costs		H		631		
Inventory capital		I		24		
TOTAL LEVELIZED COST OF CAPITAL				5,298		

TABLE D-2 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Maintenance labor		M		$ 288		
Maintenance materials		N		288		
Overhead charges		P		86		
TOTAL LEVELIZED OPERATING COSTS				1,248		
TOTAL LEVELIZED REVENUE REQUIREMENT				6,547		
Construct two pump stations	11-32					Two pump stations are needed; each must overcome 20 ft head
On-site capital		A			$176,950	
Engineering overhead and fees		C			14,092	
Project contingency		E			57,313	
Process contingency		F			62,089	
Preproduction costs		H			9,112	
Inventory capital		I			1,552	
TOTAL LEVELIZED COST OF CAPITAL					57,799	
Maintenance labor		M			12,418	
Maintenance materials		N			18,627	
Overhead charges		P			3,725	
Electricity		S			100	
TOTAL LEVELIZED OPERATINT COSTS					65,704	
TOTAL LEVELIZED REVENUE REQUIREMENT					123,503	
Install and sample ground water monitoring well system	11-22					System requires 12 wells Wells average 60 ft deep Samples are taken annually through 10-yr post-closure period for nonhazardous scenario; semi-annually through 30-yr post-closure period for hazardous scenario
On-site capital		A		24,740	24,740	
Engineering overhead and fees		C		3,711	3,711	
Project contingency		E		4,268	4,268	
Process contingency		F		3,272	3,272	
Preproduction costs		H		8,037	8,037	
Inventory capital		I		7,317	7,317	
TOTAL LEVELIZED COST OF CAPITAL				9,242	9,242	

TABLE D-2 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Variable maintenance costs		W		$2,042	$5,644	
TOTAL LEVELIZED OPERATING COSTS				2,619	7,238	
TOTAL LEVELIZED REVENUE REQUIREMENT				11,861	16,480	
Install clean water pipeline to pond area	11-28		4000 ft			System requires 4000 ft of 4" diameter ductile iron pipe
On-site capital		A		47,720	47,720	Clean water source is at power plant
Engineering overhead and fees		C		7,158	7,158	
Project contingency		E		10,976	10,976	
Process contingency		F		9,878	9,878	
Preproduction costs		H		2,227	2,227	
Inventory capital		I		380	380	
TOTAL LEVELIZED COST OF CAPITAL				14,135	14,135	
Maintenance labor		M		759	759	
Maintenance materials		N		759	759	
Overhead charges		P		228	228	
TOTAL LEVELIZED OPERATING COSTS				3,293	3,293	
TOTAL LEVELIZED REVENUE REQUIREMENTS				17,428	17,428	
Site security	11-36					Nonhazardous:
On-site capital		A		510	19,868	One 15-ft long gate needed
Engineering overhead and fees		C		128	4,967	Hazardous:
Project contingency		E		128	4,967	Site requires 2400 ft of fence
Preproduction costs		H		17	653	and three 15-ft gates, plus 10
Inventory capital		I		1	25	signs
TOTAL LEVELIZED COST OF CAPITAL				141	5,486	

TABLE D-2 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Maintenance labor		M		$ 8	$ 298	
Maintenance materials		N		8	298	
Overhead charges		P		2	89	
TOTAL LEVELIZED OPERATING COSTS				33	1,293	
TOTAL LEVELIZED REVENUE REQUIREMENT				174	6,779	
Place 6" impermeable clay-soil cover topped by 18" of soil capable of supporting vegetation	11-30		17,641,800 ft^2			Soil for cover is available on-site
On-site capital		A		7,674,186	7,674,186	
Engineering overhead and fees		C		1,151,128	1,151,128	
Project contingency		E		1,323,797	1,323,797	
Process contingency		F		1,014,911	1,014,911	
Preproduction costs		H		223,466	223,466	
TOTAL LEVELIZED COST OF CAPITAL				2,051,416	2,051,416	
TOTAL LEVELIZED REVENUE REQUIREMENT				2,051,416	2,051,416	
Record keeping and other administrative duties	11-1					A total of 3 worker-years is required
Operating labor		L		2,881	2,881	
TOTAL LEVELIZED OPERATING COSTS				5,433	5,433	
TOTAL LEVELIZED REVENUE REQUIREMENT				5,433	5,433	
Landscape finished cover	11-44		405 acres			
On-site capital		A		1,096,700	1,096,700	
Engineering overhead and fees		C		109,670	109,670	
Project contingency		E		120,637	120,637	
Process contingency		F		60,318	60,318	
Preproduction cost		H		40,779	40,779	
Inventory capital		I		6,937	6,937	
TOTAL LEVELIZED COST OF CAPITAL				258,307	258,307	

TABLE D-2 (continued)

Subtask	Table Reference	Table Variable	Unit Quantities	Nonhazardous Total	Hazardous Total	Assumptions and Notes
Operating labor		L		773	773	
Maintenance labor		M		55,493	55,493	
Maintenance materials		N		83,240	83,240	
Overhead charges		P		16,880	16,880	
TOTAL LEVELIZED OPERATING COSTS				208,774	208,774	
TOTAL LEVELIZED REVENUE REQUIREMENT				467,081	467,081	
GRAND TOTAL LEVELIZED REVENUE REQUIREMENT				22,540,634	26,705,518	

EPRI CS-2557

Below are five index cards that allow for filing according to the four cross-references in addition to the title of the report. A brief abstract describing the major subject area covered in the report is included on each card.

EPRI

EPRI CS-2557
RP1685-2
Final Report
August 1982

Manual for Upgrading Existing Disposal Facilities

Contractor: SCS Engineers

This report presents background information and guidance to the utility engineer for upgrading waste disposal sites. Current regulatory requirements for land disposal of nonhazardous utility wastes and potential problems with land disposal are discussed. The manual describes detailed engineering data on available site upgrading techniques, and a comparative cost analysis of upgrading alternatives is also presented. 538 pp.

EPRI Project Manager: D. M. Golden

Cross-References:
1. EPRI CS-2557 2. RP1685-2 3. Heat, Waste, and Water Management Program
4. Utility Waste Disposal

ELECTRIC POWER RESEARCH INSTITUTE
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EPRI CS-2557

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HEAT, WASTE, AND WATER MANAGEMENT PROGRAM

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UTILITY WASTE DISPOSAL

EPRI

EPRI CS-2557
RP1685-2
Final Report
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INVESTIGATIONS OF COAL ASH DISPOSAL

AND

ITS IMPACT UPON GROUNDWATER

DUKE POWER COMPANY

D. P. Roche
A. Gnilka
J. E. Harwood

December 1984

Investigations of Duke Power Coal Ash Disposal and Its Impact Upon Groundwater

Executive Summary

Beginning in 1978, field and laboratory investigations of the composition of coal ash leachate and its behavior in the disposal environment were conducted by Duke Power and outside contractors. Leach tests, using EPA and ASTM protocals, were conducted on dry fly ash and bottom ash from the Allen, Belews Creek, and Marshall plants, as well as on ponded ash from all ash storage basins. All results found the concentrations of toxic metals in the ash to be non-hazardous according to the EPA criterion. Groundwater monitoring, in 13 test wells installed by Duke Power around a retired and active ash basin, found over a four-year period that drinking water quality was maintained in the wells downgradient of the sites after groundwater stabilization had occurred following well installation. Additional groundwater monitoring and soil testing from the same sites, done by an EPA contractor, also found the downgradient groundwater to be drinking water quality and suggested the high ion exchange capacity of the soil lining the ash basin to be the mechanism preventing migration of soluble metals from the ash basin. These field and laboratory studies confirm that wet disposal of coal ash by Duke Power has no significant impact on groundwater.

Investigations of Duke Power Coal Ash Disposal and Its Impact Upon Groundwater

Introduction

In 1983, the burning of 14,800,000 tons of bituminous coal at Duke Power's eight fossil stations produced 1,213,000 tons of fly ash and 409,000 tons of bottom ash. Except for 68,500 tons of fly ash (in cement and filler applications) and 51,000 tons of bottom ash (lightweight aggregate) sold that year for reuse, all of the coal ash was disposed of by sluicing to storage ponds ranging in size from 14 to 500 acres surface area. The ponds have NPDES permits for discharge of the supernatant water to receiving waters via an overflow tower. While permit effluent limitations have historically been complied with for the pond discharges to surface waters, the question of any leaching of ash constituents to groundwaters was raised in 1978 in light of the increased scrutiny by regulatory agencies. Since that time Duke Power has conducted groundwater monitoring and leachate testing to resolve this issue.

Because Duke's two largest fossil stations, Marshall and Belews Creek, are beginning conversion in 1984 from sluicing and ponding of fly ash to dry collection in silos and landfilling, the question of fly ash leachate will be less relevant to Duke as over 60% of the fly ash produced by the Company will be handled dry, compacted, and landfilled. This disposal method will greatly reduce any leaching of fly ash. However, prior to this change in disposal method, the lack of adverse effects of ash leachate even in the pond environment had been demonstrated. This report provides the results of ash leaching tests for all Duke fossil stations, and extensive and intensive groundwater monitoring at Plant Allen, conducted by Duke and by outside consultants.

Ash Leachate Analyses

The Environmental Protection Agency Extraction Procedure (May 19, 1980 Federal Register) calls for addition of distilled water equal to 16 times the weight of the solid (100 gms.), pH adjustment to 5.0 ±0.2 using 0.5 N acetic acid, and agitation for 24 hours. The sample is then filtered through a .45 micron membrane and the filtrate is diluted to 20 times the initial weight of the solid (2000 ml. for 100 gms.). The leachate is then preserved by acidification to pH 1.4 to 2.0 using nitric acid and is analyzed for eight toxic metals: arsenic, selenium, barium, cadmium, chromium, lead, mercury, and silver.

The American Society for Testing and Materials (ASTM, Committee D-34) has recommended a shaker method for extraction of solid waste for leachate analysis. The method calls for a 4:1 liquid/solid ratio and a 350 gm. solid sample, rather than the 16:1 ratio and 100 gm. sample required by EPA. The sample is shaken using a shaker table for 48 hours, with no pH adjustment. The sample is filtered and preserved as described above, but the filtrate is not diluted.

Both the Extraction Procedure (EP) and ASTM method have been used to simulate leachate from Duke fly and bottom ash, both in the dry and ponded state. These results have been compared to the EPA toxicity criterion limits for a solid waste under the Resource Conservation and Recovery Act (RCRA), which are:

Element	Concentration (ppb)
Arsenic	5,000
Selenium	1,000
Barium	100,000
Cadmium	1,000
Chromium	5,000
Lead	5,000
Mercury	200
Silver	5,000

Initially (in 1980), Duke Power analyzed samples of ponded ash (mostly bottom ash combined with some fly ash) by the EP procedure for all ash ponds. The results are shown in Table 1.

In the same time period, leach tests of dry fly and bottom ash at Belews Creek were conducted by consulting laboratories for the companies marketing the ash for reuse. Southeast Laboratories used the EP procedure to obtain the following results (in ppb) for bottom ash:

Table 1. Extraction Procedure Analysis of Ponded Ash from Duke Power Ash Basins. Samples collected in 1980.

All concentrations are in parts per billion.

	Allen	Belews	Buck		Cliffside	Dan River		Lee	Marshall	Riverbend	
			Cell 1	Cell 2		Cell 1	Cell 2			Cell 1	Cell 2
Arsenic	51	31	35	35	36	33	73	22	31	82	75
Barium	1200	1,100	2400	2200	1900	1300	2100	<1000	1100	1100	1300
Cadmium	<25	30	<25	<25	<25	<25	<25	<25	<25	<25	<25
Chromium	10	70	50	50	60	30	80	100	70	20	60
Lead	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
Mercury	0.11	0.11	0.2	0.18	0.44	2.2	0.17	2	<0.1	<0.1	<0.1
Selenium	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
Silver	150	50	110	90	30	70	60	100	70	30	40

Arsenic	1.4
Barium	50
Cadmium	5
Chromium	20
Lead	10
Mercury	0.5
Selenium	0.8
Silver	10

The Georgia Institute of Technology also analyzed Belews Creek bottom ash for radionuclides and found 2.4 pCi/g Radium-226, which is well below the proposed EPA limit of 5 pCi/g.

Raba-Kistner Consultants performed both the EP and ASTM leach tests on Belews Creek fly ash. The results are shown in Table 2.

Also in 1980, as part of an ash pond investigation conducted by EPA (the A. D. Little, Inc., study) at Plant Allen, samples of dry ash from Units 1 and 3 were analyzed utilizing the EP. The results are shown in Table 3, along with a Ra-226 activity of 4.3 (Unit 1) and 4.2 (Unit 3) pCi/g.

Plant Allen fly ash, bottom ash, and coal were also tested in 1982 in a U. S. Department of Energy study by Versar, Inc. Samples were processed according to both the EP and ASTM methods. Duke split samples with Versar and did its own EP and ASTM leach tests for comparison. The DOE test results are shown in Table 4, and Duke's are given in Table 5.

Table 2. BELEWS CREEK

FLY ASH LEACHATE (ppb)

	ASTM	EPA EP	EPA Limits
pH	3.7	4.0	
Arsenic	500	<5	5,000
Barium	Not Determined	<500	100,000
Cadmium	100	<100	1,000
Chromium	115	<100	5,000
Cobalt	100	<100	
Copper	2050	600	
Iron	2000	300	
Lead	<1000	<1000	5,000
Manganese	200	100	
Mercury	Not Determined	<2	200
Nickel	300	200	
Selenium	50	<10	1,000
Silver	Not Determined	<100	5,000
Zinc	1050	300	

Source: Raba-Kistner Consultants

Table 3. Extraction Procedure Results for Plant Allen Fly Ash

RESULTS FROM INITIAL SAMPLE ANALYSES

SAMPLE INFORMATION

Utility Name: Duke Power
Plant Name: Plant Allen
Plant Location: Gaston, N.C.
Type of Sample: Fly Ash
Sampling Location: Unit 1, ESP
Date Sampled: July 16, 1980

RESULTS

Basis: These results are from analyses performed by Arthur D. Little, Inc. on grab samples obtained during the first visit to the site. The limitation on the confidence levels for both sampling and analyses are noted in the accompanying cover letter.

Concentrations of Elements Measured in EPA Extraction Procedure (Ref: Fed. Register, Vol. 45, (May 19, 1980), pp. 33127-33131)

Element	Concentration (microgram/L extract)
Arsenic	98±20
Barium (mg/L)	0.51±0.16
Cadmium	16±3
Chromium	<8
Lead	<1
Mercury	<2
Selenium	52±7
Silver	<2

Activities of Radioisotopes Measured In Solid Samples Ref: Fed. Register, Vol. 43, Dec. 18, 1978, pp. 59022-3; see cover letter for experimental details)

Isotope	Specifc Activity (picocurie/gram)
Radium-226	4.3±0.3

Table 3. (cont'd)

RESULTS FROM INITIAL SAMPLE ANALYSES

SAMPLE INFORMATION

Utility Name: Duke Power
Plant Name: Plant Allen
Plant Location: Gaston, N.C
Type of Sample: Fly Ash
Sampling Location: Unit 3
Date Sampled: July 16, 1980

RESULTS

Basis: These results are from analyses performed by Arthur D. Little, Inc. on grab samples obtained during the first visit to the site. The limitation on the confidence levels for both sampling and analyses are noted in the accompanying cover letter.

Concentrations of Elements Measured in EPA Extraction Procedure (Ref: Fed. Register, Vol. 45, (May 19, 1980) pp. 33127-33131)

Element	Construction (microgram/L extract)
Arsenic	63±10
Barium (mg/L)	0.36±0.16
Cadmium	5±3
Chromium	<8
Lead	<1
Mercury	<2
Selenium	8±2
Silver	<2

Activities of Radioisotopes Measured In Solid Samples Ref: Fed. Register, Vol. 43, Dec. 18, 1978 pp. 59022-3; see cover letter for experimental details)

Isotope	Specific Activity (picocurie/gram)
Radium-226	4.2±0.4

Table 4. Extraction Procedure and ASTM Leach Test Results (ppb) for Plant Allen Coal, Fly Ash, and Bottom Ash - Department of Energy Study

Sample	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
Coal								
EP	<10	270	<0.5	1.1	1.6	<.05	33	<.05
ASTM	41	310	<0.5	1.0	4.3	<.05	<10	.8
Fly Ash-Unit 2								
EP	460	230	<0.5	1.1	1.6	.19	150	<.05
ASTM	100	330	1.1	90	6.5	.53	94	1.3
Fly Ash-Unit 5								
EP	310	210	1.7	<1.0	3.7	<.05	19	<.05
ASTM	180	480	1.2	90	6.5	<.05	40	.42
Bottom Ash-Unit 5								
EP	12	660	<0.5	<1.0	<1.0	<.05	10	<.05
ASTM	10	260	1.4	<1.0	<1.0	<.05	10	<.05

Table 5. ALLEN LEACHATE STUDY - Duke Power Results

Sample Description	Arsenic ppb	Arsenic mg/g	Barium* ppb	Barium* mg/g	Cadmium ppb	Cadmium mg/g	Chromium ppb	Chromium mg/g
Flyash, unit #2								
EPA #1	269.3	4.08×10^{-3}	219.83	3.33×10^{-3}	3.96	6.00×10^{-5}	4.97	7.54×10^{-5}
EPA #2	274.1	4.28×10^{-3}	228.43	3.56×10^{-3}	3.41	5.32×10^{-5}	7.61	1.19×10^{-4}
ASTM #1	72.74	2.68×10^{-4}	266.03	9.80×10^{-4}	7.76	2.86×10^{-5}	119.08	4.39×10^{-4}
ASTM #2	91.9	3.33×10^{-4}	211.13	7.65×10^{-4}	1.36	4.93×10^{-6}	126.02	4.57×10^{-4}
Flyash, unit #5								
EPA #1	417.9	6.62×10^{-3}	268.93	4.26×10^{-3}	5.95	9.43×10^{-5}	16.63	2.64×10^{-4}
EPA #2	441.9	6.89×10^{-3}	433.93	6.77×10^{-3}	6.49	1.01×10^{-4}	14.41	2.25×10^{-4}
ASTM #1	254.9	9.05×10^{-4}	332.53	1.18×10^{-3}	0.45	1.60×10^{-6}	85.77	3.04×10^{-4}
ASTM #2	202.2	8.17×10^{-4}	300.93	1.07×10^{-3}	1.21	4.29×10^{-6}	80.22	2.85×10^{-4}
Bottom ash, unit #5								
EPA	<2.0	$<3.07 \times 10^{-5}$	46.37	7.10×10^{-4}	<0.20	$<3.07 \times 10^{-6}$	<0.50	$<7.68 \times 10^{-6}$
ASTM	5.84	1.92×10^{-5}	98.33	3.24×10^{-4}	0.36	1.18×10^{-6}	<0.50	$<1.64 \times 10^{-6}$
Coal								
EPA #1	<2.0	$<3.12 \times 10^{-5}$	40.53	6.33×10^{-4}	0.20	3.12×10^{-6}	0.53	8.28×10^{-6}
EPA #2	<2.0	$<3.18 \times 10^{-5}$	46.23	7.36×10^{-4}	0.29	4.61×10^{-6}	<0.50	$<7.95 \times 10^{-6}$
ASTM #1	<2.0	$<7.52 \times 10^{-6}$	141.73	5.33×10^{-4}	0.72	2.71×10^{-6}	<0.50	$<1.88 \times 10^{-6}$
ASTM #2	<2.0	$<7.65 \times 10^{-6}$	170.93	6.54×10^{-4}	0.97	3.71×10^{-6}	0.67	2.56×10^{-6}

*Corrected for filter blank.

Table 5. ALLEN LEACHATE STUDY (CONT'D)

Sample Description	Lead ppb	Lead mg/g	Mercury ppb	Mercury mg/g	Silver ppb	Silver mg/g	Selenium ppb	Selenium mg/g
Flyash, unit #2								
EPA #1	<1.0	$<1.52 \times 10^{-5}$	<0.1	$<1.52 \times 10^{-6}$	0.51	7.73×10^{-6}	68.74	1.04×10^{-3}
EPA #2	<1.0	$<1.56 \times 10^{-5}$	<0.1	$<1.56 \times 10^{-6}$	0.11	1.72×10^{-6}	69.12	1.08×10^{-3}
ASTM #1	<1.0	$<3.68 \times 10^{-6}$	<0.1	$<3.68 \times 10^{-7}$	1.48	5.45×10^{-6}	426.60	1.57×10^{-3}
ASTM #2	<1.0	$<3.63 \times 10^{-6}$	<0.1	$<3.63 \times 10^{-7}$	0.62	2.25×10^{-6}	445.30	1.61×10^{-3}
Flyash, unit #5								
EPA #1	<1.0	$<1.58 \times 10^{-5}$	<0.1	$<1.58 \times 10^{-6}$	0.56	8.88×10^{-6}	<5.0	$<7.92 \times 10^{-5}$
EPA #2	<1.0	$<1.56 \times 10^{-5}$	<0.1	$<1.56 \times 10^{-6}$	0.28	4.37×10^{-6}	<5.0	$<7.80 \times 10^{-5}$
ASTM #1	<1.0	$<3.55 \times 10^{-6}$	<0.1	$<3.55 \times 10^{-7}$	0.45	1.60×10^{-6}	13.60	4.83×10^{-5}
ASTM #2	<1.0	$<3.55 \times 10^{-6}$	<0.1	$<3.55 \times 10^{-7}$	0.39	1.38×10^{-6}	13.97	4.96×10^{-5}
Bottom ash, unit #5								
EPA	<1.0	$<1.54 \times 10^{-5}$	<0.1	$<1.54 \times 10^{-6}$	0.68	1.04×10^{-5}	<5.0	$<7.68 \times 10^{-5}$
ASTM	<1.0	$<3.29 \times 10^{-6}$	<0.1	$<3.29 \times 10^{-6}$	1.19	3.92×10^{-6}	11.74	3.86×10^{-5}
Coal								
EPA #1	<1.0	$<1.56 \times 10^{-5}$	<0.1	$<1.56 \times 10^{-6}$	0.11	1.72×10^{-6}	8.01	1.25×10^{-4}
EPA #2	<1.0	$<1.59 \times 10^{-5}$	<0.1	$<1.59 \times 10^{-6}$	0.45	7.16×10^{-6}	6.90	1.10×10^{-4}
ASTM #1	<1.0	$<3.76 \times 10^{-6}$	<0.1	$<3.76 \times 10^{-7}$	0.11	4.14×10^{-7}	26.27	9.88×10^{-5}
ASTM #2	<1.0	$<3.83 \times 10^{-6}$	<0.1	$<3.83 \times 10^{-7}$	0.22	8.42×10^{-7}	26.27	1.01×10^{-4}

In 1983, Duke Power tested dry fly ash and bottom ash from Plant Marshall by the EP method (Table 6).

Table 6. Location: Marshall Steam Station
Flyash and Bottom Ash
Toxicity Leach (Extraction Procedure)
Date: 9/23 & 29/83

Location Description

(Concentration)

	Arsenic µg/1	Barium mg/1	Cadmium mg/1	Chromium mg/1	Lead mg/1	Mercury µg/1	Selenium µg/1	Silver mg/1
Flyash 1-A 09-23-83	82	0.26	<0.014	<0.02	<0.14	<0.1	166	<0.012
Flyash 1-B 09-23-83	89	0.16	<0.014	<0.02	<0.14	<0.1	166	0.017
Bottom Ash 2-A 09-29-83	118	0.062	<0.014	0.18	<0.14	<0.1	3.8	0.017
Bottom Ash 2-B 09-29-83	75	0.074	<0.014	<0.02	<0.14	<0.1	4.1	0.014

Duke Power Groundwater Monitoring

A monitoring program more extensive than that required by RCRA has been in progress at the Allen Steam Station since 1978. This in-house program was designed to evaluate the performance of Duke's ash basins, and their effect on groundwater movement and water quality. Additional Information: Duke's Ash Basin Equivalency Demonstration, EPA's Fossil-Fired Exemption (Dietrich Letter), EPRI Report - Codisposal of Liquid and Solid Wastes from a Typical Coal-Fired Generating Unit.

The objectives of this monitoring program were:

1. Provide data for documenting the condition/quality of groundwater at the ash basin site;

2. Predict and assess the effects of ash basin leachates on the physical and chemical quality of adjacent groundwater;

3. Determine the projected length of time that a typical ash basin substrate can retain leachates; and

4. Predict/calculate the life expectancy of an ash basin with respect to ion exchange capabilities of underlying soils.

Results of this study will be used to:

1. Have groundwater quality data from our service area which may be quite different from the limited studies EPA will use for formulating regional/national groundwater quality standards for industrial waste ponds (i.e., ash basins, resin basins);

2. Participate at the state or regional level in the development of groundwater quality standards and resulting legislation; and

3. Address any future groundwater legislation by means of a strong technical data base such as was done with the Ash Basin Equivalency Demonstration.

Ash Basin History

Allen station is a five-unit, 1140 MW coal-fired steam plant located on Lake Wylie in North Carolina. Mill tailings, bottom ash, and fly ash derived from the processing and burning of coal are pumped via ash slurry lines to a series of ash basins. Development of the ash disposal site (Figure 1) began with area A, which first received fly ash from the plant in the late 1950s.

Area B contains ash that was dredged from area A in the early 1970s. In 1972-73, it was covered with 30-60 cm of earth fill and planted with a ground cover. Currently, ash sluiced from the plant is pumped directly to the ash basin designated as area C. The series of dikes around this area were completed in 1973 and the basin has been operational since then.

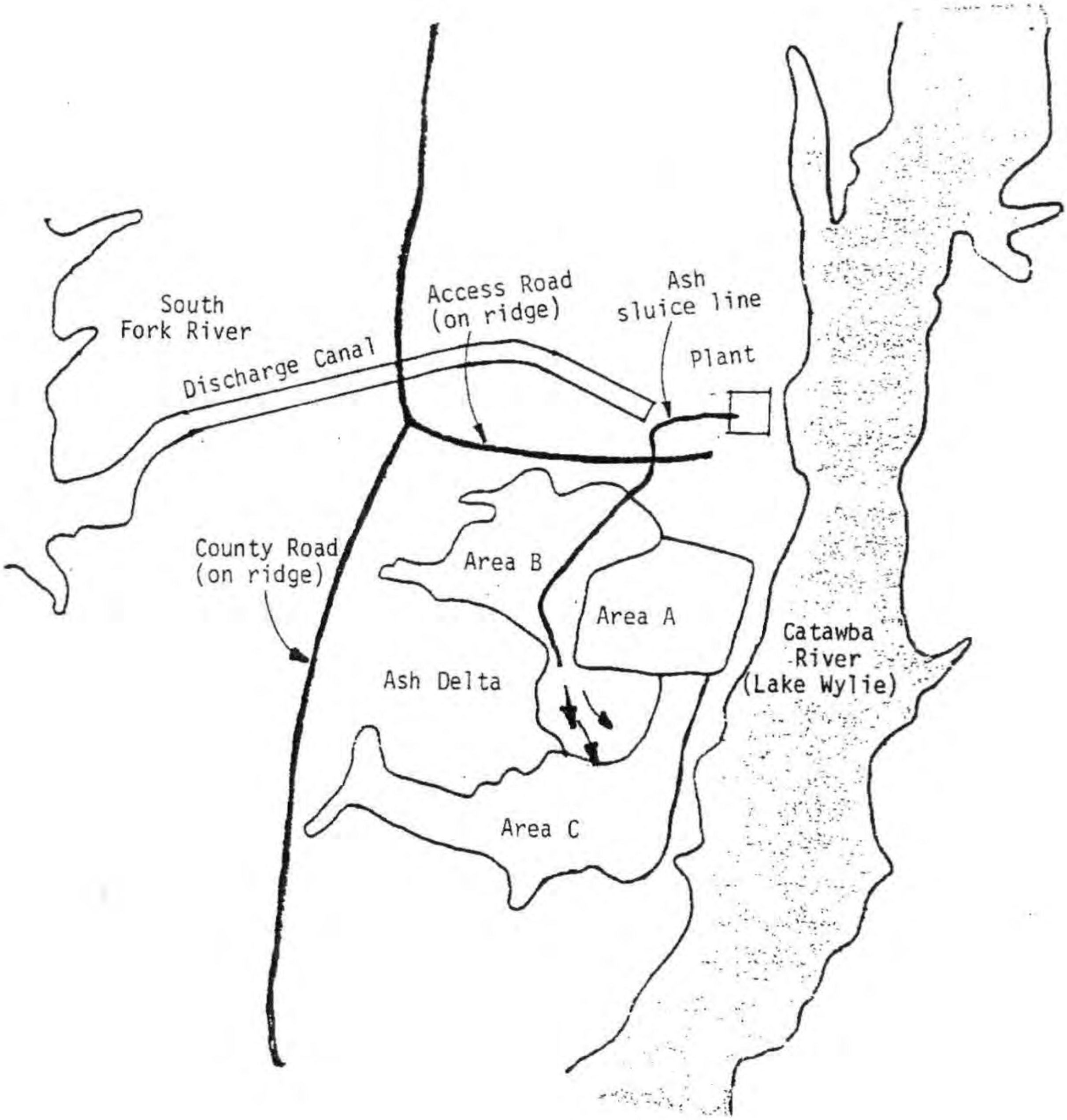

FIG. 1 - ALLEN ASH DISPOSAL SITE

These three areas typify the ash storage extremes that may exist around a steam station during the typical cycle of ash basin utilization and reclamation: stored ash generated in the plant's early days; dredge material less than 10 years old with limited reclamation; and currently generated ash. Note that the prevailing direction of movement of the groundwater is toward the river, as indicated by topographic relief in the plant vicinity (Figure 2). The series of ash basins are placed so that groundwater infiltration into the deeper acquifer is negligible, if not totally precluded. Additional Information: Allen Revegetation Study.

Well Construction

a. Layout-Physical Location/Site

Wells were located on the site based on an examination of available geological/historical/groundwater information. Field surveys were then conducted to select final well locations based on: 1) accessibility by drill rigs, 2) accessibility by well monitoring personnel, 3) placement in area which will not be disturbed by routine plant activities, 4) placement in areas not affected by future modifications of basin, 5) avoidance of unsuitable physical features, i.e., culverts, rock fill, avoid excessive clearing. The final well locations are indicated on Figure 2. Additional Information: Groundwater Monitoring Program.

b. Boring Logs

Extensive records were maintained to document all aspects of the actual well emplacement. Information included in the boring logs includes: date, well number, field, depths for sampling, soil field classification, general drilling procedures. Additional Information: See field logs of boring logs, Personal Communication: Jocassee Soils Lab; Construction personnel, DE Geologist, DE Civil Soils Engineers, Bowser-Morner, Law Engineering, Haley and Aldrich.

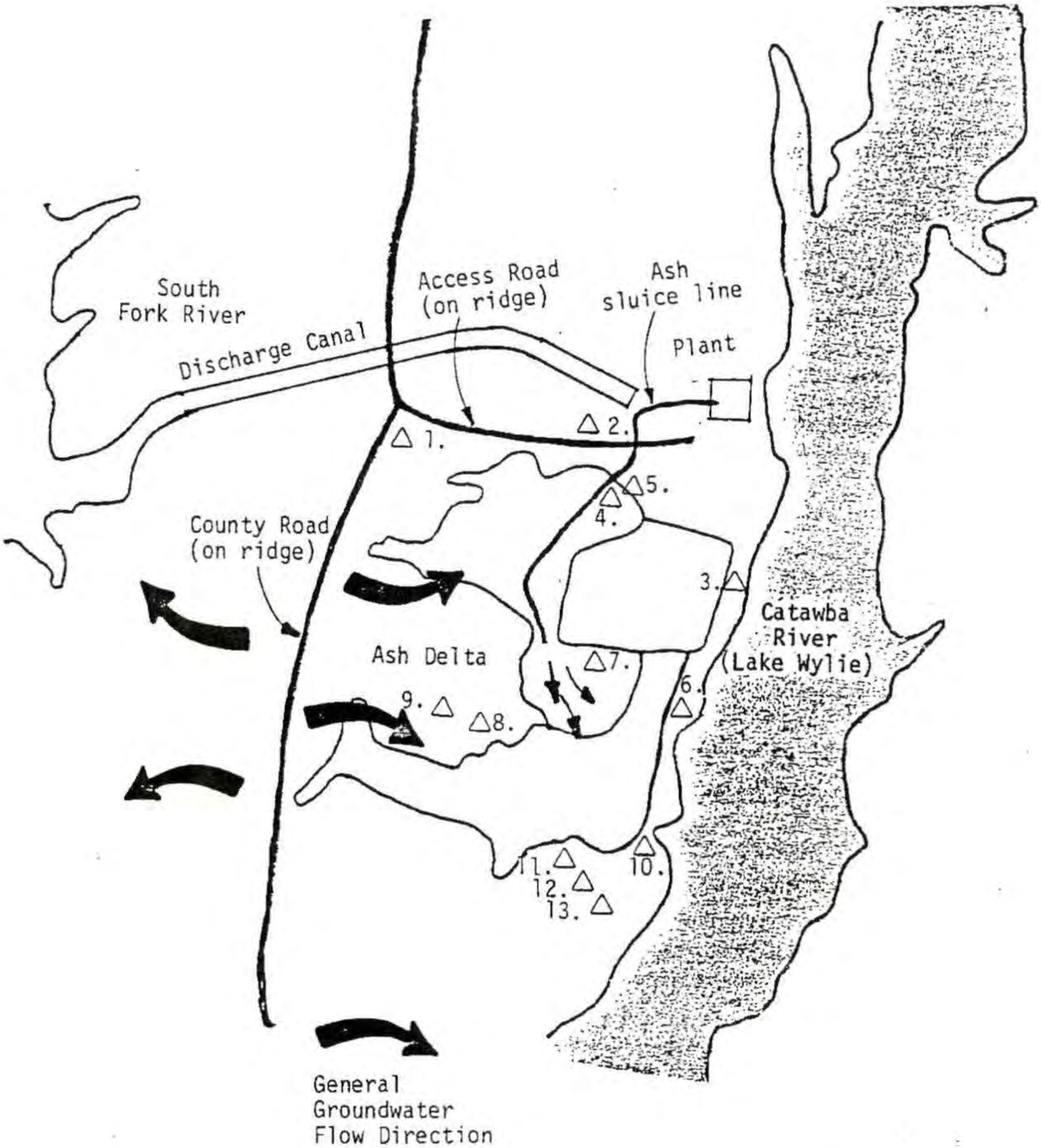

FIG. 2. - SAMPLING WELL LOCATIONS AT PLANT ALLEN

c. Soil Analyses

Soil analyses were conducted by the Jocassee Soils Laboratory. Additional Information: Results from Soils Lab are contained in separate appendix and include soil particle size analysis, grain size distribution, moisture, calculated permeabilities and soil descriptions. Results were discussed with Soil Lab personnel, Civil Engineering personnel, DE geologist, Haley and Aldrich, Weston, Inc., EPRI.

Well Design

a. Air Lift Sampler

The gas lift sampler (Figure 3) consists of two plastic tubes. The smaller tube (1/4 in. OD) supplies pressurized nitrogen from a regulated source to the discharge hole at the bottom of the gas line; the larger one (3/4 inc. OD) returns a gas-water mixture to the surface.

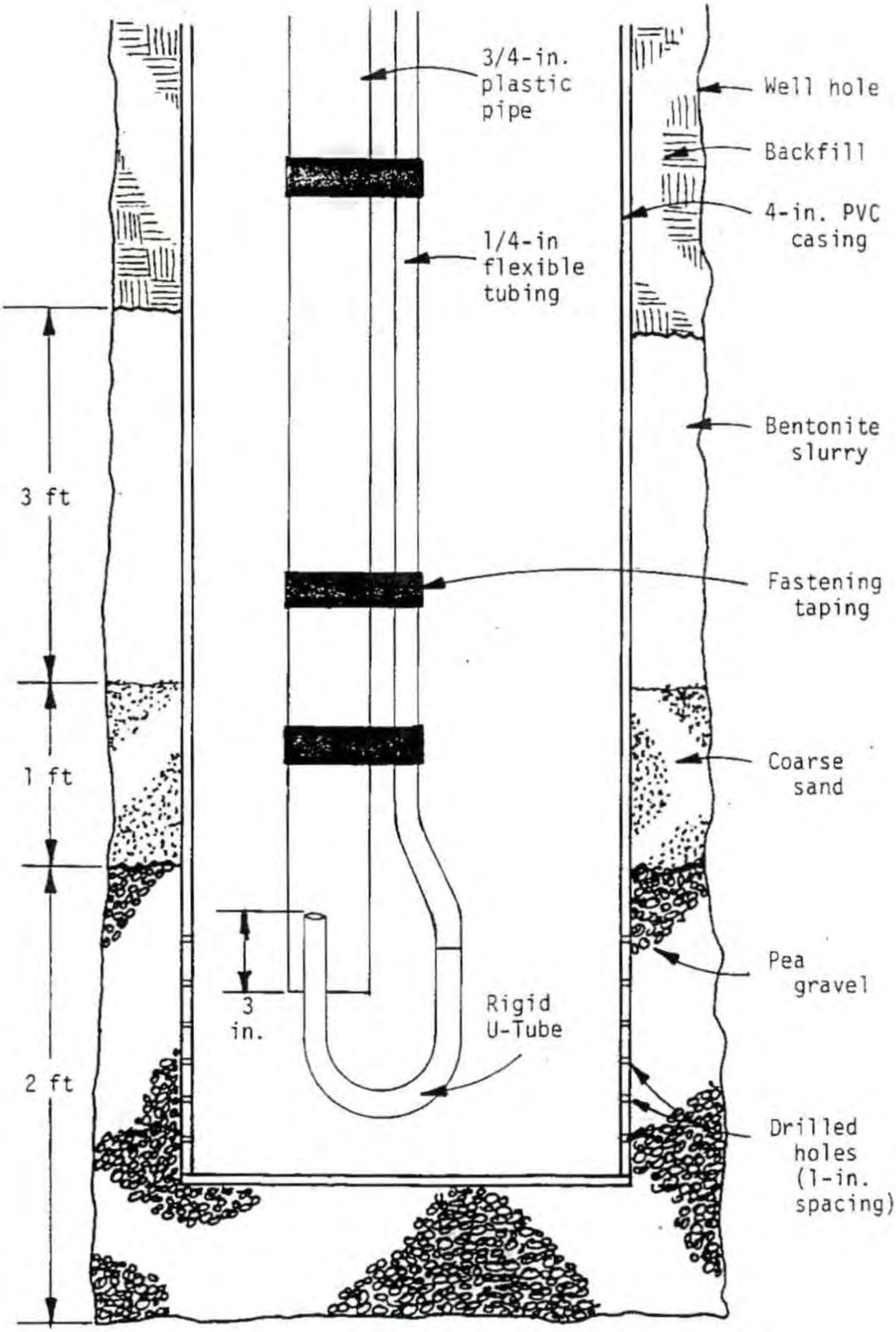

Figure 3. Schematic Diagram of gaslift sampler.

This assembly, constructed of PVC material, is inserted into a 4 inch PVC casing. The nitrogen feed line is connected to the inflow fixture and the gas is permitted to flow at a rate that produces the optimal water flow at the discharge tube. Samples are taken directly from the discharge tube opening.

b. Function of Wells

Table 7 lists the wells, general information and its function - control or monitoring. Additional information: Well installation log; surveyors log, site layout, soil boring data, general soils information, discussions with DE geologists, Civil Engineering personnel, Soils Laboratory personnel.

c. General Well Construction

All wetable surfaces of the well and associated piping and tubing were made of plastic to minimize potential metal contamination. Further details of well construction are contained in the air lift sampler description.

Sampling Procedure

a. Well Stabilization

Well installation was completed by February, 1978, and the wells were pumped using nitrogen on a weekly basis through April, 1978. This procedure ensured that drilling-related disturbances in the soil strata

Table 7. Function, location, and design details of wells.*

Well No.	Depth, ft.	Function and specifications
1	66	Control (to provide hydrological and chemical background data)
2	52	Control (same as well 1)
3	32	Monitoring; river side of old ash-basin dike, below perched-water table (nearest depth for ample groundwater volume)
5	47	Monitoring; finished to about 30 ft. below well 4
6	30	Monitoring; river side of new ash-basin dike, below perched-water table
7	43	Monitoring; on peninsula in new ash basin, finished below perched-water table
8	50	Control; northwest corner of new basin, finished below perched-water table
9	50	Control; farther west than well 8, below perched-water table
10	20	Monitoring; river side of dike of new ash-basin discharge
11	46	Monitoring; river side of south dike of new basin, sufficiently below table for ample groundwater sample
12	43	Monitoring; south and 30 ft. downgradient of well 11
13	40	Monitoring; south and 30 ft. downgradient of well 12

*Well #4 discontinued because of rerouting of ash discharge resulted in permanent lowering of water table.

had stabilized and that all water used during drill operations had been removed from the wells and surrounding soils. Conductivity measurements and spot sampling conducted during this period indicated that the wells had stabilized and a full-scale monthly sampling program was initiated.

b. Sampling Protocol

Wells were allowed to recharge prior to sampling (two-day survey) which eliminated any minor contamination from surface water infiltration, and ensured removal of waters that might be affected by different oxidation/reduction regimes as a result of exposure to the atmosphere. When these waters were removed, a more representative groundwater sample would be taken.

Although sampling initially consisted of monthly analyses, so little change was detected that quarterly sampling was deemed adequate. It should be noted, however, that in shallow wells - less than 3 m - the temperature was observed to change seasonally, even though the major chemical parameters showed no discernible trend. The procedure required that each well be pumped/sampled on two consecutive days. The wells were pumped to the lowest level possible on the first day, allowed to recharge for 24 hours, and then re-sampled. Temperature, pH, conductivity, and water level were measured in the field. Additional information: Groundwater Monitoring Program.

Analytical Procedure

a. Trace Metals

Composite samples were collected for laboratory analysis for the following: arsenic, cadmium, chromium, manganese, sodium, nickel, and zinc. The samples were put on ice and then brought to the lab where they were passed through a 0.45 µ filter (soluble fraction), transferred to acid washed glass bottles, and then acidified to a pH of approximately 2.0 with nitric acid. The maximum time between sample collection and completion of sample preservation was four hours.

The routine sample analysis consisted of calcium, chloride, magnesium, nitrate, potassium, sodium, sulfate, arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium and arsenic. Additional information: Sample study design, raw data sheets, various summaries in files.

b. Field Measurements

Sampling procedure for the field was as follows:

1) The depth to water in a monitoring well was measured using a volt-meter with calibrated coax cable and the value recorded on data sheets.

2) The 3/4 inch PVC tubing permanently mounted inside the 4 inch PVC casing was adjusted to a desirable pumping depth and this depth was recorded on field data sheets.

3) Pumping was started and the conductivity (μ mhos/cm^2) of the discharge water was monitored by a specific conductance bridge. The values for specific conductance at selected pumping times were recorded on a well pumping data sheet.

4) When conductivity reached a constant value, the temperature and pH of the discharge water were measured and values recorded on data sheets.

5) All field instruments were calibrated in the laboratory.

Summary of Analytical Results

The presence of leachate in the test wells was determined by comparing the concentration of substances present with those in the control wells and with the dissolved constituents in the old and new ash basins. Conductivities above 100 μmhos and calcium concentrations exceeding 8 mg/l were taken to indicate the presence of leachate. On this basis, wells 3, 4, and 11 were judged to be situated in the leachate plume.

For the first two years of data analyzed, the highest conductivity recorded for the control wells was 98 μmhos. By comparison, the lowest conductivity for the test wells in the plume was 180 μmhos. Average calcium concentration measured in the control wells was 2.62 mg/l, whereas the average for test wells 3, 4, and 11 was 54.5 mg/l. The elevated calcium levels were probably associated with the leading edge of the plume.

With the possible exception of test well 12, none of the other test wells appeared to be in the leachate plume. As shown in Figure 4, wells 11, 12 and 13 were situated on a hill sloping down to the river. Although well 11 is definitely situated in the plume, as mentioned, well 13 is not, because none of the parameters measured there exceeded those at the control wells. Well 12 is questionable, however, with average magnesium concentrations (2 mg/l) intermediate between those wells 11 and 13.

The concentration of trace elements in the control and test wells for the entire study is provided in Table 8, giving the single highest and lowest values recorded. For comparison, the table includes Interim Primary Drinking Water Standards.

As noted, minimum concentrations are generally near or at the detection limit of the instrumentation. In all cases, the minimum concentrations were less than the Interim Drinking Water Standards. Maximum values were observed during the early portion of the sampling period when water quality within the well was still influenced by the drilling process. Well No. 4 located at the ash/clay interface became dry during the last 2 years of the study because of

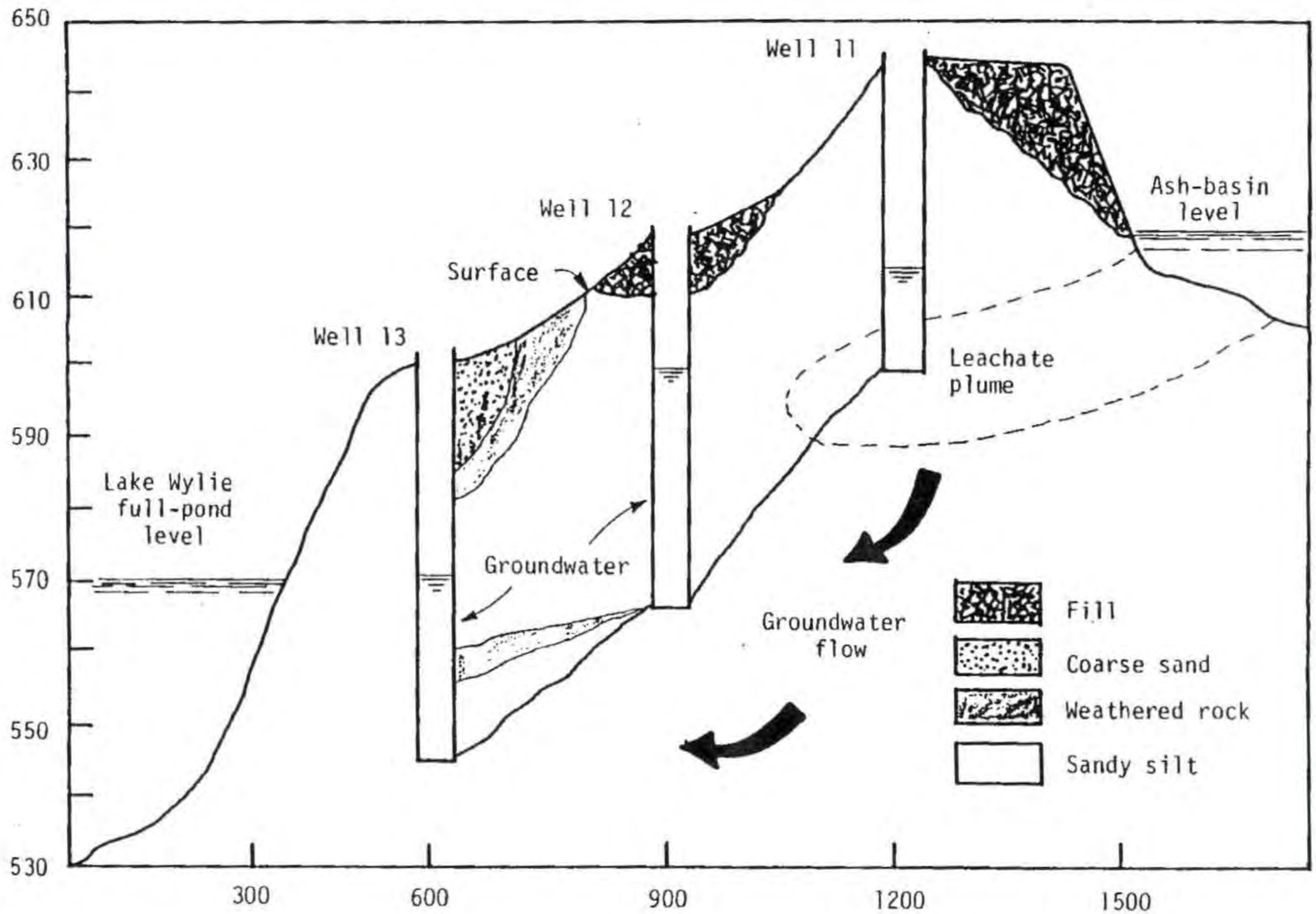

Figure 4. Horizontal movement of leachate plume is tracked over long term using calcium and conductivity data at wells 11, 12, and 13, placed downgrade from basin and each other

Table 8. Maximum - Minimum Concentrations (ppb) measured during groundwater sampling during 1979 - 1982 at Allen Steam Station.

Well No.	As Min - Max	Cd Min - Max	Se Min - Max	Cr Min - Max	Cu Min - Max	Ni Min - Max	Zn Min - Max
1	1.2 - <2.0	<0.2 - 0.3	<5.0 - 6.0	<0.5 - <20.0	<1.0 - <20.0	<5.0 - <20.0	1.2 - <20.0
2	2.0 - 6.5	0.7 - 1.1	<5.0 - 12.0	<0.5 - 90.0	1.8 - <10.0	<5.0 - 20.0	10.0 - 36.0
3	<2.0 - 9.2	<0.2 - 8.5	<5.0 - 8.5	<0.5 - 10.0	<10.0 - 30.0	<5.0 - 10.0	<1.0 - 70.0
4	8.8 - 112.5	<0.2 - 7.0	<5.0 - 19.5	<0.5 - 10.0	<1.0 - <10.0	<5.0 - 40.0	<1.0 - 80.0
5	<2.0 - 8.0	<0.2 - 7.0	<5.0 - 5.8	<0.5 - 20.0	<1.0 - <10.0	40 - 68.0	48 - 50
6	<2.0 - 2.0	<0.2 - 2.0	** - <5.0	0.7 - 10	<1.0 - <10.0	<5.0 - 20.0	4.1 - 20.0
7	<2.0 - 4.5	<0.2 - 3.5	<5.0 - 5.5	<0.5 - 10	<1.0 - <10.0	<5.0 - 10.0	11.0 - 20.0
8	<2.0 - 5.6	<0.2 - 15.0	** - <5.0	<0.5 - 20	<1.0 - <10.0	<5.0 - 10.0	1.7 - 20.0
9	1.3 - <2.0	<0.1 - *	** - <5.0	<0.5 - <20	<1.0 - <20.0	<5.0 - <20.0	<1.0 - <20.0
10	<2.0 - 6.8	7.6 - 19.0	<5.0 - 12.0	<0.5 - <20	<1.0 - <10.0	<5.0 - <10.0	8.0 - 20.0
11	<2.0 - 6.9	<0.2 - 7.7	<5.0 - 12.0	1.9 - 20	1.2 - 20.0	<5.0 - 20.0	6.6 - 90.0
12	<2.0 - 3.4	<0.2 - 7.0	<5.0 - 8.5	<0.5 - 20	<1.0 - <10.0	<5.0 - 10.0	11.0 - 30.0
13	<2.0 - 5.1	<0.2 - 2.8	<5.0 - 11.5	1.6 - 50	2.1 - 10.0	<5.0 - <10.0	2.2 - 30.0
EPA[1]	50	10	10	50	1000	NC[2]	5000

1- EPA Interim Primary Drinking Water Standards
2- No criterion
* - One sample only
** - Detection limit changed from <1.0 to <5.0

rerouting of ash sluice lines in the area. Consequently, these data reflect the quality of interstitial water in the ash pond rather than the actual groundwaters.

Environmental Protection Agency Contract No. 68-02-3167:
Characterization and Environmental Monitoring of Full Scale
Utility Waste Disposal Sites

Prime Contractor: Arthur D. Little, Inc.

Geotechnical Subcontractor: Bowser-Morner Testing Laboratories, Inc.

Chemical Analysis Subcontractor: TRW, Inc.

The purpose of this program was to obtain information to enable promulgation of federal regulations under RCRA for the storage, treatment, and disposal of coal ash and flue gas desulfurization sludge.

The study involved geohydrologic and ground water quality investigations at six utility waste sites. Soil borings were performed to take split spoon and Shelby tube samples and to install test wells. Flush joint, steel casing (4 inch ID) borings, using wash-boring techniques, were employed. Soil samples were obtained at 5 ft. intervals, with the split-spoon sampler used to determine Standard Penetration. Wells consisted of 2 in. ID, Schedule 80 PVC pipe with slotted well points surrounded to 5 ft. above the point with Ottawa sand. The casings were backfilled with sand, cement grouted at ground surface, and completed with a 3 ft. stand pipe with vented locking cap. Samples of dry fly ash were also taken for leachate analysis.

The Plant Allen site was selected as being representative of the Piedmont region and the combined ponding of fly and bottom ash. The site was also selected to investigate Duke Power's practice of treating boiler cleaning waste in the ash basin.

The geology of the Allen site was found to consist primarily of residual (silty clay with low organic content) soils with some very localized alluvial deposits from former surface drainage areas. The original groundwater table was located at a maximum depth of 33 ft. Groundwater flow was found to be 5 X 10^5 m^3/yr. The A. D. Little subcontractors decided upon 12 test wells to characterize the retired and active ash basins, in locations similar to those selected by Design Engineering for the Duke study. Two background wells (3-4 and 3-4A) were located upgradient from DP well #8, and seven downgradient wells were installed. Well 3-5 was placed near DP #11, Wells 3-6A and B near DP #10, Well 3-7 further upriver, Well 3-9 and 3-8A near DP #6 and Well 3-8 upriver and downgradient of the dike separating the retired and active basins. Well 3-1 was located within the retired pond and Wells 3-2 and 3-3 were placed in the active pond. Well 3-2 sampled the water in the ash at the bottom of the pond. In addition, the toe drains of the active pond dike were designated 3-10, 3-11, and 3-12, and the pond NPDES discharge was designated 3-13. The sampling locations are shown in Figure 5. All wells were flushed after installation and were subsequently sampled by peristaltic pump. Groundwater sampling occurred in February and March 1981 and in July 1982. Samples of boiler cleaning waste were taken during the cleaning of Allen #4 in November 1981.

Groundwater samples were analyzed by Inductively Coupled Argon Plasma emission spectroscopy, except for analysis of arsenic and selenium by hydride evolution atomic absorption and analysis of sulfate (and five other anions) by ion chromatography. Data for some selected parameters are shown in Table 9

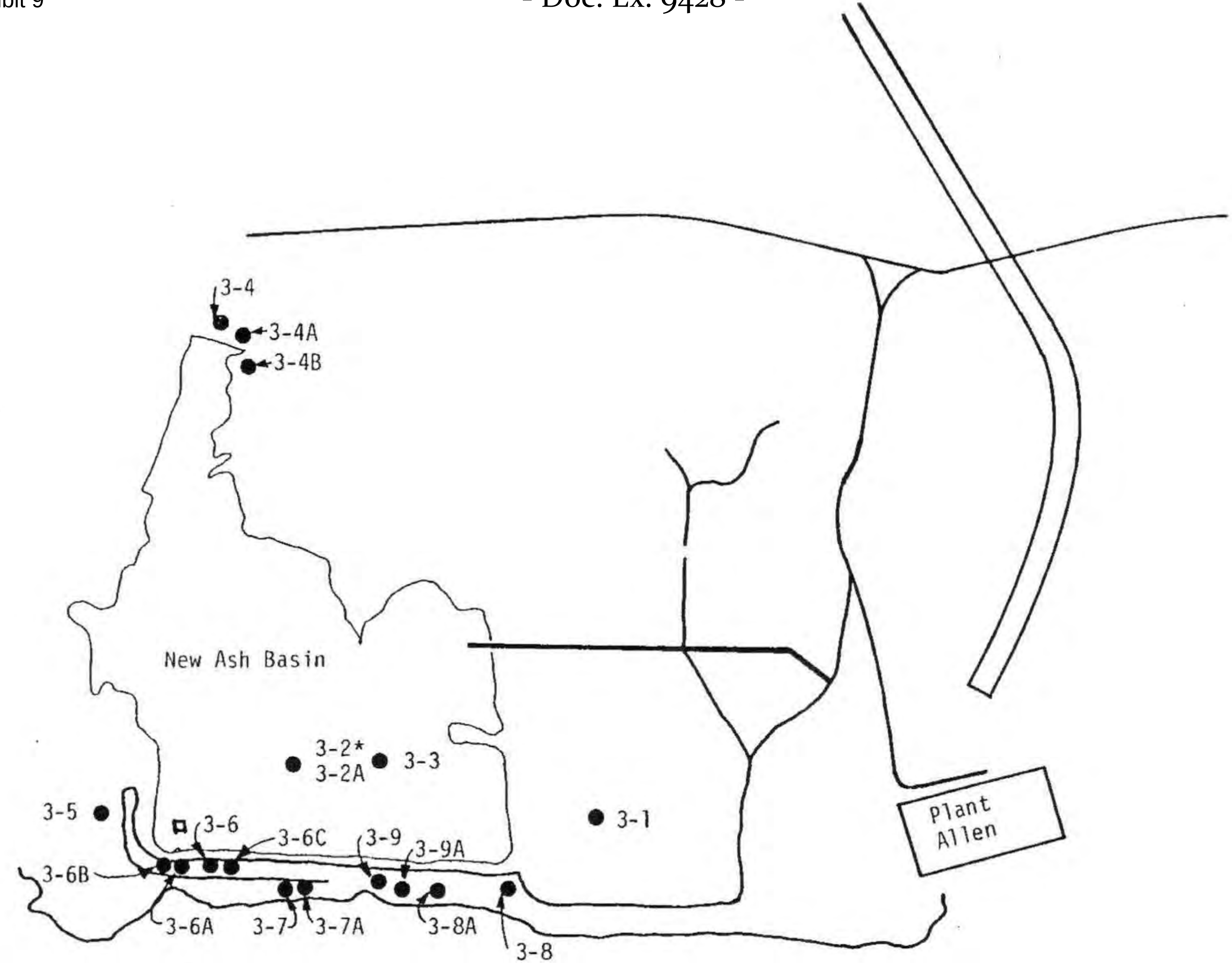

Figure 5. EPA/ADL Groundwater Monitoring Wells In-Place at Plant Allen as of June 30, 1982.

*3-2 - Depth at ash/clay interface
3-2A - Well point within the ash.

Table 9. Selected Groundwater Data for Plant Allen Sampling Location

DATE	February 1981		March 1981				July 1982			
Location	3-2	3-9	3-2	8	3-9	6	3-2	8	3-9	6
As (ppb)	1550	NA	2425	<2	<0.2	<2	318	<5	<0.1	NS (Inaccessible)
Se (ppb)	3	NA	<2	<5	<.26	<5	6.6	<5	<0.1	NS (Inaccessible)
Cu (ppm)	<.008	<.008	<.005	2.2	<.005	<1	<.008	<1	<.008	NS (Inaccessible)
Mg (ppb)	10.5	7.9	11.7	1.2	8.7	1.2	6	1.15	7.1	NS (Inaccessible)
SO_4 (ppm)	320	<4	320	NA	<4	NA	169	NA	4	NS (Inaccessible)

NS = Not Sampled
NA = Not Analyzed

for Wells 3-2 (worst case high concentrations) and 3-9 (downgradient of active pond) with some data from Duke wells 8 (background) and 6 for comparison. The parameters shown are arsenic and selenium (primary drinking water standards), magnesium (indicator of ion exchange capacity), and copper and sulfate (secondary drinking water standards). The difference in the concentration of arsenic and sulfate between that found within the active pond and in the downgradient well is noteworthy. The arsenic concentrations detected in the interstitial waters of the ash-soil interface at the bottom of the active pond (well 3-2) were much higher than the leachable arsenic found in dry fly ash from Allen Unit 1 (98 ppb) and Unit 3 (63 ppb), yet no arsenic was detected in well 3-9 downgradient of the active pond.

Soil attenuation is suggested by A. D. Little as the mechanism preventing migration of arsenic from the ponds. This was demonstrated by lab experiments in which interstitial water from well 3-2 (fortified with cadmium, chromium, copper, lead, and selenium) was used as a test leachate to be combined in 50-ml aliquots with .05, .5, 5, and 25 gms. of soil from the borings for 3-2. The slurries were shaken for 24 hrs., filtered through a .45 um filter, and aliquots were either preserved with nitric acid for ICAP or cooled for ion chromatography. Analyses were performed both on solutions and on digested solids.

Statistically significant decreases in concentration between starting solutions and equilibrated solutions were considered to be the quantity adsorbed by the soil. The starting solution concentrations of arsenic and selenium were 512 and 125 ppb, respectively. The alluvial soil used from the bottom of well 3-2 was 69% sand, 28% clay, 8% silt, with 0.08% total organic carbon and 4940 ppm manganese. The pH of the leachate/soil mixtures was 8.97 for the .05 gms. solution, 8.58 for .5 gms., 6.99 for 5 gms., and 6.5 for the 25 gms. solution.

The equilibrated final solutions contained as much as 360 ppb arsenic and 113 ppb selenium for the smallest amount of soil but as little as <0.2 ppb arsenic and 0.2 ppb selenium for the 25 gm. soil sample, indicating the soil's high adsorptive capacity, the highest of any site studied by A. D. Little. The high manganese content of the soil is suggested as the explanation for its ability to adsorb arsenic and selenium.

The soil from 3-2, the groundwater from the downgradient wells, and the pond toe drains and discharge water did not have concentrations of copper, nickel, and zinc above background, confirming that the high concentrations of these metals added to the pond during a boiler cleaning are precipitated and confined within the pond.