Wells ________ - Public Staff
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ABSTRACT

This report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study was conducted by Arthur D. Little, Inc., under EPA contract 68-02-3167, and involved characterizing wastes, gathering environmental data, assessing environmental effects, and evaluating the engineering/costs of disposal practices at six selected sites in various locations around the country. Results of the study are providing technical background data and information to EPA, State and local permitting officials, and the utility industry for implementing environmentally sound disposal practices.

Data from the study suggest that no major environmental effects have occurred at any of the six sites. For example, data from wells downgradient of the disposal sites indicate that the contribution of waste leachate to the groundwater has generally resulted in concentrations of chemicals less than the primary drinking water standards established by EPA. Although occasional exceedances of the standards were observed, these were not necessarily attributable to coal ash and FGD waste. A generic environmental evaluation based on a matrix of four waste types, three disposal methods, and five environmental settings (based on climate and hydrogeology) shows that technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, measures must be taken to avoid adverse environmental effects. However, site-specific application of good engineering design and practice can mitigate most potentially adverse effects of coal ash and FGD waste disposal. Costs of waste disposal operations are highly system- and site-specific.

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SECTION 1.0

EXECUTIVE SUMMARY

1.1 OVERVIEW

This final report was prepared by Arthur D. Little, Inc. (ADL) for the Environmental Protection Agency (EPA) as part of a study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired power plants. The study involved characterizing wastes, gathering environmental data, and assessing the environmental effects and engineering/costs associated with disposal practices at six selected sites at various locations around the country. Results of the study will be used: (1) as a technical basis to help EPA determine the degree, if any, to which disposal of these wastes should be managed to protect human health and the environment; and (2) to provide useful information on environmentally sound disposal of coal ash and FGD wastes to utility planners and state and local permitting officials.

This three-year effort consisted of several work elements. The first step was to select six waste disposal sites for detailed field and laboratory evaluations. The selection was based on an analysis of all available information on coal ash and FGD waste disposal at coal-fired utility plants in the U.S. During this site-selection process, waste types, methods of disposal, and environmental settings were considered.

The second step was to develop sampling infrastructures at these six sites. These efforts consisted of placing borings, groundwater wells and test pits to study stratigraphy and to gather wastewater and soil samples. After site development, samples of groundwater, surface water, wastes, and soils were subjected to comprehensive physical and chemical analyses. Additional groundwater and surface water samples were gathered at the sites over a one-year period for further analysis.

Data from site development and sampling/analysis were used to assess environmental effects. The primary focus of the environmental assessment was to study the fate of waste constituents (including trace elements) by examining the relative concentrations in liquids and solids at background, in-waste, and downgradient locations. The environmental assessment effort continued until the end of the project.

At each of the six sites, engineering information was gathered on the handling and disposal of coal ash and, if present, FGD wastes. This engineering information formed the basis for developing process flow sheets, capital costs, and first year annual costs for waste handling and disposal.

Throughout this project, related programs, including those sponsored by EPA, the Electric Power Research Institute (EPRI), the Department of Energy (DOE), the Tennessee Valley Authority (TVA), and others in the utility industry were evaluated.

Based on all the data and information, a generic assessment of coal/ash and FGD waste disposal was undertaken. The generic assessment serves as a basis for anticipating environmental effects for a mix of waste types, methods of disposal, and environmental settings. This generic assessment also provides a data base on capital and annual costs for coal ash and FGD waste handling facilities for a mix of waste types and methods of disposal. Finally, a decision methodology was developed to serve as a tool for federal, state and local permitting officials and utility planners in developing environmentally sound waste management practices for coal ash and FGD wastes under a variety of circumstances.

1.2 TECHNOLOGY AND PRODUCTION OF WASTES

Coal-fired power plants based on conventional combustion technology generate two major types of waste materials: coal ash (fly ash, bottom ash, or boiler slag) and FGD wastes. Both are produced in fairly large amounts and so are usually referred to as "high volume wastes." Numerous additional wastes, generated in smaller quantities, are associated with other processes or maintenance operations in a power plant. These include coal pile runoff, boiler blowdown, cooling tower blowdown, water treatment wastes, maintenance cleaning wastes, general power plant trash, and plant sanitary wastes. This project focused primarily on the high volume wastes.

Fly ash from coal-fired utility boilers is collected by mechanical collectors and/or electrostatic precipitators, fabric filters, or wet scrubbers. By late 1982, about 103,000 MW of coal-fired generating capacity - operational, under construction, and in various stages of planning - had been committed to FGD systems. Flue gas desulfurization can be accomplished by nonregenerable throwaway systems, which result in FGD wastes, or by regenerable systems, which produce a saleable product (sulfur or sulfuric acid). Operational nonregenerable FGD systems are currently predominated by wet scrubbing technology; however, some dry FGD scrubbing systems were coming on-line in 1982 to 1983. The major types of systems used in utility power plants are based on direct limestone, direct lime, alkaline fly ash, dual alkali, and lime- or sodium-based dry FGD systems (1).

Table 1.1 gives some projections on the generation of coal ash and FGD wastes [together, these are designated as flue gas cleaning (FGC) wastes] in the U.S. Most of the coal ash and almost all FGD wastes are sent to disposal (2,3). In view of the expected increase in coal consumption in the U.S., this trend should continue for many years. Utilization of FGC wastes should grow, but at a slower rate than that at which it is generated. Typical uses of coal ash include soil stabilization, ice control, and as an ingredient in cement, concrete, and blasting compounds. FGD wastes are not presently used in the U.S., except for some minor amounts in road base and other applications. On balance, disposal will continue to be the major option for FGC waste management in the U.S. for the foreseeable future.

TABLE 1.1

PROJECTIONS OF FGC WASTE GENERATION BY UTILITY PLANTS IN THE UNITED STATES (1980-1995)

Waste Type	Waste Generation (10^6 Metric tons/yr) 1980	1985	1995
Coal Ash[a]	62.4	83.2	110.0
FGD Wastes[b]	8.6	26.9	48.6
TOTAL	71.0	110.1	158.6
	(78.3)[c]	(121.4)[c]	(174.8)[c]

[a]Coal ash quantities are shown on a dry basis.
[b]FGD waste quantities are shown on a wet basis (50% solids).
[c]10^6 tons/year.

Source: Arthur D. Little, Inc.

All FGC waste disposal is on land. At-sea disposal may be a future alternative if it can be practiced under environmentally and economically acceptable conditions (4,5). The main methods of disposal on land are: ponding, landfilling (including disposal in surface mines), and interim ponding followed by landfilling. Table 1.2 summarizes disposal practices based on practices at 176 plants.

Ponding of FGC waste is more common than any other disposal method. Ponding can be used for a wide variety of coal ash and FGD wastes, including chemically treated FGD wastes. Ponds can be designed based on diking or incision, but the construction of dams or dikes for ponds is usually costly. Regulatory developments under the Clean Water Act have encouraged dry handling and disposal of fly ash. In the future, even in existing plants, ponding will probably be limited to those sites that will involve minimal construction of dams or dikes. One exception could be a special case of wet ponding - FGD gypsum "stacking." In this case, gypsum slurry from a forced oxidation system would be piped to a pond, allowed to settle, and the supernate recycled. Periodically the gypsum would be dredged and stacked around the perimeter of the pond, thus building up the embankments.

Landfilling of FGC waste is also widely practiced, and can involve one or more of a variety of handling operations before the disposal operation. For example, bottom ash is almost always sluiced from the plant, so it must be dewatered before it is transported. Dewatering must also be applied to fly ash that is sluiced from the plant or is wet-scrubbed from the flue gas - with or without significant quantities of SO_2. Wet FGD waste must be dewatered via thickening, vacuum filtration, and, if necessary, blending with dry fly ash for stabilization or chemical treatment (fixation) additives such as lime. On the other hand, fly ash slated for landfill is typically transported directly from the plant in a dry state, with only enough moisture added for dust control and compaction in the landfill. Wastes from a spray dryer FGD system can also be transported directly; during this project, commercial operation of these systems on utility boilers was just beginning. A properly designed and operating landfill system can potentially enhance the value of the disposal site after termination or at least permit post-operational use.

Mine disposal is a variation of landfilling that is receiving increased attention. Surface coal mines, particularly those serving "mine-mouth" plants, offer the greatest capacity and economic attractiveness for disposal of wastes from power plants (4,5). Since the volume of FGC wastes produced is considerably less than the amount of coal burned, many mines would have the capacity for disposal throughout the life of the power plant. Several plants, particularly in the Plains States (i.e., North Dakota), have recently practiced this disposal method.

Interim pond/landfill has been an important waste disposal method in the past, but is likely to decline in the future, especially since dry ash handling and disposal is being more widely practiced.

TABLE 1.2

CURRENT FGC WASTE DISPOSAL METHODS USED AT
UTILITY COAL-FIRED POWER PLANTS IN THE U.S.

(Data Base: 176 Plant >200 MW)[2]

Type of Waste	Number of Plants		
	Pond[b]	Landfill[c]	Interim Pond/Landfill[c]
Fly ash only	18	46	6
Bottom ash only	29	13	29
Combined fly and bottom ash	69	9	16
FGD waste only	5	--	--
Mixed fly ash and FGD waste	7	7	--
Mixed bottom ash and FGD waste	1	--	1
Mixed fly ash and FGD waste (stabilized)	2	6	--
Mixed fly ash, bottom ash, and FGD waste	2	1	1

[a]Coal-fired plants on which data were available (>80 of their power generated from coal in 1977) which have generating capacities >200MW with the exception of four plants employing FGD systems. Figures represent the number of plants at which each waste type/disposal method is practiced. (Many plants use more than one method.)

[b]Includes direct ponding and interim/final ponding methods.

[c]Includes managed and unmanaged fills and mine disposal.

Source: Arthur D. Little, Inc.

1.3 PROJECT RATIONALE

The environmental impact of coal ash and FGD waste disposal is influenced by three factors: type of waste generated (physical and chemical characteristics), disposal method (ponding, landfilling, or other), and disposal site characteristics (soil type, hydrogeology, climate, etc.). In this project, a mix of waste types, methods of disposal, and site characteristics was selected to provide a broad range for environmental assessment and engineering cost estimates. The disposal methods examined included the more prevalent methods used by the utility industry.

In planning and executing this project, priority was given to those potential environmental effects that are addressed by the Resource Conservation and Recovery Act (RCRA). Highest priority was given to three areas: the effects of waste disposal on groundwater quality; effect on surface water quality from nonpoint sources; and the use of potentially mitigative design, management; or control practices. The generic assessment and the decision methodology that were developed also took into account the many related efforts sponsored by EPA, EPRI, DOE, TVA and the utility industry.

1.4 SITE SELECTION AND TEST PLAN PREPARATION

The site selection process is described in detail in Appendix A. Site selection consisted of three major efforts - selection of candidate sites, selection of final sites, and preparation of test plans for each final site.

1.4.1 Candidate Site Selection Process

The purpose of the candidate site selection process was to evaluate available data on coal-fired power plants and recommend several candidates and backup sites. The contiguous 48 states were divided into 14 physiographic regions. Plants in each region were screened to develop a list of candidate and backup sites. A target of 25 to 30 sites, including 18 candidate and 7 to 12 backup sites, was desired. Based on an assessment of present and future FGC waste disposal practices, a preliminary distribution of the targeted number of candidate sites in each regional was agreed upon. In screening selections, investigators remained aware of the targeted number in each region, but were not absolutely limited by that number. The attempt was to choose desirable plants in as many regions as possible. The list of plants in all the regions that came through this filtration process amounted to 26. These 26 were then ranked. Eighteen were nominated as candidate sites and the remainder as backup sites.

1.4.2 Final Selection Process

The candidate and backup sites were subjected to a more detailed evaluation. These evaluations included one or more detailed site visits by engineering, environmental, and hydrogeologic specialists. Their findings, together with continuing evaluations on the overall mix of the sites, supported an iterative process resulting in the selection of the final six sites. Table 1.3 gives some information on the final six sites that were selected for evaluation; Figure 1.1 shows the site locations.

TABLE 1.3

SELECTED SITES

Plant	Utility	Location: State	Location: County	Capacity (MW): Nameplate Generating	Capacity (MW): FGD Unit On	Startup Date (mo/yr): Plant	Startup Date (mo/yr): FGD	Waste Site Under Study: Waste Type	Waste Site Under Study: Disposal Method[a]	High Priority Issues Under Study: Ground-water Quality	High Priority Issues Under Study: Surface water Quality	High Priority Issues Under Study: Employment of a Potentially Mitigative Practice
Allen	Duke Power	NC	Gaston	1155	-	-/57	-	Combined fly and bottom Ash	Pond (UL)	x	x	x
Elrama	Duquesne Light[b]	PA	Washington	510	510	6/52	10/75	Stabilized FGD waste Combined fly and bottom ash	Landfill (UL; offsite) Landfill (UL)	x	x	x
Dave Johnston	Pacific Power & Light	WY	Converse	750	-	-/57	-	Fly Ash	Landfill (UL)	x	-	x
Sherburne County	Northern States Power	MN	Sherburne	1458	1458	5/76	5/76	Fly ash/FGD	Pond (AL)	x	-	x
Powerton	Commonwealth Edison	IL	Tazewell	1786	-	-/72	-	Combined fly and bottom ash	Landfill (AL)	x	x	x
Smith	Gulf Power	FL	Bay	340	-	6/65	-	Combined fly and bottom ash	Pond (UL)	x	x	x

Notes:
[a]UL - Unlined
AL - Artificially Lined

[b]Disposal site operated by Conversion Systems, Inc.

Source: Arthur D. Little, Inc.

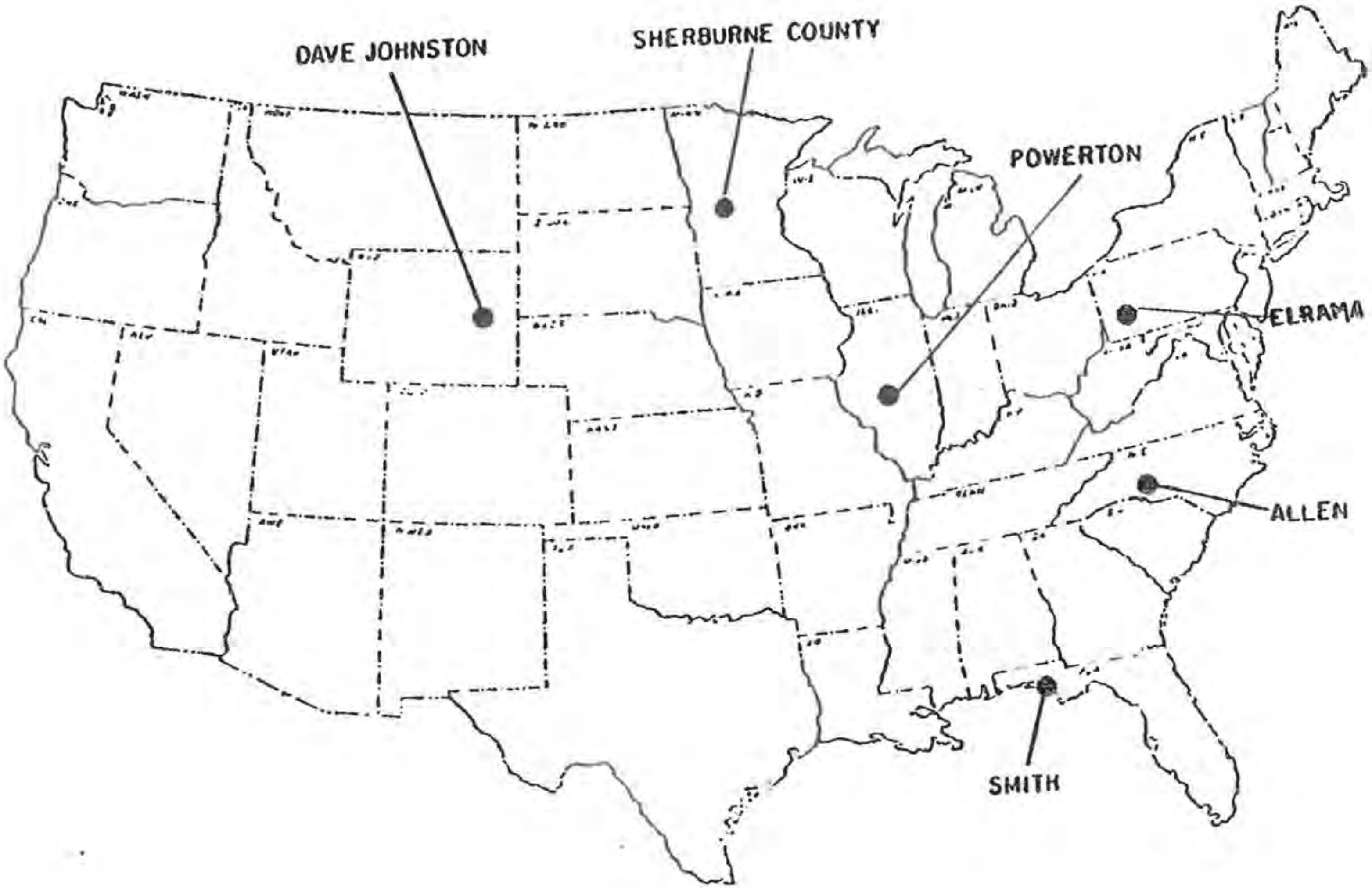


FIGURE 1.1 SELECTED SITES FOR EVALUATION

1.4.3 Test Plan Preparation

Detailed test plans were developed to provide: background information on each of the sites; a description of the proposed program of site development; physical and chemical sampling and analysis; and environmental and engineering/cost assessments. The test plans were reviewed by EPA and the utility involved, and their comments were incorporated. The finalized test plans guided the work at each site.

1.5 SITE DEVELOPMENT AND PHYSICAL TESTING

After approval from the utility and, in some cases, from state regulatory agencies, site development was begun. Site development and physical testing were guided by procedure manuals developed for this project (Appendices B and C). The activities involved in site development included the drilling of borings; excavating test pits; collecting waste, soil, and water samples; conducting field permeability tests; installing groundwater monitoring wells and piezometers; and documenting each activity. These activities took place at each of the six sites in time periods of 2 to 4 weeks. Table 1.4 indicates the timing under which the six sites were developed and the extent of the activities at each site. The Table also gives the number of physical tests performed. Preliminary water balances were developed for each site.

1.6 CHEMICAL SAMPLING AND ANALYSIS

At each site, a program of chemical sampling and analysis was undertaken. This involved characterizing waste, water, and soil samples taken during site development, and groundwater well and (in some cases) surface water samples later obtained during visits scheduled to correspond with relatively wet, relatively dry, and intermediate periods for each site. Table 1.5 summarizes the chemical sampling and analysis programs.

Chemical samples were subjected to several types of analyses: ion chromatography (IC) for six anions, inductively coupled argon plasma emissions spectroscopy (ICAP) for 26 metals; and atomic absorption spectroscopy (AA) for selected metals. As shown in Table 1.5, these analyses were performed on a mix of solid and liquid samples for each site. In addition, experiments were conducted to assess the attenuative capacity of various soils obtained at the sites. During the initial phase of this project, 23 grab samples of wastes from 18 plants were obtained and analyzed using EPA Extraction Procedures (EP); a summary of results from these tests is given in Table 1.6. Further details, as well as results of radioactivity measurements, are available in Appendix D.

1.7 SITE-SPECIFIC ENVIRONMENTAL EVALUATION

The data and information from site development and sampling/analysis activities were evaluated throughout the project in terms of potential environmental effects. The procedure for the individual site evaluations is described below.

TABLE 1.4

SUMMARY OF SITE DEVELOPMENT/PHYSICAL TESTING

Plant	Data Development Completed (mo/yr)	Number of: Borings	Wells	Test Pits	Soil Samples	Number of Laboratory Physical Tests: Unified Soil Classification Series (USCS)	Permeability
Allen	01/81	20	20	2	152	18	4
Elrama	03/81	20	16	4	199	17	13
Johnston	05/81	14	12	10	154	12	7
Sherburne County	08/81	11	8	--	178	20	6
Powerton	11/81	11	9	1	112	30	8
Smith	12/81	25	24	--	146	15	8

TABLE 1.5

SUMMARY OF CHEMICAL SAMPLING AND ANALYSIS PROGRAM

Site	Samples[a] Trip 1	Samples[a] Trips 2, 3, and 4	Analyses[b] Trip 1 ICAP	Analyses[b] Trips 2, 3, and 4 IC	As/Se	Field Data	Other
Allen[c]	wells	wells and surface waters	X	X	X	X	
	ash solids		X		X		
	interstitial liquors		X	X	X		
	soils		X		X		
Elrama	wells	wells, lysimeters, surface waters	X	X	X	X	X[d]
	waste solids		X		X		
	soil		X		X		
	waste extracts			X			
Sherburne County	wells	wells and surface liquors	X	X	X	X	
	waste interstitial liquors		X	X	X		
	waste solids		X				
	liner solids		X				
	liner liquor		X	X			
	soil solids		X				
	soil extracts		X				
Smith	liquors	wells and surface waters	X	X	X	X	
	waste solids		X				
	interstitial waste liquors		X	X			
	soil		X				
	soil liquors		X	X			
Powerton	wells	wells and surface waters	X	X	X	X	
	waste solids		X				
Dave Johnston	wells	wells and surface waters	X	X	X	X	
	waste solids		X		X		
	waste extracts			X			
	soils		X				

[a]Samples obtained during site development and subsequent sampling and analysis trips.

[b]Analyses performed are abbreviated as follows:

ICAP - Ag, Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, Th, Ti, V, Zn, Zr. (Does not include B, Ba, and Si for solids.)

IC - F^-, Cl^-, NO_3^-, SO_4^{-2}, Br^-, PO_4^{-3}.

As/Se - either or both on selected samples.

Field Data - groundwater level, pH, dissolved oxygen, conductivity, temperature.

[c]Other samples were obtained (boiler cleaning wastes). Analysis was limited to ICAP, pH, and bromate.

[d]Includes solids characterization for SO_4^{-2}, total oxidizable sulfur, slurry pH, acid insolubles.

TABLE 1.6

SUMMARY OF RESULTS OF EXTRACTION PROCEDURE (EP) TESTS OF 20 FLY ASH AND 3 FGD WASTE GRAB SAMPLES

Metal	Overall Range Observed, μg/l		Interim Primary Drinking Water Standards[a], μg/l	Ratio of Range Observed to Standards	
	Fly Ash	FGD Waste		Fly Ash	FGD Waste
Arsenic	<2 - 410	<2 - 65	50	<0.04 - 8.2	<0.04 - 1.30
Barium	<100 - 700	<150 - 230	1000	<0.1 - 0.7	<0.15 - 0.23
Cadmium	<2 - 193	<2 - 20	10	<0.2 - 19.3	<0.2 - 2
Chromium	<8 - 930[b]	<11 - 26[b]	50[b]	<0.16 - 18.6	<0.22 - 0.52
Lead	<3 - <36	<5	50	<0.06 - 0.72	0.1
Mercury	<2	<2	2	<1	<1
Selenium	<2 - 340	8 - 49	10	<0.2 - 34	0.8 - 4.9
Silver	<1	<1	50	<0.02	<0.02

[a] Reference 6 gives these standards "...for use in determining whether solid waste disposal activities comply with groundwater criteria." Standards included in Reference 6, but not measured in these tests, are for fluoride: 1400-2400 μg/l (depending on temperature), and for nitrate (as N): 10,000 μg/l.

[b] Reference 7 contains an amendment to the chromium criteria for the EP, revising it from total chromium to Cr(VI); since the total chromium values were measured by atomic absorption (AA), the measured ranges represent upper limits for Cr(VI) in the samples.

First, available background information on the disposal operation and its environmental setting was reviewed. This information, together with results obtained during this project, was used to identify present disposal-related water quality effects. Apparent cause/effect relationships were hypothesized to explain the findings at the sites. Potential future ranges of water quality effects were taken into account. Finally, industry-wide implications of the findings at the individual sites were considered in the generic assessment, discussed below.

Environmental evaluation of all six sites provided substantial data and information. The general results are that:

- Data suggest that no major adverse environmental effects have occurred at any of the sites. For example, data from wells downgradient of the disposal sites indicate that the contribution of waste leachate to the groundwater has generally resulted in concentrations of chemicals less than the primary drinking water standards established by EPA (6). Occasional exceedances of the standards were observed, but these could not be attributed to the coal ash and FGD wastes.

- The results from the sites are internally consistent. Analyses of samples taken on different dates at the same locations are very similar.

The total integrated evaluation of data from site development, site water balances, physical testing of wastes samples, and chemical sampling and analysis has provided a large data base to explain many of the environmental effects that can result from coal ash and FGD waste disposal. A brief account of the results at each of the sites is presented below.

1.7.1 Results from Allen Plant

Leachate generated within the ash ponds at the Allen Plant contains elevated (over background) concentrations of several waste-related chemical constituents (i.e., boron, sulfate, calcium, arsenic). However, the surrounding soils have attenuated significant fractions of some leachate contaminants within the immediate vicinity of the ponds.

Leachate water from the upgradient portions of the ash ponds has not moved enough to create steady-state concentrations of unattenuated constituents (i.e., sulfate) in the downgradient wells. But concentrations of these constituents are expected only to reach or barely exceed Secondary Drinking Water Standards (for sulfate, 250 ppm).

1.7.2 Results from Elrama Plant

Before disposal of FGC wastes, much of the site at Elrama was contaminated by acid mine drainage, resulting in low pH (4.5 to 5) and high concentrations of chemical constituents (i.e., about 2000 ppm sulfate) in the groundwater. The landfill and runoff collection ponds serve as additional sources of some of the same constituents. An elevated level (about 0.2 ppm) of arsenic was repeatedly measured at one waste/soil interface lysimeter, but may not be a general problem in view of the substantial attenuation of arsenic by soils at the site that is expected.

The relative absence of elevated levels of waste-related constituents in downgradient groundwater may be explained by the relatively short time that the fill had been in operation (4 years) and by chemical/physical attenuation phenomena (including the effects of the treatment/disposal process).

The landfill does not seem to alter significantly the local concentrations of some constituents (such as sulfate) potentially available from both mine drainage in the area and FGC wastes in the landfill.

1.7.3 Results from Dave Johnston Plant

At the Dave Johnston Plant, the water balance and estimates of plume arrival time indicate that the widespread measurement of what might elsewhere be considered elevated chemical constituent levels (i.e., sulfate, about 1000 ppm) is due to background elevations and not waste landfills. The estimates of plume arrival time for the peripheral wells downgradient from (not directly under) the active landfill are in excess of 100 to 300 years, assuming only travel time in the saturated zone. Travel time from the inactive landfill to the downgradient well is longer than 20 years (the period since the landfill was completed and this sampling effort was undertaken).

Most of the "elevated" measurements reflect pervasively high background levels characteristic of highly mineralized groundwater in many western settings. However, lower measured values (i.e., sulfate, about 100 ppm) at one background and one peripheral well indicate that, even in highly mineralized arid areas, there may be areas of good water quality that require protection. Measurements of several waste-related parameters, such as calcium and strontium, indicate a waste-related concentration gradient in waters within the waste deposit.

1.7.4 Results from Sherburne County Plant

Leachate movement from the ponds at Sherburne County has so far been retarded enough by the clay liner to prevent significant elevations of chemical constituents in the water sampled at downgradient wells. A waste-related influence is reflected in the slightly elevated levels (of boron and sulfate) measured in the peripheral/downgradient wells to the west and southwest. It is unclear whether this is due to past leakage from the sheet piling/conduit area, or to leachate that has moved through the liner.

Because of the pervious soils in the site area and the apparent profile of contaminant migration through the liner, some increases in concentrations of major soluble species in downgradient wells are possible over the next few years. Secondary Drinking Water Standards will probably be exceeded in these wells. But the effects of these species off-site will be diluted about 305 m (1000 ft) downgradient by the Mississippi River, which flows by the plant.

The higher concentrations of waste parameters in FGC pond supernatant vs. underlying waste interstitial waters may be due to two factors. For one, the conversion by the utility to a system involving recycle of the FGC waste transport water would have caused increased concentrations of chemicals in the water. Evaporation of water in the pond would also raise chemical concentrations.

1.7.5 Results from Powerton Plant

Although the completed landfill at Powerton was supposed to have a 0.25-m (8-in) Poz-O-Pac® liner, an absence of liner material was observed during the coring operation at most sampling sites on the abandoned landfill. This observation is consistent with the fact that it is difficult to place uniformly such a relatively thin layer of soil-like material over a large area. Engineering practice suggests that a minimum thickness of 0.45 to 0.60 m (18 to 24 in) of liner placement is required to ensure full effectiveness. Near downgradient wells showed waste-related contamination of boron and sulfate, the latter in excess of the Secondary Drinking Water Standard.

The surface water analytical results for Lost Creek stream (which is immediately downgradient) are consistent with the water balance calculations. Both sets of results indicate that the stream has enough assimilative/-dilution capacity to lower current concentrations of chemical constituents in leachate reaching Lost Creek to slightly elevated but insignificant levels. The results also suggest that the stream, if an effective groundwater flow divide, may limit the extent of further downgradient groundwater contamination by the waste plume.

Elevated concentrations of nitrate at various sampling locations at the site can be attributed to local agricultural and urban nonpoint source activities and not the coal ash landfill.

1.7.6 Results from Smith Plant

At the Smith Plant site, a steady state seems to exist between the concentrations of soluble species in the pond and in the immediately adjacent downgradient areas. These downgradient areas have apparently been affected by leachate from the pond. Concentration gradients for waste-related parameters (calcium and strontium) are evident.

Little or no chemical attenuation of the waste-related parameters is apparent, but rather a progressive reduction in concentrations in the downgradient direction. This agrees with what would be expected due to admixing of leachate with the greater amounts of dilution water.

The use of high total dissolved solids Bay water in the pond for makeup and its presence in adjacent downgradient areas create a situation where little incremental effect is detectable from such typical ash pond "tracer" species as sulfates, chlorides, and boron.

1.8 ENGINEERING AND COST ASSESSMENT

The purpose of the engineering and cost assessment was to develop conceptual engineering designs and corresponding capital and annual costs for generic waste handling and disposal operations. This information was prepared in a form that would be useful as a decision-making tool for preliminary waste management planning purposes. To accomplish this, site-specific engineering and cost data were prepared for the solid waste handling and disposal operations at the six study sites based on information supplied by the participating utilities and data developed during this project. The results of this effort, along with engineering and cost data developed in other pertinent studies, were adjusted and refined to produce a generic engineering and cost data base. Tables 1.7 and 1.8 summarize the costs provided by this generic data base. The ranges shown represent variations in specific plant operations as well as differences in the many cost estimates used to develop the data base.

1.8.1 Site-Specific Engineering and Cost Assessments

Conceptual engineering designs and capital and annual cost estimates were developed for the solid waste handling and disposal operations at the six study sites. This effort called for:

- Preliminary conceptual engineering designs for the solid waste handling and disposal systems at the six study sites, based on data provided by the participating utilities and engineering data developed as a result of a preliminary plant visit.

- Finalized conceptual engineering designs for the solid waste handling and disposal systems of the six study sites, based on revisions to the preliminary design, as provided by the utilities, and data developed during a final plant visit (if such a visit was necessary).

- Capital and annual cost estimates for the systems specified in the final engineering design.

- Final, site-specific engineering/cost packages consisting of the conceptual engineering process designs and cost estimates developed.

The site-specific engineering and cost evaluations of the solid waste handling and disposal operations at all six sites were conducted in the same manner. For each site, the waste types and process systems of interest were identified. Three major utility coal combustion wastes were taken as the primary focus: fly ash, bottom ash or boiler slag, and FGD waste. The battery limits of the waste handling and disposal system were then established. In every case the system evaluated included all waste handling, processing, storage, transport, and disposal activities, up to and including disposal site reclamation.

After the waste types and solid waste handling and disposal operations had been identified, the system was divided into modules. Up to five modules were considered for the management of any particular waste type: raw

TABLE 1.7

GENERIC CAPITAL COST ESTIMATES FOR FGC WASTE DISPOSAL

Late 1982 Dollars [a]

Module	Submodule	Capital Cost Range ($/kW) Plant Size (MW) 250[b]	500[b]	1000[b]
Fly ash handling/processing	Wet handling w/o recycle	2.3-4.3	1.9-3.5	1.5-2.9
	Wet handling w/recycle	3.7-6.8	3.0-5.5	2.[illegible]-6.[illegible]
	Dry handling	2.2-4.1	1.8-3.3	1.[illegible]-2.[illegible]
Fly ash storage	Dry	4.7-8.8	4.2-7.7	3.7-6.8
Fly ash transport	Wet sluicing	3.5-6.4	2.7-5.1	2.2-4.0
	Dry trucking	0.3-0.5	0.3-0.6	0.3-0.5
Fly ash placement/disposal	Unlined pond	15.1-27.8	12.9-23.9	11.0-20.5
	Landfill	4.3-8.1	3.3-6.1	2.5-4.7
Bottom ash handling/processing	Wet handling w/o recycle	2.2-4.1	1.7-3.2	1.3-2.5
	Wet handling w/recycle	2.5-4.6	2.0-3.7	1.6-3.0
Bottom ash transport	Wet sluicing	3.0-5.6	2.4-4.5	1.9-3.5
	Dry trucking	0.2-0.4	0.2-0.3	0.1-0.2
Bottom ash placement/disposal	Unlined pond	6.4-11.8	5.1-9.6	4.2-7.7
	Landfill	1.3-2.4	1.1-2.0	0.9-1.6
Raw materials handling/storage	Dry (lime and fly ash)	2.4-4.5	2.1-3.9	1.9-3.4
FGD waste handling/processing[c]	Wet handling	18.1-33.6	15.2-28.3	12.8-22.8
FGD waste transport	Wet sluicing	0.7-1.3	0.5-1.0	0.4-0.8
	Dry trucking	0.4-0.7	0.3-0.6	0.3-0.5
FGD waste placement/disposal	Unlined pond	10.0-18.6	8.9-16.5	7.9-14.7
	Landfill	4.1-7.6	3.3-6.2	2.7-5.0

[a]Engineering News Record (ENR) Index = 3931.11 (1913 = 100)
= 365.97 (1967 = 100)

[b]Relationship between plant size and waste generation for typical case:

	Annual Waste Generation Rate (dry metric tons/MW of Plant Generating Capacity)
Fly Ash	280
Bottom Ash	70
FGD Waste	240

"Typical Case" Assumptions

Coal Properties:	[illegible] S, 13% Ash, 10,500 Btu/lb
Load Factor:	70%
Heat Rate:	10,250 Btu/kWh
SO_2 Removal:	90%
Lime Stoichiometry:	1.1
Fly Ash/Bottom Ash Ratio:	80/20

[c]Assumed FGD System: Wet Lime Scrubbing

Source: Arthur D. Little, Inc. estimates

TABLE 1.8

GENERIC ANNUAL COST ESTIMATES FOR FGC WASTE DISPOSAL

(Late 1982 Dollars)[a]

Module	Submodule	Annual Cost Range ($/dry metric ton) Plant Size (MW) 250[b]	500[b]	1000[b]
Fly ash handling/processing	Wet handling w/o recycle	2.5-4.6	1.0-3.7	1.6-3.0
	Wet handling w/recycle	3.7-6.8	2.9-5.4	2.3-4.3
	Dry handling	2.5-4.7	2.1-3.9	1.7-3.2
Fly ash storage	Dry	3.3-6.1	3.0-5.6	2.8-[illegible]
Fly ash transport	Wet sluicing	4.2-7.6	3.2-5.9	2.5-4.7
	Dry trucking	1.7-3.1	1.5-2.8	1.3-2.5
Fly ash placement/disposal	Unlined pond	11.5-21.3	9.1-16.8	7.2-13.5
	Landfill	7.0-13.0	5.6-10.5	4.6-8.3
Bottom ash handling/processing	Wet handling w/o recycle	11.3-21.0	9.0-16.7	6.9-12.8
	Wet handling w/recycle	12.3-22.8	10.3-19.1	8.4-15.7
Bottom ash transport	Wet sluicing	9.2-17.1	7.3-13.5	5.6-10.3
	Dry trucking	3.4-6.3	2.3-5.2	2.2-4.1
Bottom ash placement/disposal	Unlined pond	9.2-17.1	7.9-14.6	6.5-12.1
	Landfill	5.4-10.0	4.7-8.8	4.1-7.6
Raw materials handling/storage	Dry (lime and fly ash)	4.1-7.6	3.7-6.7	3.4-6.2
FGD waste handling/processing[c]	Wet handling	17.2-31.9	13.8-25.5	11.0-20.5
FGD waste transport	Wet sluicing	1.1-2.1	0.9-1.7	0.7-1.3
	Dry trucking	3.0-5.4	2.3-4.3	1.8-3.3
FGD waste placement/disposal	Unlined pond	8.5-15.8	6.7-12.4	5.2-9.7
	Landfill	4.0-7.5	3.4-6.3	2.8-5.3

[a]Engineering News Record (ENR) Index = 3931.11 (1913 = 100)
= 365.97 (1967 = 100)

[b]Relationship between plant size and waste generation for typical case:

Annual Waste Generation Rate
(dry metric tons/MW of Plant Generating Capacity)

Fly Ash	280
Bottom Ash	70
FGD Waste	240

"Typical Case" Assumptions

Coal Properties:	2% S, 13% Ash, 10,500 Btu/lb
Load Factor:	70%
Heat Rate:	10,250 Btu/kWh
SO_2 Removal:	90%
Lime Stoichiometry:	1.1
Fly Ash/Bottom Ash Ratio:	80/20

[c]Assumed FGD System: Wet Lime Scrubbing

Source: Arthur D. Little, Inc. estimates

materials handling and storage; waste processing and handling; waste storage; waste transport; and waste placement and disposal (including site monitoring and site reclamation). This approach was valuable for many reasons. The ultimate benefit was that the engineering and cost data were provided in a format to facilitate their ultimate use. The generic modules serve as building blocks that may be combined and interchanged to obtain generic engineering designs and capital and annual costs for a variety of solid waste handling and disposal schemes.

1.8.2 Generic Engineering and Cost Assessment

The site-specific engineering and cost data developed for the six study sites, together with the engineering and cost data available in the literature, were used to develop generic capital and annual cost data for various combinations of the three waste types and five process modules.

Capital cost curves (capital cost vs. power plant size, MW) were developed for fly ash and bottom ash handling and disposal; similar curves (capital cost vs. FGD waste generation, metric tons) were developed for handling and disposal of FGD waste. Annual cost curves (annual cost vs. power plant size, MW, and annual cost vs. ash generation, metric tons/year) were developed for fly ash and bottom ash waste handling and disposal; in addition, cost curves (annual cost vs. FGD waste generation, metric tons/year) were developed for the handling and disposal of FGD wastes. (Results were summarized in Tables 1.7 and 1.8.)

The method of estimating waste handling and disposal system costs for a specific application involves first determining both the capital and annual costs for every process module used in the handling/processing and ultimate disposal of the various waste types generated at the proposed plant. This is accomplished by using the appropriate capital and annual cost ranges presented in Tables 1.7 and 1.8, respectively. One then simply adds all of the module costs to arrive at a total waste handling and disposal system cost for the plant being considered. (This method is intended to provide a conceptual cost estimate [with accuracy of plus 30 percent minus 10 percent] for preliminary planning purposes only, and should not be substituted for more detailed estimates prepared from detailed engineering and site-specific information.)

1.9 GENERIC ENVIRONMENTAL EVALUATION OF COAL ASH AND FGD WASTE DISPOSAL

The environmental effects of solid waste disposal are determined by three factors: waste type, disposal method, and environmental setting. The data base from this project and other studies suggests that present and future practices of coal ash and FGD waste disposal may be effectively evaluated through a matrix consisting of four waste types, three disposal methods, and five environmental settings.

The four waste types are:

1. Fly ash or fly ash admixed with other materials. A significant body of literature suggests that most trace metals available for leaching

from utility solid wastes may be associated with wastes containing fly ash. This category of wastes thus includes fly ash or fly ash mixed with bottom ash, and fly ash/bottom ash/ FGD waste mixtures (excluding chemically treated FGD wastes; see item 3, below).

2. Non-fly ash materials. In this category are bottom ash (or boiler slag) and FGD wastes that are disposed of separately from fly ash (including forced oxidation wastes). This group usually contains lesser concentrations of trace metals, but can result in high concentrations of major species (i.e., chlorides from FGD waste).

3. Chemically treated FGD wastes (fixation). FGD wastes may be treated for full-scale disposal by a variety of processes. Processes presently in commercial practice involve the addition of lime and fly ash, or processed slag. Lime/fly ash treatment for landfill disposal is presently practiced at some power plants and will likely become more important. Chemically treated FGD wastes comprise a separate category because of the differences in their physical and chemical properties created by the fixation process.

4. Dry FGD wastes. Several dry FGD systems are expected to come into commercial use over the next 3 years (2). These systems provide a waste containing fly ash and sulfur compounds in a relatively dry form that is likely to be sent for disposal to a managed landfill. The physical and chemical properties of these wastes are expected to differ from those of the other waste types discussed above. Even limited field-scale information is lacking as to their leaching characteristics.

The three disposal methods for coal ash and FGD wastes that are practiced and expected to continue are: pond disposal; interim ponding followed by landfill disposal; and landfill disposal (including disposal in mines, which is considered a special case of landfilling).

Three of the five environmental settings for solid waste disposal are based on major differences in climate and hydrogeology. These are: (1) coastal areas, specifically those areas where surface water and groundwater are influenced by the ebb and flow of tides; (2) arid areas, characteristic of much of the western U.S., where net evaporation generally exceeds precipitation by a significant margin; and (3) interior areas, typical of the non-coastal portions of the eastern U.S. In interior areas, precipitation and evaporation are fairly balanced, and permanent surface water bodies are so abundant that they are near many disposal sites.

Evaluations during this project suggested that two more special categories would be useful because of their significant characteristics. These additional categories are: (1) arid areas in the west where groundwaters and surface waters are very highly mineralized, and (2) interior areas subject to acid mine drainage. Both of these, as well as the coastal setting, tend to have water quality characteristics that can potentially show less of an incremental effect from coal ash and FGD waste leachates. This is because the waters in these areas already contain a number of chemicals found in the leachate.

Table 1.9 is a matrix of waste types, methods of disposal, and environmental settings, and indicates combinations for which field-scale and other information is available. Sources of data and information other than this study included the Utilities Solid Waste Activities Group (USWAG), EPRI, and DOE. As shown, some information is available for most of the combinations that are being practiced today or are likely to be applied in the future.

On balance, it appears that the technology exists for environmentally sound disposal of coal ash and FGD wastes based on any of the modes of disposal. Potential environmental effects are highly site- and system-specific. For some combinations of waste types, disposal methods, and environmental settings, mitigative measures must be taken to avoid groundwater and/or surface water contamination. However, proper site selection and site-specific application of good engineering design and practice can mitigate most potentially adverse environmental effects of high-volume, utility coal waste disposal.

1.10 DECISION METHODOLOGY

As part of this project, a decision methodology was developed to assist utilities and planners with the many issues related to coal ash and FGD waste management. Typical questions may range from assessing waste management options for new coal-fired power plants or expanding existing plants to projecting the continuing operations for several years into the future. Changes in disposal operations may be indicated. The potential impact of abnormal events, such as hurricanes and floods, on a waste disposal site must also be considered.

Figure 1.2 shows the decision methodology prepared as part of this project. Eight steps are involved in evaluating alternatives for coal ash and FGD waste disposal. The first consists of gathering data and information on the disposal alternatives. An evaluation of these alternatives that considers the large data base on coal ash and FGD waste management is the second step. Step 3 involves defining the information requirements for the site-specific environmental setting - geology, hydrogeologic conditions, surface water information, climatic conditions, and the like. Once information is available on waste characteristics, disposal methods and costs, and environmental settings, the environmental effects can be evaluated (Step 4). The generic environmental assessment methodology must consider the generation of leachate, and its transport and admixing with the surrounding surface and groundwater. Chemical and physical attenuation by the soil and surrounding materials should also be examined.

Based on the information developed during Steps 1-4, the decision-maker can make an initial selection of disposal alternatives (Step 5). These must be investigated further in Step 6 in terms of utility-specific factors and regulatory requirements. Additional laboratory field studies and engineering evaluations may be warranted (Step 7). The final step in this process, selecting the proper disposal methods and sites, can now be made.

TABLE 1.9

SUMMARY OF INFORMATION AVAILABLE FOR COMBINATIONS OF WASTE TYPES, DISPOSAL METHODS, AND ENVIRONMENTAL SETTINGS

	Ponding				Interim Ponding/Landfilling				Landfilling			
	Fly Ash[a]	Non-Fly Ash	Processed FGD	Dry FGD	Fly Ash[a]	Non-Fly Ash	Processed FGD	Dry FGD	Fly Ash[b]	Non-Fly Ash	Processed FGD	Dry FGD
COASTAL SETTING	X Smith[c]	P	NA	NA	X/PD Chisman Cr. (USWAC)	P	P	NA	P	P	P	P[e]
ARID WESTERN SETTING - Not Highly Mineralized	P	P	NA	NA	P	P	P	NA	X	P	P	P[e]
ARID WESTERN SETTING - Highly Mineralized	P	P	NA	NA	P	P	P	NA	X Dave Johnston Milton Young (DOE/EPA)	P	P	P[e]
INTERIOR SETTING - Not Highly Acidic	X Allen, Sherburne County, Michigan City (USWAG), Wallingford (USWAG)	P	X Bruce Mansfield	NA	X/Pd Bailly (USWAG)	P	P	NA	X Powerton, Zuellinger (USWAG), Hunts Brook (USWAG) Dunkirk (DOE)	P	X Conesville (EPRI/USWAG)	P[e]
INTERIOR SETTING - Highly Acidic (mine drainage)	P	P	P	NA	P	P	P	NA	P	P	X Elrama	P[d]

Notes:
- a. Includes co-disposal of fly ash with other wastes.
- b. Includes FGD wastes without fly ash and bottom ash.
- c. Plants for which data and information are obtained are listed in their appropriate positions.
- d. Either the interim pond of landfill aspect of operation studies at field scale, but not both.
- e. Laboratory data only.

Key:
- X = Data available from full-scale field studies.
- P = Data available from laboratory and/or limited-scale field studies for projection purposes.
- NA = Matrix combination not applicable due to lack of present and future practices.

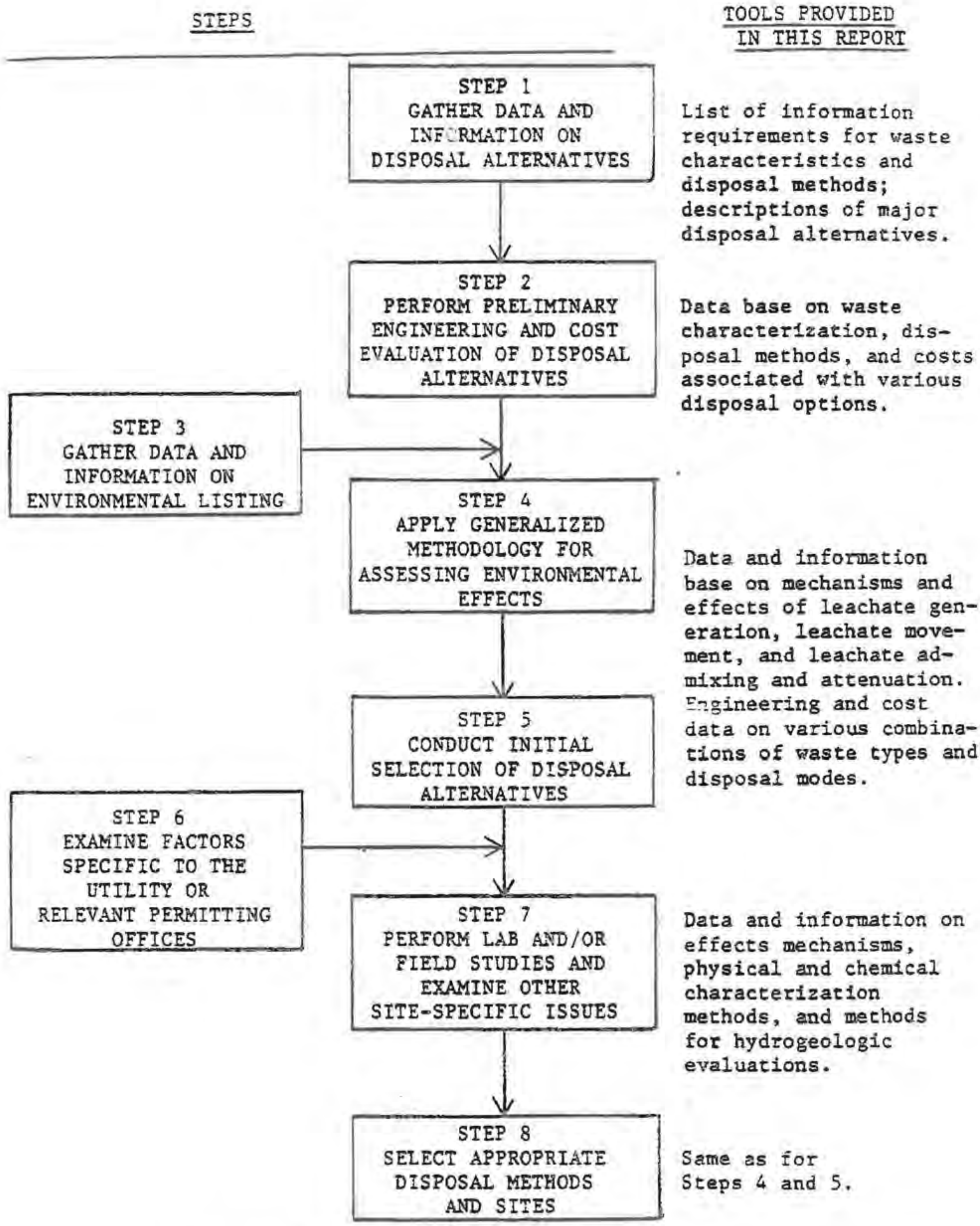


FIGURE 1.2 OVERALL DECISION-MAKING PROCESS

Section 8 of this report provides more information on the decision methodology process. It has been designed as a generic tool to aid the decision-maker. The ultimate environmental effects of coal ash and FGD waste disposal, however, are highly site- and system-specific and cannot be overly generalized.

SECTION 2.0

INTRODUCTION

2.1 PROJECT BACKGROUND

The U. S. Environmental Protection Agency's (EPA's) Office of Research and Development (ORD) contracted with Arthur D. Little, Inc. (ADL) to conduct a study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired power plants. EPA's Office of Solid Waste (OSW) worked closely with ORD on this program. The study involved waste characterization, water and sampling and waste analysis, environmental evaluation, and engineering/cost assessment of disposal practices (for coal ash and FGD wastes) at six full-scale waste disposal sites at various locations around the country.

This project was initiated in October 1979, and all technical work was completed by November 1982. This final report provides an overall summary of the data and information gathered and presents the results and conclusions from the project.

2.2 PROJECT GOALS

The overall objective of the project was to provide EPA with the technical background data and information to assist the Agency in determining the degree, if any, to which disposal of coal ash and FGD wastes needs to be managed to protect human health and the environment.

Results from this study will be used by EPA in preparing a report to Congress required under the 1980 Amendments to the Resource Conservation and Recovery Act (RCRA). The results also provide useful technical guidance concerning environmentally sound disposal of coal ash and FGD wastes (which together are called flue gas cleaning, or FGC wastes). This information is valuable to state and local permitting officials and to the electric utility industry.

2.3 SCOPE OF THE PROJECT

This project was organized into three major tasks:

- Task I - Site Selection and Test Plan Preparation.
- Task II - Site Development, Waste Characterization, Site Evaluation (Physical and Chemical

Sampling/Analysis), and Site-Specific Engineering Cost Evaluation.

- Task III - Environmental Evaluation and Generic Engineering Cost Assessment.

Figure 2.1 shows the flow of information in the overall project. The individual tasks are discussed in more detail below.

2.3.1 Task I: Site Selection and Test Plan Preparation

The purpose of this task was to select the disposal sites for evaluation and to develop a test plan for each site. The site selection process was conducted in two steps. First, all available data were evaluated to select 18 candidate and eight backup sites for further investigation, including information assembled during visits by hydrogeologic and engineering teams. These site visits served to verify and amplify the technical information and also allowed the utilities' willingness and ability to participate to be determined. The additional information acquired during those visits was used in various mid-course evaluation steps. The result of these activities was the selection of six sites for detailed environmental characterization and evaluations, together with the development and assessment of engineering cost information on the handling and disposal of coal ash and FGD waste at each of the six sites. The Site Selection Report (Appendix A) provides more detailed information on this process.

Another activity during Task 1 was to define baseline procedures and approaches for: developing a FGD waste disposal site; characterizing the waste in surrounding soils; conducting environmental evaluations; and gathering engineering/cost data. The major documents guiding the site development and sampling and analysis activities were: Hydrogeologic and Geotechnical Procedures Manual (Appendix B) and Sampling and Analysis Procedures Manual (Appendix C).

Test plans were then prepared for each of the six sites. The six individual test plans provided a detailed account of the individual steps to be taken for site development, physical and chemical sampling/ analysis and engineering/cost evaluations. These test plans, after approval by the EPA Project Officer, were reviewed by the utilities involved. All review comments were incorporated into the final test plans.

To conduct extraction procedure (EP) and radioactivity testing, grab samples were gathered during initial visits to many waste disposal sites and were subjected to the EP procedure specified in RCRA Section 3001, EP Protocol (8). This procedure requires determining the concentrations of eight trace elements (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) in the EP extract of the wastes. These wastes were also analyzed for radioactivity. The results of these evaluations are summarized in the draft report Application of EPA Extraction Procedure and Radioactivity Measurements to Coal-Fired Utility Wastes (Appendix D).

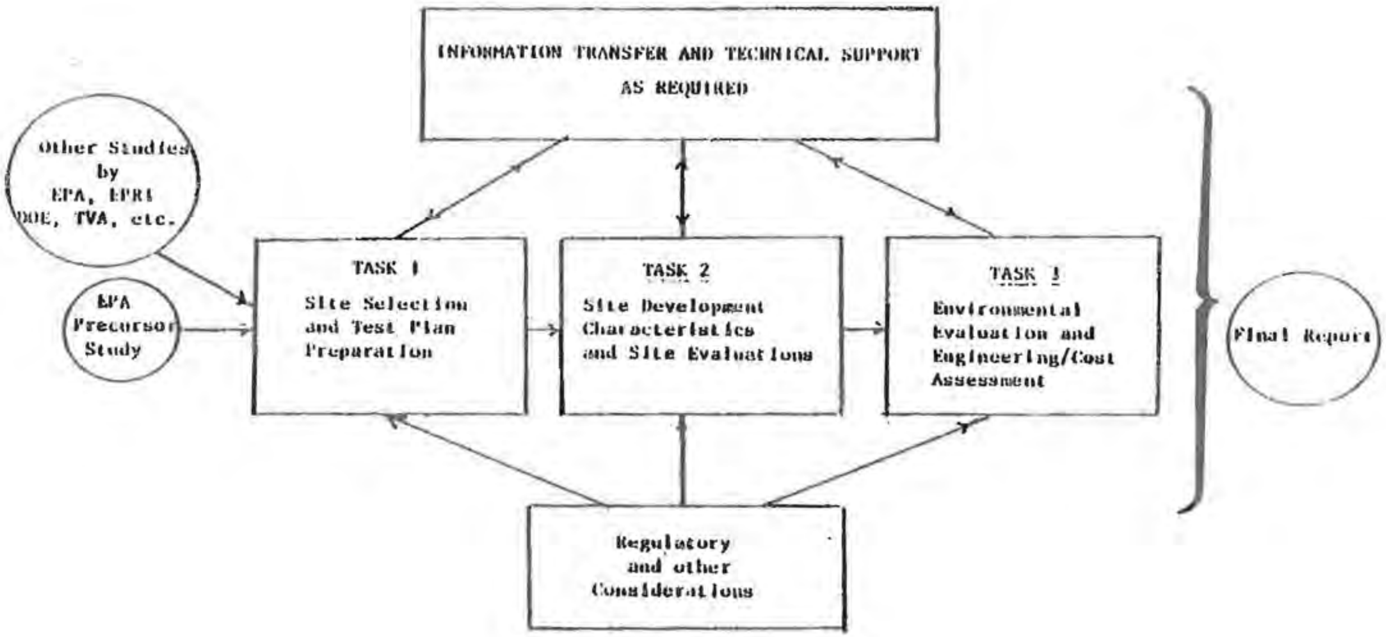


FIGURE 2.1 OVERALL PROJECT INFORMATION FLOW

2.3.2 Task II - Site Development, Waste Characterization, Site Evaluations and Engineering Cost Evaluation

During Task II, data and information were gathered for the various sites. The first step was to develop the appropriate contractual requirements with the utility and state or local environmental permitting agencies. In all cases, a letter of understanding with the utility or a full contract defining the study was required. In some instances, state environmental agencies had their own additional permitting requirements which had to be fulfilled. Access to the site was obtained after completion of all these contractual requirements and approval of the test plans by EPA and the utility.

The site was then ready to be developed. Site development involved gathering hydrogeologic and geotechnical information on the sites by an appropriate mix of borings, wells and the like. The geotechnical and hydrogeologic team guided the activities of the drilling outfits to obtain this information.

In addition to the many soil waste and water samples gathered during site development, sampling and analysis teams visited the sites periodically over a one-year period. The samples gathered were subject to chemical analysis, and, as appropriate, to physical analysis.

Another effort under Task II was to perform engineering cost evaluations. The investigative team interacted closely with the various utilities to develop process flow sheets and cost estimates for the waste handling and disposal practices at each site.

2.3.3 Task III - Environmental Evaluation, Engineering/Cost Assessment and Development of Preliminary Decision Methodology

Task III consisted of four major steps. The first was an environmental evaluation of the results from site development and physical and chemical sampling and analysis. Other sources of data, including those provided by the utilities, were also used. The assessment effort had actually begun at the very outset of sampling and analysis and continued throughout the project. Assessment memoranda were prepared for all six sites. Preliminary recommendations were made concerning approaches for sound environmental management of these wastes. These recommendations were based on the environmental data base gathered under Task II.

An engineering/cost assessment was conducted under Task III to provide generic cost information for waste handling and disposal operations. Results from the site-specific engineering cost assessments (performed under Task II), along with engineering and cost data developed for other pertinent studies, were adjusted to produce the generic engineering and cost data base.

The final major effort under Task III was to develop a preliminary decision methodology to assist state and local permitting officials or the utility industry in planning waste management options.

2.4 ORGANIZATIONS INVOLVED IN THIS STUDY

2.4.1 Contractor and Subcontractors

Arthur D. Little, Inc. (ADL) was the prime contractor for this project. Five subcontractors (Bowser-Morner Testing Laboratories, Inc., Haley & Aldrich, Inc., Kaiser Engineers Power Corp., TRW, Inc., and the University of Louisville) assisted ADL. Table 2.1 shows these participants and their areas of responsibility.

2.4.2 Utility Interfacing

Interaction with the utilities and utility cooperation were key elements in this project. FGC system requirements and waste disposal regulations are important issues to many utilities, who have a strong interest in ensuring that necessary environmental protection measures are cost effective and technically sound. The utilities thus had incentive to participate in the study, providing that proper channels of communication were set up. From the outset of the project, close communication with the utility industry was established. This included initial and follow-up contacts with specific utilities and with appropriate Electric Power Research Institute (EPRI) and Edison Electric Institute (EEI) staff members.

Two review committees were formed: the Advisory Committee, with representatives of EPA, Department of Energy (DOE), EEI, and American Public Power Association (APPA); and the Technology Committee, consisting of representatives of EPA, ADL, EPRI, and several utilities. The Committees reviewed and commented on the project as it proceeded.

As an additional mechanism for coordination, data and information obtained during the test program and the results of the field and laboratory work were provided to the utilities for review.

2.5 ORGANIZATION OF THE FINAL REPORT

This report discusses:

- The data and information gathered from the field activities, laboratory work and engineering and environmental assessments. This includes a summary of all findings and conclusions.
- Generic projections on the implications of the findings from this project and other studies by EPA, EPRI, DOE, the Tennessee Valley Authority (TVA) and others. The generic findings have been formatted to accommodate specific views by state or local permitting officials or the utility industry.
- The decision methodology developed to serve as a tool for state or planning officials or the utility industry in planning new coal ash and FGD waste disposal facilities or in modifying existing ones.

TABLE 2.1

CHARACTERIZATION AND ENVIRONMENTAL MONITORING OF FULL-SCALE

UTILITY WASTE DISPOSAL SITES

Project Area	Principal Participants
Prime Contractor/Project Management	Arthur D. Little, Inc. Cambridge, MA 02140
Chemical Sampling and Analysis	Arthur D. Little, Inc. Cambridge, MA 02140
	TRW, Inc. Redondo Beach, CA 90278
Engineering/Economic Evaluation	Arthur D. Little, Inc. Cambridge, MA 02140
	Kaiser Engineers Power Corp. Oakland, CA 94623
Geotechnical & Field Drilling	Bowser-Morner Testing Laboratories, Inc.[a] Dayton, OH 45401
Hydrogeologic Activities	Haley & Aldrich, Inc. Cambridge, MA 02142
Physical Sampling & Analysis	Bowser-Morner Testing Laboratories, Inc. Dayton, OH 45401
	University of Louisville Louisville, KY 45208

Notes:

[a]Other local drillers also were involved on some sites.

Section 3. , Background, provides information on the electric utility industry, with emphasis on coal-fired power plants. Present industry size, anticipated growth, coal utilization trends, current and future waste generation trends and disposal practices are discussed; along with an introduction to environmental settings.

Section 4.0, Approach, outlines the scope and overall approach used in site selection, site development, physical sampling and analysis, chemical sampling and analysis, engineering cost assessment and environmental assessment.

Section 5.0, Results, provides the results of this study, including an overview on the environmental assessment of the six disposal sites together with conceptual engineering designs and capital and annual costs for waste handling and disposal at each one. This section serves as a baseline for the subsequent generic assessments.

Section 6.0, Engineering Cost Assessment, gives a generic conceptual engineering designs for and the capital and annual costs of coal ash and FGD waste handling and disposal. To the extent possible, all engineering design data and cost information developed in this project have been incorporated with cost estimates from other studies to provide generic engineering flow diagrams and cost relationships for a range of waste handling and disposal options.

Section 7.0, Environmental Assessment, is an overview of the generic assessment of coal ash and FGD waste disposal based on data from the six sites and from other studies by EPA, EPRI, DOE, TVA and others. Generic projections are made for the implications of the effects from various combinations of waste types, disposal modes, and environmental settings.

Section 8.0, Decision Methodology, provides a decision methodology tool based on state-of-the-art practices to assist state and local planning officials and industry planners in decision-making for new coal-fired power plants.

Finally, detailed procedures, data, and a summary of the environmental effects of various combinations of waste types, disposal methods, environmental settings are presented in Appendices A through I.

SECTION 3.0

BACKGROUND ON COAL ASH AND FGD WASTE GENERATION

3.1 OVERVIEW OF ELECTRIC POWER GENERATION

Energy forecasts indicate significant shifts in prospective fuel usage for generating electric power in the United States. As oil and gas prices rise, coal and uranium are expected to emerge as the primary fuels during the mid-1980 to mid-1990 period. In 1980 oil and gas fuels were used to generate 26% of the total electric power produced in the United States. By 1995, assuming finances permit existing oil- and gas-fired power plants to be displaced by new nuclear or coal-fired power plants, the combined contribution of oil and gas fuels to electric power production will be reduced to only 8%. Coal is expected to provide 61% of the total electric power generation in 1995, compared with 51% in 1980 (9).

By the late 1990's, the major emerging utility technologies are likely to be non-nuclear. Most new electric power generating units will be based on conventional coal combustion. Table 3.1 gives some estimates on committed new generating capacity. Projections such as these are subject to change, mostly because of variations in electric power demand. But it is interesting that nearly two-thirds of all announced new capacity commitments are coal-fired plants. This trend is potentially important from the environmental perspective, since conventional coal combustion generates significant quantities of solid waste. These wastes -- the amounts generated, their characteristics, and methods of disposal -- are discussed briefly in this section.

3.2 COAL COMBUSTION WASTES

3.2.1 Conventional Coal Combustion

Three major technologies are used to generate electric power from coal:

- Conventional coal combustion.
- Fluidized bed combustion (atmospheric or pressurized).
- Coal gasification and combined cycle power generation.

Of these, only conventional coal combustion has reached commercialization. Although the others may be used commercially in the 1990's, conventional coal combustion will remain the predominant method for the next 25 years.

TABLE 3.1

COMMITED NEW ELECTRIC GENERATING PLANTS AND CAPACITIES: 1982 AND LATER

Technology	TIME FRAME 1982-1985 No.	MW	1985-1990 No.	MW	1990-1995 No.	MW	1995-1999 And Later No.	MW	TOTAL No.	MW
Coal and Lignite	67	32,299	68	38,671	33	19,000	35	17,678	203	107,648
Oil and Gas	4	126	1	120	--	--	--	--	5	246
Biomass	1	40	--	--	--	--	--	--	1	40
Multifuel[a]	4	1,716	2	1,320	--	--	--	--	6	3,036
Combustion Turbine	1	170	--	--	--	--	1	250	2	420
Hydroelectric	73	10,775	41	6,711	7	1,578	16	5,620	137	24,684
Pump and Storage	2	1,250	8	3,775	2	435	19	10,402	31	15,862
Geothermal	10	636	9	752	1	110	--	--	20	1,498
Nuclear	37	37,068	33	34,886	6	7,380	12	13,790	88	93,124
TOTAL	199	84,080	162	86,235	49	28,503	83	47,740	493	246,558

NOTES:

[a]Coal-oil, coal-water, or coal-refuse mixture.

Source: Reference 10

Table 3.2 lists the waste output of a conventional coal-combustion based power plant. Coal-fired power plants based on conventional combustion technology generate two categories of waste materials, based on the volume of material. The high-volume wastes are coal ash (fly ash, bottom ash or boiler slag) and flue gas desulfurization (FGD) wastes. The low-volume wastes are those associated with numerous other processes or maintenance operations in a power plant.

This project is concerned primarily with high-volume wastes. In some cases the disposal sites studied also received (in addition to one or more high-volume wastes) one or more low-volume wastes; such as coal pile runoff or maintenance cleaning wastes. In such cases, the environmental effects of these low-volume wastes were also studied.

3.2.2 Coal Ash Collection Technology

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

The total amount of coal ash produced varies with the ash content of the coal fired and can range from a few percent of the weight of the coal fired to as much as 35%. The partitioning of ash between fly ash and bottom ash usually depends on the type of boiler. Standard pulverized coal-fired boilers typically produce 80% to 90% of the ash as fly ash. In cyclone-fired boilers which are frequently used to burn lignite, the fly ash fraction is usually somewhat less, and in some cases bottom ash accounts for most of the total ash.

Collecting bottom ash (or boiler slag) does not involve systems outside the boiler itself. Fly ash, however, is an important source of particulate emissions and requires a major collection system. Fly ash carried in the flue gas stream can be collected in many ways to meet the current particulate emission control requirements. Typical methods have included mechanical collection, electrostatic precipitation, fabric filtration and wet scrubbing. However, with the tightening of regulatory requirements, future systems will have to be highly efficient in removing submicron particulate matter. This criterion means that all mechanical collectors and many wet scrubber systems will not be sufficient when used as the only method of control. But the mechanical collector may function as a preliminary collector followed by a more efficient collector.

Any particulate control devices used in utility boiler applications will have to be commercially available and proven for this application. This constraint eliminates, for the immediate future many hybrid wet scrubber systems and novel collectors that are now under development. In the long run, however, such advanced systems may be used.

TABLE 3.2

COAL COMBUSTION WASTES[a]

High-Volume Wastes

- Fly ash
- Bottom ash or boiler slag (economizer ash[b] and pyrites typically included)
- Flue gas desulfurization (FGD) wastes

Low-Volume Wastes

- Coal pile runoff and other surface drainage
- Boiler blowdown
- Cooling tower blowdown
- Water treatment wastes
- Maintenance and cleaning wastes
- General power plant trash
- Plant sanitary wastes

[a]Basis: Conventional coal combustion in a utility power plant.

[b]Ash produced as the flue gas passes through the economizer.

Electrostatic precipitators and fabric filters may be the only systems capable of meeting particulate emissions control requirements in the foreseeable future. In addition, dry fly ash handling systems will become more attractive, especially for new plants, because of environmental and cost considerations.

3.2.3 Flue Gas Desulfurization (FGD) Technology

Options -- Flue gas desulfurization (FGD) wastes are produced as a result of controlling emissions of sulfur oxides to the atmosphere. FGD processes are being applied increasingly to control sulfur oxide emissions from fossil fuel combustion in industrial and utility boilers, and many processes have been developed for these wastes. Table 3.3 shows present and projected total FGD controlled generating capacities. The specific FGD process breakdowns are given in Tables 3.4 and 3.5. These tables indicate a rapid expansion in the projected use of FGD systems. In general, the technology falls into two categories: nonrecovery, or throwaway systems, which produce a waste material for disposal; and recovery systems, which produce a potentially saleable byproduct (either sulfur or sulfuric acid) from the recovered SO_2.

Nonrecovery FGD Processes -- Nonrecovery processes make up the overwhelming majority of operating FGD systems. Of the nine different FGD processes and process variations that can be considered commercially available, seven are nonrecovery systems. These seven processes constitute more than 95% of the capacity currently operating on utility and industrial boilers, a trend which is expected to continue.

Nonrecovery FGD consists of wet and dry processes. Wet processes involve contacting the flue gas with aqueous slurries or solutions of absorbents and producing wastes in the form of solutions or slurries. These wastes can be directly discharged or processed further before disposal. In most cases, waste slurries are partially dewatered and processed to produce a soil-like material for landfilling. Dry processes, on the other hand, produce essentially moisture-free solids. These systems are based on dry injection of adsorbents into the flue gas or the use of spray dryers.

Most nonrecovery processes in operation, as well as those due to come on line until the end of 1984, involve wet scrubbing. In these, gaseous sulfur oxides are absorbed in the slurry where they react with an alkaline reagent to form calcium sulfite, calcium sulfate (gypsum) and a calcium sulfite-sulfate coprecipate. The degree of oxidation determines the composition of these wastes. Gypsum is desirable because it has better dewatering characteristics than calcium sulfite.

Some dry FGD systems are now operational, and a number of contracts have been signed for the application of dry systems to utility boilers. These systems have been scheduled for startup in the early to mid-1980's.

Of the seven different types of nonrecovery processes now in commercial use on industrial and utility boilers, five involve converting SO_2 to some form of solid waste (sludge) for disposal in either wet ponds or landfills. Most utility applications of nonrecovery FGD processes involve solid

TABLE 3.3

NUMBER AND TOTAL CAPACITY OF FGD SYSTEMS AS OF EARLY 1982

Status	Number of Units	Total Controlled Capacity, MW[a]	Equivalent Scrubbed Capacity, MW[b]
Operational	92	34,937	31,738
Under construction	42	18,226	17,457
Planned:			
Contract awarded	16	9,385	9,169
Letter of intent	11	8,293	8,235
Requesting/evaluating bids	10	5,630	5,630
Considering only FGD systems	51	30,726	30,398
TOTAL	222	107,197	102,627

Notes: [a]The summation of the gross unit capacities (MW) brought into compliance FGD systems regardless of the percent of the flue gas scrubbed by the FGD systems(s).

[b]The summation of the effective scrubbed flue gas in equivalent MW based on the percent of the flue gas scrubbed by the FGD system(s).

Source: Reference 11

TABLE 3.4

DISTRIBUTION OF FGD SYSTEMS BY PROCESS
AS OF DECEMBER 1982

Process	FGD Capacity, MW Operational	Under Construction	Contracted Awarded/Planned	Total
Nonrecovery				
Limestone[a]	15,420	9,362	16,100	40,882
Lime[b]	13,013	3,710	1,660	18,383
Lime/Spray Drying	110	2,893	1,260	4,263
Lime/Limestone	20	0	0	20
Lime/Sodium Carbonate	100	0	0	100
Sodium Carbonate	1,255	250	1,650	3,155
Sodium Carbonate/Spray Drying	440	0	0	440
Dual Alkali	1,181	842	265	2,288
Aqueous Carbonate/Spray Drying	100	0	0	100
Recovery				
Lime	0	65	0	65
Limestone	0	166	0	166
Lime/Limestone	0	475	0	475
Magnesium Oxide	240	484	0	724
Wellman-Lord	1,959	0	0	1,959
Citrate	60	0	0	60
Not Yet Selected	0	0	30,148	30,148
TOTAL	33,898	18,247	51,083	103,228

[a]Includes limestone and alkaline fly ash/limestone systems.
[b]Includes lime and alkaline fly ash/lime systems.

Source: Reference 12

TABLE 3.5

SUMMARY OF FGD SYSTEMS BY PROCESS

		Percent of Total	
		September 1981[a]	December 1999[b]
Nonrecovery Processes			
Wet Systems			
Lime		36.8	20.6
Limestone		48.7	36.9
Dual Alkali		3.7	2.0
Sodium Carbonate		4.0	3.1
NA[c]		-	5.2
Dry Systems			
Lime		0.3	3.4
Lime/Sodium Carbonate		-	0.1
Sodium Carbonate		1.4	0.4
Saleable Product Process			
Process	Byproduct		
Aqueous Carbonate/ Spray Drying	Elemental Sulfur	-	0.1
Citrate	Elemental Sulfur	0.2	0.1
Lime	Gypsum	-	0.1
Limestone	Gypsum	-	0.2
Lime/Limestone	Gypsum	-	0.5
Magnesium Oxide	Sulfuric Acid	-	0.7
Wellman-Lord	Sulfuric Acid	2.3	1.2
Wellman-Lord	Elemental Sulfur	2.6	0.8
Process Undecided		-	24.6
TOTAL		100.0	100.0

[a]Actual as of September 1981.
[b]Estimates for December 1999.
[c]NA - Not available. These systems are committed to nonrecovery processes; however, the actual process is unknown at this time.

Source: Reference 11

waste-producing systems. In contrast, the large majority of industrial boiler FGD applications generate liquid wastes. Solid waste-producing systems are conventional direct lime scrubbing, conventional direct limestone scrubbing, conventional limestone scrubbing with forced oxidation, alkaline fly ash scrubbing, and dual alkali scrubbing. Two systems, once-through-sodium scrubbing and ammonia water scrubbing, produce a soluble waste which is discharged as an aqueous liquor to holding ponds or wastewater treatment systems.

Wet scrubbing nonrecovery systems can usually withstand some levels of simultaneous particulate collection and, in the past, many scrubbers were designed for simultaneous sulfur oxides and particulate removal. However, most FGD systems being installed today on utility-scale boilers follow high efficiency particulate control systems in order to ensure reliable service of the FGD system.

Several factors, including increased coal use and the 1979 New Source Performance Standards (NSPS) for utility boilers, have promoted the use of dry FGD processes. Three different approaches have been actively pursued:

- Injection of solid sorbents into the flue gas stream with collection of sorbents downstream in a particulate control device.
- Injection of solid sorbents into the boiler combustion zone.
- Contacting of flue gas with alkali sorbent slurries in a spray dryer.

Of these, spray dryer FGD is the major commercially applied dry FGD process. The others are in earlier stages of development.

Recovery Processes -- As in the case of nonrecovery processes, recovery processes can be categorized into wet and dry systems, according to the mode of SO_2 removal. They can be further classified according to the type of byproduct -- concentrated SO_2 for conversion to sulfur or sulfuric acid, sulfur only, or sulfuric acid only.

Only two recovery processes have been commercially demonstrated on large industrial- or utility-scale boilers -- the Wellman-Lord process and magnesium oxide scrubbing. The citrate scrubbing process has been tested on a large industrial boiler. All three are based on wet scrubbing. The total capacity attributable to these three wet processes was less than 5% of the total FGD operating capacity in 1980, and the market share for such systems is expected to remain below 5% of the total installed FGD capacity on boilers in the United States through early 1990. No dry sorbent recovery FGD systems are operating on utility or industrial boilers, although some are in the advanced stages of development.

Even recovery FGD systems are not waste free. All available processes, as well as many development, produce a certain amount of waste. The wet processes generally cannot tolerate any significant contamination of the absorbent with fly ash, chlorides, or other trace species in the flue gas and usually require a prescrubber ahead of the SO_2 absorber. Treatment of the blowdown from the prescrubber can generate wastes in amounts up to 15% of those produced by nonrecovery FGD processes. There may also be secondary waste streams, formed by oxidation of the absorbent, that require purging.

3.3 CURRENT WASTE GENERATION AND TRENDS

Coal ash and FGD wastes (collectively known as flue gas cleaning or FGC wastes) can be classified into four major waste types:

- Fly ash or fly ash admixed with other materials. This category of wastes includes fly ash, fly ash mixed with bottom ash, fly ash, bottom ash, and FGD wastes that are disposed together. Wastes containing fly ash are known as stabilized wastes. They are worthy of separate consideration, since the majority of trace metals available for leaching from utility solid wastes may be associated with the fly ash-containing fractions.

- Non fly ash materials. In this category are included bottom ash (or boiler slag), unstabilized wastes, and FGD wastes that are disposed separately from fly ash, including forced oxidation wastes. These materials usually contain lesser concentrations of trace metals compared to fly ash wastes but can have higher concentrations of major species.

- Treated FGD wastes. FGD wastes may be chemically treated (a process known as fixation) for full-scale disposal. Lime/fly ash fixation for landfill disposal is presently practiced at some power plants and is expected to become more prevalent. Chemically treated FGD wastes are placed in a separate category because of the differences in their physical and chemical properties created by the fixation process.

- Dry FGD wastes. Several dry FGD systems are coming into commercial use. Dry FGD systems provide a combined waste containing fly ash and the sulfur compound in a relatively dry form. This waste will likely be sent for disposal in a managed landfill. The physical and chemical properties of these wastes are expected to be different from other waste types. Even limited field-scale information on their leaching characteristics is lacking.

More detailed information on waste types is available in Section 6.

Table 3.6 shows how much coal ash and FGD wastes have been generated from coal combustion over recent decades. With New Source Performance Standards (NSPS) requirements that all new coal-fired utility boilers constructed after September 18, 1982 scrub at least 70% of their sulfur oxides emissions, FGD waste generation is projected to increase dramatically in the immediate future. Recent estimates on future growth in electric power demand have been very modest compared to the growth over the past 20 years. Table 3.7 presents some estimated data on ash generation in the United States by EPA Region for

TABLE 3.6

WASTE GENERATION FROM COAL COMBUSTION

Waste Type	Amount of Waste Generated (10^6 metric tons)		
	1966	1975	1979
Fly Ash[a]	15.5	38.4	52.2
Bottom ash[a]	7.3	16.1	16.1
FGD wastes[b,c]	NA	NA	NA

Notes: [a]Dry basis

[b]Wet basis as 50% solids

[c]FGD waste estimates are based on 100% scrubbing (no bypass) and use of the FGD system wherever the boiler is operating. Actual waste generation is probably considerably less.

Source: References 13 and 14

TABLE 3.7

PROJECTIONS FOR ASH GENERATION BY UTILITY PLANTS
IN THE UNITED STATES BY FEDERAL EPA REGION
(1978-1995)

EPA Region	Ash Generation (10^6 Metric Tons/yr) 1978[a]	1985[a]	1995[a]
I	0.1	0.3	1.8
II	1.4	2.9	5.5
III	8.9	10.6	13.8
IV	14.8	20.2	26.3
V	18.6	23.2	27.0
VI	3.0	10.3	15.2
VII	4.5	7.1	8.3
VIII	2.8	5.9	7.8
IX	1.2	2.2	3.8
X	0.3	0.5	0.5
TOTAL	55.6	83.2	110.0

Notes:

[a]Includes both new and existing plants as well as those plants converting from oil/gas to coal.

Source: Reference 2

1985 and 1995. These estimates include both fly ash and bottom ash. (For an average coal-fired power plant, the ash is normally distributed as follows: bottom ash, 20 to 25% of total ash; fly ash, 70 to 80%; economizer ash, 1 to 5%; and uncollected ash, about 5% of total ash.) Table 3.8 gives estimates on total coal ash and FGD waste generation rates for 1980, 1985 and 1995. Over the time period shown, the total volume of waste generated is projected to more than double.

3.4 COAL ASH AND FGD WASTE CHARACTERISTICS

Physical and chemical characteristics of coal ash and FGD wastes are critical parameters in the proper design and operation of waste handling and disposal systems. Design and operation of ponds and landfill depend on the physical and engineering properties, while environmental effects of leachate movement are determined by the waste's chemical and engineering properties. These characteristics are discussed below, with emphasis on leachate mobility, which was the primary focus of this project.

3.4.1 Chemical Characteristics

This section summarizes the chemical composition of the major categories of FGC wastes:

- Fly ash/bottom ash,
- FGD Wastes (lime, limestone and dual alkali),
- Dry sorbent FGD waste (sodium and calcium based), and
- Chemically treated FGD wastes.

The chemical compositions of these wastes are described in terms of major components, trace components, and liquors and leachate.

This section is not a comprehensive review of available data but rather points to general concentration ranges observed. Greater detail on previous studies and a more comprehensive compilation are available in References 2 and 3.

3.4.1.1 Major Components of FGC Wastes--

Coal Ash -- Coal ash consists mainly of fly ash and bottom ash. The chemical characteristics of fly ash depend on a variety of factors -- the type of coal, the extent of coal preparation and treatment before burning, and the particular operating conditions of the boiler. The method of ash collection is also important because the size distribution of the resultant ash particles affects its chemical composition.

The ash represents the fraction of the original coal which does not burn and is typically composed mostly of silicon, aluminum, and iron oxide species. Ash composition is usually analyzed in terms of elemental composition (e.g., for Al) rather than species present (e.g., Al_2O_3). Table 3.9 shows ranges for major components (median concentrations greater than about 0.5% by weight) according to coal rank (eastern and western bituminous and western lignite).

TABLE 3.8

PROJECTIONS OF COAL ASH AND FGD WASTE GENERATION

UTILITY PLANTS IN THE UNITED STATES

(1980-1995)

Waste Type	Waste Generation (10^6 Metric tons/yr)		
	1980	1985	1995
Coal Ash[a]	62.4	83.2	110.0
FGD Wastes[b]	8.6	26.9	48.6
TOTAL	71.0 (78.3)[c]	110.1 (121.4)[c]	158.0 (174.8)[c]

[a] Coal ash quantities are shown on a dry basis.
[b] FGD waste quantities are shown on a wet basis (50% solids).
[c] 10^6 tons/yr.

Source: Reference 2

TABLE 3.9

CHEMICAL COMPOSITION OF FLY ASHES ACCORDING TO COAL RANK - MAJOR SPECIES (WEIGHT PERCENT)

	Eastern Bituminous			Western Bituminous			Western Lignite		
Chemical Species[a]	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	1.45	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	3.88-35.40	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
Phosphorous Pentoxide P_2O_5	<0.02-0.42	2.73	16	1.19-0.70	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

[a]Composition reflects only element breakdown of constituents and reported as their oxides and is not meant to indicate actual compounds present.

Source: Reference 3

The presence of particular crystalline phases has been reported for a limited number of fly ash samples (3,15,16). The following crystalline phases have been observed:

- α Quartz (SiO_2),
- Anhydrite (β-$CaSO_4$),
- Lime (CaO),
- Mullite ($3Al_2O_3 \cdot 2SiO_2$),
- Magnetite (Fe_3O_4),
- Hematite (α Fe_2O_3), and
- Periclase (MgO).

Bottom ash is collected either in a dry or a molten state (the latter is referred to as boiler slag). Bottom ash has a different particle size distribution than fly ash and its bulk density is higher. Its major component chemical composition is similar to that of fly ash. Boiler slag is a black, glassy substance composed chiefly of angular or rod-like particles, ranging in size from that of fine gravel to sand.

FGD Wastes -- Flue gas desulfurization wastes are wastes produced by wet scrubbing of SO_2 with calcium-based reagents and include calcium salt components due to scrubber reagent present in the waste and fly ash that is simultaneously removed with the waste. Table 3.10 summarizes the major components in the solid phase of these wastes.

The waste composition is affected by many factors, and the presence of certain components can vary widely:

- calcium salts ($CaSO_4$, $CaSO_3$, $Ca(OH)_2$, $CaCO_3$),
- fly ash,
- inert materials (present in reagents), and
- composition and quantity of excess scrubber liquor (containing Ca^{+2}, Cl^-, Mg^{+2}, K^+, Na^+, SO_4^{-2}, SO_3^{-2}).

The amount of $CaSO_4$ present (i.e., $CaSO_4 \cdot 2H_2O$ or $CaSO_4 \cdot \frac{1}{2}H_2O$) depends on the extent of oxidation in the system. This is usually higher in systems burning low sulfur coal and in direct limestone systems vs. direct lime systems. Oxidation can be promoted in many systems (including dual alkali) to generate wastes with low $CaSO_3$ content. $CaSO_4$ is preferable to $CaSO_3$ because it gives the waste material better disposal properties.

The amount of fly ash in FGD waste depends on whether the SO_2 scrubber is also used to remove fly ash (particulate control) or whether the fly ash is admixed with the FGD waste after separate collection of each. The amount of inerts and excess reagents ($Ca(OH)_2$, $CaCO_3$) varies with the quality and utilization of the reactant raw materials. These wastes may also contain quantities of Mg salts (i.e., $MgSO_4$), which crystallize out of scrubber solutions in plants with a tight water balance where concentrations of soluble species can rise to high levels.

TABLE 3.10

MAJOR COMPONENTS IN FGD WASTE SOLIDS[a]
Range (%)

FGD Process	$CaSO_3 \cdot 1/2\ H_2O$	$CaSO_4 \cdot 2H_2O$	$CaCO_3$	Fly Ash	Other
Limestone	8-40	5-85	0-74	1-65	0-5[b], 0-10[c]
Lime	2-94	2-95	0-3	3-60	0-2[b]
Dual Alkali	0.2-90	5-64	2-11	0-9	0-20[b], 0-7[d]
Limestone (with forced oxidation)	<3	47-62	5-10	30-40	
Lime (with forced oxidation)	<3	52-62	2-5	30-40	
Fly Ash Scrubbing	0-5	5-40	<1	40-70	5-30[b]

[a] Data is for a limited number of plants including full scale, prototype and pilot.
[b] $MgSO_4$ (or NaCl)
[c] $CaSO_4 \cdot 1/2\ H_2O$ or $CaSO_4$
[d] $Na_2SO_4 \cdot 7H_2O$

Source: References 2,13,17

FGD wastes carry with them occluded or free (excess) liquor from the process. These liquors contain varying amounts of major common species (such as Na^+, Cl^-, Ca^{+2}, SO_4^{-2}, Na^+, SO_3Y-2, K^+ and Mg^{+2}), as well as trace components. The amount of liquor varies according to the extent of dewatering before disposal and can range from 10 to 90% of the total weight of the waste (3). Concentration ranges observed for the major species in waste liquors are given in Reference 3. Such concentrations are dictated either by solubilities (e.g., $CaSO_4$ or $CaSO_3$) or by the rate at which the ions enter the system from various sources (e.g., Na^+, Cl^- from ash or flue gas). Sodium levels in direct lime and limestone systems are generally much lower than in the sodium-based dual alkali system, where levels can reach 10,000 ppm or more, depending on the degree of cake washing. Levels of Ca^{+2}, SO_4^{-2} and SO_3^{-2} are generally dictated by solubility of the respective salts.

Dry Sorbent FGD -- Dry sorbent SO_2 scrubbing units use both sodium- and calcium-based reagents. Sodium-based systems involve bicarbonate and carbonate scrubbing materials, either by solids injection or spray drying, to produce Na_2SO_4 and Na_2SO_3 products. Calcium-based systems use a slurry of lime or limestone to produce salts similar to those obtained in other wet scrubbing systems ($CaSO_4$, $CaSO_3$). Fly ash may also exist as a major component. The chemical composition of these wastes is only generally known. The waste tends to differ from wet calcium scrubbing wastes in terms of content of unreacted lime or limestone, particle morphology, hydrated states of products, as well as trace element distribution. Also, no liquid phase is expected. Reference 18 gives more details on the composition of waste materials from dry sorbent FGD.

Chemically Treated FGD Wastes -- Procedures to produce chemically treated FGD waste have been studied. The processing generally involves adding agents to the waste to modify chemical or physical properties (sometimes both) to help increase strength, decrease permeability, and produce a product that will be more environmentally acceptable for disposal.

The major components of the chemically treated wastes are the FGD waste, fly ash, the additive needed for the particular procedure, and any chemical reaction product produced by the interaction of the additive with the fly ash and FGD waste. The most common additives are lime and fly ash, which help to form a pozzolanic product.

Several companies offer waste solids fixation processes, but only two processes - Dravo's Calcilox® and Conversion systems, Inc. (CSI) Poz-O-Tec® - have been sufficiently developed and tested to be commercially feasible for use with FGD waste solids. In the Dravo process, Calcilox®, a product derived from blast furnace slag, is added to the waste solids. The CSI process involves vacuum filter dewatering of FGD solids, followed by addition of time, dry fly ash, and other substances to produce a dry product called Poz-O-Tec®, which can be used as landfill.

These fixation processes depend on formation of cementitious calcium silicate and aluminate-type pozzolanic products. Limited data are available on the composition of individual process products, although Reference 2 provides some useful information. Products of the pozzolanic stabilization reactions have been identified as ettrignite ($3Ca(OH)_2 \cdot AlH_2O_3 \cdot CaSO_4 \cdot 32H_2O$), tetracalcium aluminate monocarbonate hydrate, tetracalcium monosulfite hydrate, and calcium silicate hydrate gel. Other investigators have found the sulfite analog of ettrignite as a product.

3.4.1.2 Trace Components--

Coal Ash Solids -- Trace elements in coal ash derive mostly from their original presence in the coal and to a minor extent from the water used in coal handling. Table 3.11 gives the ranges of trace element concentrations in a variety of ashes. Concentrations of some elements are directly related to the original content of the coal, while others (such as As and Sb) do not correlate well, either because of their volatile nature or because their concentrations are unevenly distributed in terms of the fly ash particle size.

Particular elements, notably S, Hg and Cl, are almost completely volatilized and leave the boiler as gaseous products which are not collected downstream in the dry ash collection equipment. Other volatile species may recondense on the fly ash particle surface downstream from the boiler and would account for the elevated levels on the finer particles that have larger surface areas. Antimony, selenium, arsenic and lead are notable for being significantly enriched on suspended particles in the stack (3).

Radioactive radium (^{226}Ra) concentrations and radon emanation have been measured in ash samples, both as part of this and other studies (see, for example, Section 5 and Reference 19).

Trace Components in FGD Wastes -- Trace element concentrations in FGD wastes depend primarily on:

- Levels of trace elements in the coal.
- Amount of ash admixed with the FGD waste.
- Efficiency of the scrubber in capturing trace species.
- Trace elements in reactant feed and process makeup waters.

Thus, to the extent that the waste contains ash, trace elements in the ash will be present in the waste. Trace components in any remaining scrubber liquor will also be present. Significant correlations of the trace element levels in the waste with the concentrations in the coal are less likely, because of the varying amounts of ash that can be admixed and the other sources of trace elements (reactant feeds). Table 3.12 shows concentration ranges for trace elements in FGD waste solids.

Dry Sorbent FGD Wastes -- Only limited data are available regarding trace element composition of dry sorbent FGD wastes. To the extent these wastes contain co-collected or admixed fly ash, they are expected to show the composition of the ash component. Trace chemical components present in wastes from two dry sorbent processes are presented in Table 3.13.

TABLE 3.11

CONCENTRATION RANGE OF TRACE SPECIES PRESENT IN COAL ASHES[a]

Element[b]	Concentration Ranges (ppm) Lignites and Subbituminous	Anthracites	Bituminous
Ag	1-50	1	1-3
As	9-45		11-990
B	320-1900	63-130	74-2800
Ba	55-13900	540-1340	96-4660
Be	1-28	6-11	4-60
Br	2-3		2-4
Ce	<95-130		<53-250
Cl	41-90		76-270
Co	11-310	10-165	10-440
Cr	11-140	210-395	36-490
Cu	53-3020		30-850
F	16-1000		30-380
Ga	10-30	30-71	10-135
Ge	20-100	20-20	20-285
La	34-90	115-220	19-270
Li	56-100		48-500
Mn	310-1030	58-365	31-4400
Mo	6-11		12-17
Nb	21-34		31-78
Ni	20-420	125-320	20-610
Pb	20-165	41-120	23-1500
Rb	17-43		29-<1000
Sc	2-58	50-82	7-155
Se	5-16		10-37
Sn	10-660	19-4250	10-825
Sr	230-8000	80-340	40-9600
Th	21-43		26-54
V	20-250	210-310	60-860
W	7-14		16-30
Y	21-120	70-120	29-460
Yb	2-10	5-12	3-23
Zn	50-320	155-350	50-1200
Zr	100-490	370-1200	115-1450

[a] Atomic absorption data on coals ashed at 600°C (1140°F). Concentrations are ppm.

[b] Elements with concentrations <2ppm include Ru, Pd, Re, Os, Ir, Rt, Au, Rh, Te, Bi, W, Hf, Lu, I, Cd.

Source: Reference 3

TABLE 3.12

CONCENTRATIONS OF TRACE METALS IN FGD WASTES AND COAL

Elements	FGC Waste Solids (ppm)	FGC Waste Liquor (ppm)	Range in Coal (ppm)
Antimony	---	0.09-1.6	---
Arsenic	0.6-63	<0.004-1.8	3-60
Beryllium	0.05-11	<0.001-0.18	0.08-20
Cadmium	0.08-350	0.004-0.11	---
Chromium	3-250	0.001-0.5	2.5-100
Copper	1-76	0.002-0.6	1-100
Lead	0.2-21	0.001-0.55	3-35
Manganese	11-120	<0.01-90	---
Mercury	0.001-6	<0.001-0.07	0.01-30
Molybdenum	---	0.9-5.3	---
Nickel	6-27	0.005-1.5	---
Selenium	0.2-19	<0.001-2.7	0.5-30
Zinc	10-430	0.01-27	0.9-600

Source: Reference 3

TABLE 3.13

TRACE COMPONENTS IN LIME-BASED DRY SORBENT FGD WASTES[a]

Element	Concentration (ppm)	
	Sample 1[b]	Sample 2[c]
Ag	< 0.5	< 0.5
As[d]	30	38
Ba	350	100
Be	4.3	12
Cd	< 1	< 1
Cr	52	33
Co	4.9	14
Cu	16	15
Pb[d]	< 20	< 20
Mn	630	71
Mo	16	3.6
Ni	215	43
Se[d]	< 20	< 20
Sb	< 8	< 8
Sr	1,900	300
V	580	52
Zn	37	69

[a]As analyzed using inductively coupled argon plasma spectroscopy.
[b]Joy/Niro test facility at Riverside Power Station.
[c]Mikropul test facility at Strathmore Paper Company.
[d]Measured by atomic absorption.

Source: Reference 18

Chemically Treated FGD Wastes -- The trace element composition of chemically treated FGD wastes is affected by the same variables that determine the major chemical constituents. The particular fixation process will largely determine the concentrations and distribution of the trace elements in the final product. Table 3.14 shows the range of concentrations of trace species observed in several chemically treated FGD waste samples (lime, limestone and dual alkali FGD wastes before and after fixation) via four different fixation processes.

3.4.1.3 Liquors and Leachate Compositions--

The mobility of waste species in aqueous phases is critical because of potential for leachate migration and groundwater contamination. Although the waste solids contain certain elements, it is the concentration of elements in the aqueous phases produced by the wastes in their respective disposal environment that is of primary importance. This means that, for wet disposal scenarios, concentrations of pond liquors (either surface liquors or interstitial liquors in the waste solid phase) are primary indicators of leachate composition. The waste solids composition represents the reservoir available for leaching over the longer term.

For wastes that contain a smaller amount of moisture such as untreated FGD wastes which are disposed of in a landfill, the composition of the occluded liquor is also of primary importance, since the occluded liquor will be flushed with incoming water, and the resulting liquor will comprise the primary leachate. Subsequent volumes of water will produce leachate more in keeping with the solid waste composition. Data on these types of leachates are available from laboratory and some field studies.

In dry disposal, the primary chemical composition of the leachate has generally been estimated by performing laboratory and field studies on the extractability of waste species contacted with aqueous phases. A variety of batch and column test procedures has been used, including those proposed by the EPA (EPA-Extraction Procedure) (8) and the American Society for Testing and Materials (ASTM Methods A and B) (20). Limited data have also been produced from field studies where site groundwater or surface water contacted and/or percolated through the unsaturated waste to generate a leachate that was collected in sampling devices. In this project, EPA extraction tests were conducted and reported on 18 grab samples of coal ash and FGD waste (Appendix D).

Fly Ash and Bottom Ash Pond Liquors -- The chemical composition of fly and bottom ash pond liquors varies greatly, depending on the composition of the ash, the quality of water used to sluice the ash, as well as the contact time of the liquid and solid phases. Table 3.15 shows concentration ranges for a limited number of ash pond discharges.

The acidity of the slurry produced greatly affects concentrations of other components in the aqueous phase. Generally, the higher the acidity, the greater the rates of solubilization of the elements. Composition of the discharge may be quite different from that of the interstitial pond liquor due to the different contact mode and time and environment (e.g., reducing vs. oxidizing) of each.

TABLE 3.14

TRACE COMPONENTS IN WASTE SOLIDS
BEFORE AND AFTER FIXATION[a]

Element	Before Fixation (ppm)	After Fixation (ppm)
As	13-170	2-60
Be	BDL[b]-27	BDL[b]-8.5
Cd	2.3-18	4.4-26
Co	35-83	11-29
Cr	25-130	14-90
Cu	38-280	24-77
Hg	0.08-1.9	0.06-0.5
Mn	44-600	25-78
Ni	50-220	20-76
Pb	84-380	15-85
Sn	19-84	5.5-48
V	69-530	35-180
Zn	67-170	45-110

[a]Ranges reported for trace components of wastes from 4 fixation processes: fly ash and lime additive; two additives to produce soil-like product; two additives to produce concrete-type product; and patented additive with pH adjustment to produce clay-like product.

[b]BDL = Below Detection Limit.

Source: Derived from References 2 and 3

TABLE 3.15

ILLUSTRATIVE ANALYSES OF ASH POND DISCHARGES (in ppm)

Substance	Fly Ash Pond Range	Avg.	Data Pts.
Arsenic	0.01 - 1.1	0.38	3
Barium	0.2 - 0.3	0.25	2
Cadmium	0.001 - 0.037	0.019	2
Chloride	6 - 7	6.5	2
Chromium	0.02 - 0.067	0.044	2
Copper	0.02 - 2.4	0.91	3
Cyanide	-	-	-
Iron	1.44 - 630	211.12	3
Lead	0.01 - 0.91	0.33	3
Manganese	0.13 - 0.48	0.31	2
Selenium	0.002 - 0.33	0.12	3
Silver	-	-	-
Sulfate	209 - 358	283.5	2
Zinc	0.06 - 2.2	1.26	3

Substance	Bottom Ash Pond Range	Avg.	Data Pts.
Arsenic	0.006 - 0.018	0.012	2
Barium	0.1 - 0.2	0.15	2
Cadmium	0.001 - 0.003	0.002	2
Chloride	7 - 8	7.5	2
Chromium	0.009 - 0.01	0.095	2
Copper	0.041 - 0.065	0.053	2
Cyanide	-	-	-
Iron	5.29 - 5.98	5.64	2
Lead	0.02 - 0.02	0.02	2
Manganese	0.16 - 0.58	0.37	2
Selenium	0.002 - 0.011	0.007	2
Silver	-	-	-
Sulfate	49 - 139	94	2
Zinc	0.09 - 0.14	0.12	2

Substance	Combined Ash Pond Range	Avg.	Data Pts.
Arsenic	0.005 - 0.038	0.038	9
Barium	0.1 - 0.2	0.19	10
Cadmium	0.001 - 0.005	0.002	6
Chloride	3 - 14	7.2	10
Chromium	0.004 - 0.043	0.015	10
Copper	0.01 - 0.[illegible]8	0.042	10
Cyanide	0.01 - 0.[illegible]5	0.[illegible]3	3
Iron	0.23 - 2.3	0.8	10
Lead	0.01 - 0.025	0.014	10
Manganese	0.01 - 0.39	0.09	9
Selenium	0.003 - 0.065	0.016	10
Silver	-	0.01	1
Sulfate	59 - 156	109.[illegible]	10
Zinc	0.03 - 0.12	0.[illegible]	10

Source: Reference 21

Further data on composition of ash pond effluents (overflow) are available (2,3). The data presented in this study on field interstitial liquors (those present within the waste solids) represent most of the limited set of existing data for these types of samples. Additional information on field interstitial liquors is available from a TVA study (22).

FGD Waste Liquors -- The composition of FGD waste liquors depends to a great extent on the specific FGD process. Typical levels are shown in Table 3.16. Speciation of the various components in liquors and in leachates of these wastes is important in terms of their subsequent mobility in the environment (e.g., extent of soil attenuation under the sites), as well as their possible toxicity. Little information is available regarding speciation of particular elements (e.g., As) in ash pond liquors. The presence of both As^{+3} and As^{+5} depends on the oxidizing/reducing conditions. In addition, thermodynamic data have been used to calculate concentrations of ion pairs and complexes present in solution (2,23). Field data on interstitial waste pond liquors are extremely sparse.

Leachate Composition -- Leachate data (for unsaturated disposal conditions) have been derived mainly from laboratory tests and from some pilot studies. The various types of tests used on the different samples of ash and FGD waste provide a range of information, much of which is useful in understanding leaching mechanisms. However, the data are very specific to the particular experimental conditions of the given test.

Compositions of wet disposal leachates can be better estimated initially from waste liquor compositions. For dry disposal, field data or lab data are needed. To normalize leaching test methods, both EPA and ASTM have developed standard leaching test procedures (8,20). The EP method has been widely practiced to obtain extract data on ash and FGD wastes and provides a large data base for the various types of utility wastes. Table 3.17 shows some data obtained for a variety of ash and FGD samples. Additional information is available in References 25 and 26 and in Appendix D.

3.4.2 Physical and Engineering Properties

Certain physical and engineering properties of coal ash and FGD wastes are important in terms of how they affect the waste's disposal characteristics. These include:

- Grain properties
- Compaction behavior
- Permeability
- Strength properties

These properties are briefly described below. More detail is available in References 2, 3, 27, and 28 and in Appendix E of this report.

3.4.2.1 Grain Properties--

Particle size distribution is an important grain property because it affects many engineering parameters. A material with a very small range of

TABLE 3.16

TYPICAL LEVELS OF CHEMICAL SPECIES IN FGD WASTE LIQUORS AND ELUTRIATES

	Eastern Coals			Western Coals		
Species	Range in Liquor (ppm)	Median (ppm)	Total No. of Observations	Range in Liquor (ppm)	Median (ppm)	Total No. of Observations
Antimony	0.46-1.6	1.2	4	0.09-0.22	0.16	2
Arsenic	<0.004-1.8	0.020	15	<0.004-0.2	0.009	7
Beryllium	<0.0005-0.05	0.014	16	.0006-0.14	0.013	7
Boron	41	41	1	8.0	8.0	1
Cadmium	0.004-0.1	0.023	11	0.011-0.044	0.032	7
Calcium	470-2,600	700	15	240-(~45,000)[b]	720	6
Chromium	0.001-0.5	0.020	15	0.024-0.4	0.08	7
Cobalt	<0.002-0.1	0.35	3	0.1-0.17	0.14	2
Copper	0.002-0.4	0.015	15	0.002-0.6	0.20	7
Iron	0.02-0.1	0.026	5	0.42-8.1	4.3	2
Lead	0.002-0.55	0.12	15	0.0014-0.37	0.016	7
Manganese	<0.01-9.0	0.17	8	0.007-2.5	0.74	6
Mercury	0.0009-0.07	0.001	10	<0.01-0.07	<0.01	7
Molybdenum	5.3	5.3	1	0.91	0.91	1
Nickel	0.03-0.91	0.13	11	0.005-1.5	0.09	6
Selenium	<0.005-2.7	0.11	14	<0.001-2.2	0.14	7
Sodium	36-20,000[a]	118	6	1,650-(~9,000)[a]	--	2
Zinc	0.01-27	0.046	15	0.028-0.88	0.18	7
Chloride	470-5,000	2,300	9	1,700-43,000[b]	--	2
Fluoride	1.4-70	3.2	9	0.7-3.0	1.5	3
Sulfate	720-30,000[a]	2,100	13	2,100-18,500[a]	3,700	7
TDS	2,500-70,000[a]	7,000	--	5,000-95,000[b]	12,000	3
pH	7.1-12.8	-		2.8-10.2	--	

[a] Levels of soluble sodium salts in dual alkali sludge (filter cake) depend strongly on the degree of cake wash. The highest levels shown reflect single measurements on an unwashed dual alkali filter cake.

[b] Levels of soluble chloride components in sludges are dependent upon the chloride to-sulfur ration in the coal. The highest levels shown are single measurements for a western limestone scrubbing system operating in a closed-loop using cooling tower blowdown for process makeup water.

Source: Reference 3

TABLE 3.17

CONCENTRATIONS OF METALS IN EP EXTRACT OF ASH AND FGD SAMPLES
(ppm)

	No. of Points	pH	Ag	As	Ba	Cd	Cr	Hg	Pb	[illegible]
Bituminous Coal[a] Fly Ash #2	5	[illegible]	[illegible]	[illegible]	[illegible]-0.72	[illegible]-0.78	[illegible]-2.1	<0.0001-0.0018	[illegible]	[illegible]
Bituminous Coal[b] Fly Ash #1	6	4.15-5.17	[illegible]	[illegible]	[illegible]	[illegible]	0.06-0.2	[illegible]	[illegible]	[illegible]
Bituminous Coal[c] Bottom Ash	[illegible]	4.75-5.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	<0.0001-0.005	0.0001-[illegible]	[illegible]
Lignite Coal Fly Ash[d]	7	6.95-11.46	<0.009-0.06	[illegible]	[illegible]	0.002-0.7	0.011-0.18	0.0001-0.0006	0.0027-0.4	[illegible]
Lignite Coal[e] Scrubber Sludge	9	[illegible]-5.4	<0.009-0.06	0.0001-0.025	[illegible]	0.001-0.01	0.00175-0.5	0.00002-0.0003	<0.005-0.05	[illegible]
Sub-bituminous Coal[f] Fly Ash	6	[illegible]	[illegible]-0.08	[illegible]	[illegible]	[illegible]	0.08-0.16	[illegible]	[illegible]	[illegible]
Bituminous Scrubber[g] Sludge (Untreated)	8	[illegible]	[illegible]	[illegible]	0.2-2.5	0.00003-0.063	[illegible]-0.13	<0.0002-0.0096	0.0004-0.41	[illegible]
Bituminous Scrubber[h] Sludge (Treated with Calcilox®)	9	[illegible]-7.8	[illegible]	[illegible]	0.29-2.5	[illegible]	[illegible]-0.13	0.00006-0.0016	0.0004-0.26	[illegible]

[a] [illegible] Plant of Ohio Power Co., Moundsville, West Virginia, Unit #1. Samples taken Feb. 1979.
[b] Harrison Power Station, West Virginia, Monongahela Power [illegible] Samples taken early 1979.
[c] Harrison Power Station, West Virginia, Monongahela Power [illegible] Samples taken early 1979.
[d] Milton Young Power Plant, Minnkota Power Cooperative, Center, North Dakota. Samples taken Feb. 28, 1979.
[e] Milton Power Station, Unit #2, Minnkota Power Cooperative, Center, North Dakota. Samples taken Feb. 28, 1979.
[f] Waukegan Station, Commonwealth Edison Co., Chicago, Illinois.
[g] [illegible] Power Station, Pittsburgh, Pennsylvania.
[h] [illegible] Power Station, Pittsburgh, Pennsylvania. Treated by addition of Calcilox Additive® of Dravo Corporation.

Source: Reference 24

particle sizes is said to be uniformly graded (sometimes known as poorly graded). A material with a well dispersed assortment of particle sizes is considered well graded. The distinction is important, since a well graded material can be readily compacted to a dense condition and will generally develop greater shear strength and lower permeability than uniformly graded material.

The distribution of particle size can be expressed as a curve of particle size versus percent of particles smaller than the particle size. Figure 3.1 describes the entire spectrum of fly ashes, including those from a variety of coals. Materials with steeper curves have a smaller range of particle size and are more uniformly (or poorly) graded. Fly ash is usually uniformly graded material with particles primarily in the silt range.The particle size of fly ash ranges from 1 µm to 100 µm in diameter for the glassy spheres, with an average of 7 µm, and from 1[illegible] µm to 300 µm in diameter for the more angular carbon particles. The grain size distribution can be altered by blending with other materials (e.g., bottom ash).

Figure 3.1 also indicates the range of grain size distributions for bottom ash and boiler slag. Bottom ash and boiler slag have particles ranging in size from that of fine sand to that of fine gravel. Boiler slag is more uniform in size than the bottom ash.

Grain size distribution for sulfite-rich FGD wastes without ash centers in the 2-74 µm range (62-93%), with smaller amounts (4-8%) in the >74 µm and <2 µm range. Sulfate-rich FGD wastes without ash similarly center in the 2-74 µm range (66-76%), but a larger fraction is in the >74 µm range (18-30%) and a smaller fraction (2-6%) in the <2 µm range. Addition of fly ash materials to FGD wastes increases the fraction in the 2-74 µm range (3).

3.4.2.2 Compaction Behavior--

Compaction behavior is related to compressibility, density, and moisture content. The compressibility of a fly ash fill affects the rate and amount of settling which may occur. Non-self-hardening fly ash behaves like a cohesive soil in terms of consolidation and settlement. The compressibility of fly ash near its maximum dry density is low. Typical values for compressibility (percent of original height at 50 psi or 345 Pa) are 1.8 for fly ash and 1.4 for bottom ash.

The compaction behavior of sulfate and sulfite FGD wastes is largely determined by the particle morphology, grain size distribution, and specific gravity of the material. Generally, addition of fly ash to sulfate and sulfite wastes increases maximum dry density and decreases moisture content at the maximum dry density. Repeated impacts on sulfite wastes appear to cause progressive breakdown of the waste particles. Sulfate wastes are generally less compressible than sulfite wastes due in part to different particle morphology. Consolidation tests indicate that uncompacted sulfite FGD wastes may compress as much as 10% of their original height in a fill. Sulfate wastes are much less compressible (21, 27, 31, 32).

Density, the weight per unit volume of material, is important because it influences the permeability, stiffness, and strength. These in turn affect

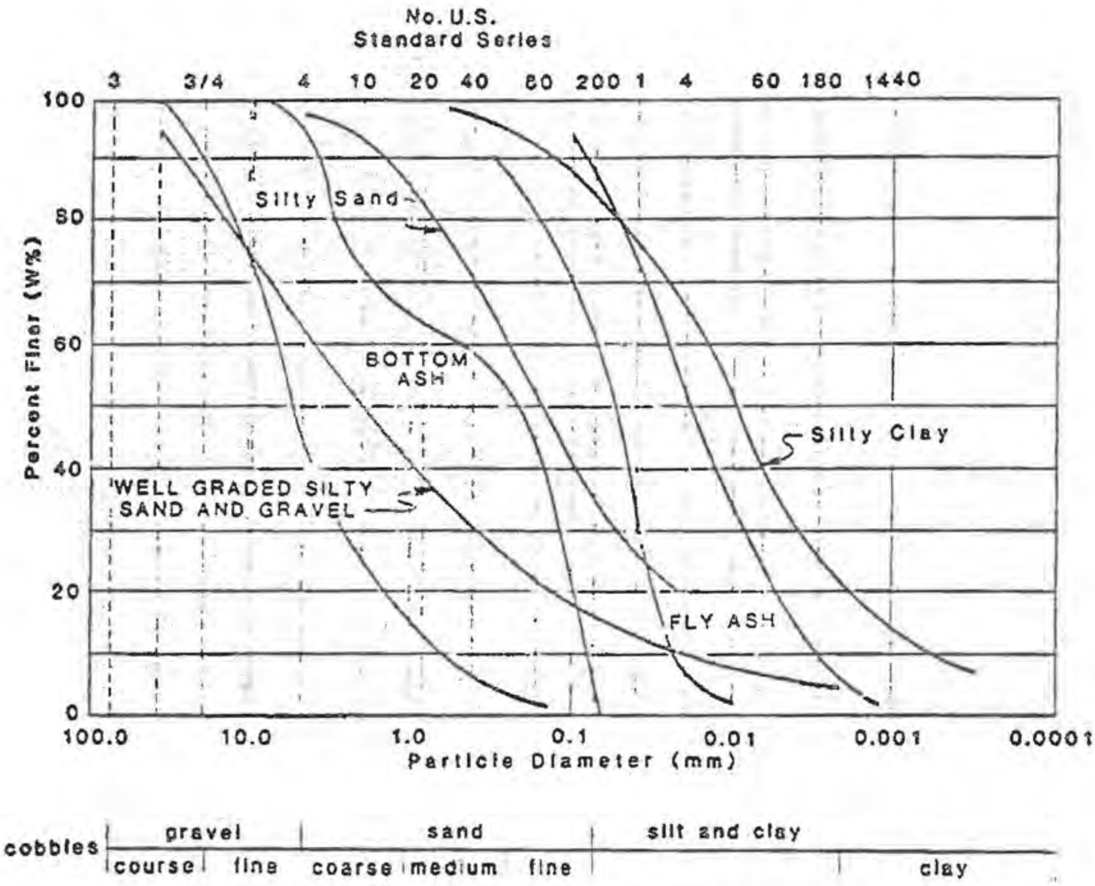


FIGURE 3.1 RANGE OF TYPICAL ASH GRAIN SIZE CURVES

Source: References 29.30

the extent of settlement and stability of a fly ash landfill, as well as leachate mobility. Density can be dry or wet. Dry density occurs when the pore spaces in the waste contain only air. If all or part of the voids is filled with water, the density is known as a wet density, with a corresponding moisture content. The ash is said to be saturated if all the voids are filled with water. Reference 33 discusses density and specific gravity in detail.

The ash moisture content refers to the amount of water present in the voids of the ash. Moisture content affects weight and other handling and engineering properties, including compaction behavior of the waste. Expressed as a percentage of the ash's dry weight, moisture content is determined by dividing the weight of the water in the voids by the weight of the ash when dry, and then multiplying this figure by 100. Two moisture contents, the natural (or in-place moisture content) and the optimum moisture content, are important. The optimum moisture content of an ash is related to the maximum density obtained by compaction in the laboratory. The in-place moisture content is a function of the deposition environment of the ash. Typical values of natural moisture content are 2 to 5 percent for silo-stored ash and 50 to 100 percent for lagoon-stored ash (2, 3).

Due to tension forces and the small pore size distribution in these wastes, capillary action causes water to be drawn into the waste. Thus, in situations where the waste is placed above groundwater, the waste can become saturated.

3.4.2.3 Permeability--

Permeability is a function of the viscosity of the water, the size and shape of the waste grains, the degree of compaction, and the number of discontinuities present in the waste mass. The coefficient of permeability is a convenient indicator of the quantity of water which will seep through the waste in a given period of time. Since leachate is produced when water contacts the waste and then migrates from the disposal site, permeability data provide a way to estimate leachate migration rates and quantity.

Fly ash is a freely draining material, with a permeability around 0.5 to 5×10^{-4} cm/sec. The permeability of sulfite-rich FGD wastes is generally lower than that of sulfate-rich FGD wastes, although well-managed gypsum formation in a dual alkali plant may produce low permeability waste. Addition of stabilizing agents may decrease permeability by one or more orders of magnitude. Unstabilized sulfite-rich FGD wastes have permeabilities in the range of 0.9×10^{-5} to 4×10^{-5}. Stabilization leads to values around 5×10^{-8} to 11×10^{-5}. Unstabilized sulfate-rich FGD wastes have values in the 1×10^{-5} to 98×10^{-5} range (2, 3, 28, 34). A decrease in permeability is also observed with an increase in fly ash content of FGC waste due to a decrease in the void ratio (or increase in solids content).

By comparison, clean gravel can have permeabilities as high as 30 cm/sec, while clays can have values as low as 10^{-9} cm/sec (21).

3.4.2.4 Strength Properties--

Shear strength of the waste is important in engineering the waste disposal, since it will determine the steepness and fill slopes as well as the ability of the waste to support loads. Shear strength is a function of cohesion and the angle of internal friction. Cohesion is a measure of individual particles' attraction for each other, while the angle of internal friction is a measure of friction between particles.

Dry fly ashes which are not self-hardening possess little cohesion, although pore moisture may lead to apparent cohesion due to capillary forces. This apparent cohesion can be eliminated by drying or saturation. Fly ashes which self-harden develop strength. This strength more closely resembles the chemical bonding strength of cement than the cohesive strength of a soil. The angle of internal friction of fly ash varies with the degree of compaction, as does the shear strength of bottom ash and boiler slag. The angle of internal friction for bottom ash and boiler slag in a loose condition can vary from 38° to 42.5° (30).

FGD wastes generally show insignificant effective cohesion but unconfined compression strength in the 10-20 psi range is obtained for samples at their maximum dry density. Strength parameters for stabilized wastes are sensitive to moisture content and age of the waste. Stabilizing agents such as fly ash and lime can greatly cause great increases in strength for the cured materials (2, 3).

3.5 DISPOSAL OPTIONS

Most coal ash and all FGD wastes generated today are sent to disposal. This trend should continue for many years, in view of the expected increase in coal consumption for generating electric power. Over the longer term, an effective way to manage coal and FGD wastes will be to utilize them. A significant fraction of the total generation of coal ash can be used as soil stabilizers, for ice control, and as ingredients in cement, concrete, and blasting compounds (2, 3). Utilization of FGC wastes is expected to grow, but at a slower rate than FGC waste generation. In 1980, there was no utilization of FGD wastes in the United States.

Currently, all FGC waste disposal options involve some form of land disposal. At-sea disposal may be a future alternative if practiced under environmentally and economically acceptable conditions. The land-based disposal options can be characterized in terms of the nature of the wastes, the type of disposal, and site characteristics. Table 3.18 lists some of the potential disposal options. Sulfur is included in this table as a potential waste product, although it is more likely that sulfur as a by-product of recovery FGD systems will be produced for utilization.

Recovery FGD processes are likely to require prescrubber systems to remove particulate absorbent liquors. Prescrubber blowdown from these systems will result in waste analogous to the waste from nonrecovery FGD systems, albeit in smaller quantities. Hence, even if recovery processes are used more extensively in the future, FGD waste quantities will be reduced, not eliminated.

TABLE 3.18

LAND DISPOSAL OPTIONS FOR UTILITY SOLID WASTES

Disposal Method	FGD Wastes: FGD Waste	FGD Wastes: Codisposal[a]	FGD Wastes: Chemically Treated Waste	Other Wastes: Coal Ash	Other Wastes: Sulfur
Conventional Wet Ponding	C[b]	C	C	C	-
FGD Gypsum Stacking[d]	P[c]	-	-	-	-
Managed Fill	C	C	C	C	P
Surface Mine	P	C	P	C	P
Underground Mine	P	P	-	P	P

Notes:

[a]Codisposal of coal ash and FGD waste.

[b]Commercial practice.

[c]Reasonable potential.

[d]From forced oxidation FGD systems.

Source: Reference 3

Land disposal methods for utility wastes are wet ponding, disposal in managed fills, and mine disposal. These are reviewed below, along with some comments on ocean disposal, which may be an alternative in the future.

Wet ponding is more widely used than any other method of coal ash/FGD waste disposal, although it will probably be less prevalent in the future because it is a fairly costly disposal method. Ponding is suitable for a wide variety of FGC wastes, ranging from unstabilized FGD materials to waste that has been treated by a proprietary chemical fixation process. Pond designs are based on diking or incision. Ponds can also be engineered on slopes. These options are discussed further in Section 6. A special case of wet ponding, gypsum stacking, is now under evaluation. It involves pumping gypsum slurry (typically from forced oxidation system) to a pond, where it is allowed to settle. The supernatant is recycled. Periodically the gypsum is dredged and stacked around the embankments, thus building up the entrainment.

Disposal in managed fills may include:

- Landfilling of dry fly ash.
- Interim ponding of FGC wastes followed by dewatering and in some cases, excavation and landfilling.
- Mechanical dewatering and landfilling of FGC wastes.
- Stabilization, or blending of FGD wastes and dry fly ash, followed by landfilling of the mixed FGC wastes.
- Fixation of FGD with additives, followed by landfilling of the chemically treated waste.

Typically, before disposal in a managed fill, FGD wastes and/or coal ash handled in wet systems are thickened and dewatered to a high solids content. Dry fly ash may be directly disposed of with no treatment. FGD wastes may be blended with fly ash and, in some cases, lime, thus forming a material with cementitious properties. The waste material is transported to the disposal site where it is spread on the ground and compacted. Layering proceeds to an ultimate depth that can range from 30 to as much as 80 feet or more. A properly designed and operated dry impoundment system can potentially enhance the value of the disposal site after disposal is completed, or at least permit post operational use.

Mine disposal is receiving increased attention. Surface coal mines and underground room and pillar mines for coal, limestone, or lead/zinc ores offer particular potential (10). Coal mines, especially surface coal mines, are the most likely candidates. They offer the greatest capacity for disposal and are frequently tied directly to power plants. In fact, many new coal-fired power plants are "mine-mouth" (located adjacent to or within a few miles of the mine), with the mine providing a dedicated coal supply. Since the quantity (volume) of FGC wastes produced is considerably less than the amount of coal burned, such mines would usually have enough space for waste disposal throughout the power plant's life.

Ocean disposal is not practiced today. But if applied under environmentally acceptable conditions, ocean disposal could represent an important utility waste management option, particularly in the Northeast where land available for disposal operations is limited. Viable techniques are available for transporting FGC wastes to offshore disposal sites. The sites may be in the shallow ocean (on the continental shelf) or deep ocean (off the continental shelf). Each has a different ecosystem with its own set of potential impacts. Potential waste materials with suitable disposal properties include fly ash-free gypsum and chemically treated mixtures of FGD waste, fly ash, and lime.

3.6 CURRENT DISPOSAL PRACTICES

Table 3.19 summarizes current disposal practice based on a survey of 176 coal-fired power plants, or about 75% of all coal-fired power plants in the U.S. that generate at least 80% of their power from coal, with capacities of at least 200 MW. As shown, combined fly ash and bottom ash ponding is the most common method of disposal for coal ash, with nearly 45 percent (by weight) of all fly ash and bottom ash codisposed of in ponds (35). Landfilling of fly ash was also reported as a significant disposal option -- more than 30 percent (by weight) of all fly ash is disposed of in this manner (35). Interim ponding followed by landfilling seems to be a major method of bottom ash disposal where separate disposal of bottom ash is practiced; this method accounts for between 25 and 30 percent (by weight) of all bottom ash sent to disposal (35). Bottom ash is also often ponded. Separate ponding of fly ash and bottom ash is practiced to a lesser extent (about 20 percent by weight) than combined fly ash and bottom ash ponding, while mixed disposal of coal ash/FGD waste and disposal of chemically treated FGD wastes are only now coming into more extensive use.

To consider current disposal from another perspective, Table 3.20 presents data on ash handling systems used by utility plants on the basis of physiographic region. In regions with the highest concentrations of coal-fired utility plants (B and D), wet handling of fly and bottom ash is the most common disposal procedure.

While most coal ash and FGD wastes are now disposed of by ponding, economic, environmental, and regulatory developments are likely to encourage the use of dry disposal methods in the future. Complementing the development of dry disposal methods, FGD waste fixation (chemical treatment) processes are likely to find a broader acceptance. As of mid-1980, there were more than 12 plants practicing FGD waste fixation, and this number is likely to grow in the future (12).

3.7 PRIOR DATA BASE ON CHARACTERISTICS AND ENVIRONMENTAL EFFECTS

To provide a perspective for this project, this section includes a brief review of earlier studies concerning characterization of FGC wastes and environmental evaluation of waste disposal. More detailed information on these studies is available in References 2 and 14. These results were considered in the assessments described in Section 5.

TABLE 3.19

CURRENT FGC WASTE DISPOSAL METHODS USED AT UTILITY COAL-FIRED POWER PLANTS[a]

	Number of Plants[b]		
	Pond[c]	Landfill[c]	Interim Pond/Landfill[d]
Fly ash only	18	46	6
Bottom ash only	29	13	29
Combined fly and bottom ash	69	9	16
FGD waste only	5	-	-
Mixed fly ash and FGD waste	7	7	-
Mixed bottom ash and FGD waste	1	-	1
Mixed fly ash and FGD waste (chemically treated)	2	7	-
Mixed fly ash, bottom ash, and FGD waste	2	1	1

[a]Data base: 176 coal-fired plants (≥80% of their power generated from coal in 1977 with generating capacities ≥200 MW except for four plants that employ FGD systems).

[b]Figures represent the number of plants at which each waste type/disposal method is practiced. (Note that many plants utilize more than one method.)

[c]Includes direct ponding and interim/final ponding methods.

[d]Includes managed and unmanaged fills and mine disposal.

Source: Reference 35

TABLE 3.21

SOME RECENT CHEMICAL CHARACTERIZATION PROGRAMS

Organization Performing Research	Areas Of Investigation	Status in 1982
WES[a]	Stabilized-Wastes Laboratory Leaching and Analysis	Completed
Rutgers University[b]	Characterization of Stabilized Wastes Completed	
SUNY[a]	Characterization of Stabilized Wastes/Ocean Disposal	Ongoing
Radian Corporation[a]	Characterization of Stabilized Wastes Completed	
ADL[a]	Characterization and Environmental Monitoring of Full-Disposal Sites	Under Way
ADL[a]	Chemical and Physical Characteristics of Wastes	Completed
ADL/NEA[a]	Characterization of Stabilized Wastes/Ocean Disposal	Completed
ADL/UND[a]	Monitoring of Mine Disposal	Completed
Michael Baker Associates[c]	Monitoring of Stabilized Waste Disposal Under Way	
CEA[c]	Stabilized-Waste Disposal (Scholz) Completed	
Aerospace Corporation[a]	Characterization of Unstabilized Wastes Completed	
WES[a]	Ash Leaching Effects on Groundwater	Completed
University of Notre Dame[b]	Fly Ash Leaching and Speciation and Groundwater	Completed
TVA[a]	Coal Ash Leaching, Soil Studies	Completed
TVA[a]	Ash Leaching	Completed

(continued)

TABLE 3.21 (continued)

Various Organizations[d]	Leaching Tests Evaluation of Wastes	Completed
ERCO[b]	Leaching and Radioactivity of Ashes	Completed
University of Tennessee[b]	Dry Sorbent Waste Leaching	Completed
Various Organizations[b,f]	Organics in Ash	Completed
Illinois Geological Survey[b]	Leachates Characterization	Completed

WES - Waterways Experiment Station
SUNY - State University of New York
ADL - Arthur D. Little, Inc.
NEA - New England Aquarium
UND - University of North Dakota
EPRI - Electric Power Research Institute
CEA - Combustion Equipment Associates
TVA - Tennessee Valley Authority
DOE - Department of Energy
ASTM - American Society for Testing and Materials
ES - Engineering Science
ERCO - Energy Resources Company

[a]Funding by EPA
[b]Funding by various organization
[c]Funding by EPRI
[d]One study with many participants
[e]Funding by EPRI/DOE/ASTM/ES
[f]Smaller studies

TABLE 3.20

DIVISION OF UTILITY PLANTS BY ASH HANDLING SYSTEMS AND PHYSIOGRAPHIC REGION

Physiographic Region		Dry Fly + Dry Bottom		Dry Fly + Wet Bottom		Dry/Wet Fly + Wet Bottom		Wet Fly + Dry Bottom		Wet Fly + Wet Bottom	
A1	Gulf Coastal Plain	1		5		0		0		9	
A2	Piedmont & Coastal Plain	1		2		1		0		17	
B	Appalachian	0		12		1		0		30	
C	New England	0		1		0		0		1	
D	Interior Lowlands	0		6		6		1		22	
E	Ozark	0		1		0		0		2	
F	Great Lakes	0		8		3		0		6	
G	Superior	3		1		1		0		2	
H	Great Plains & West	0	4	1	5	0	3	0	0	0	5
I		0		1		3		0		2	
J		1		3		0				2	
K		2		0		0		[illegible]		1	
L		0		0		0		0		0	
M		1		0		0		0		0	
TOTAL NUMBER OF PLANTS (% of Total)		9 (5.6)		41 (25.6)		15 (9.4)		1 (0.6)		94 (58.8)	

Source: Reference 35

3.7.1 Chemical Characterization of Coal-Fired Utility Wastes

Several studies of utility waste -- principally coal combustion and coal cleaning wastes -- have been undertaken. The Environmental Protection Agency (EPA), Electric Power Research Institute (EPRI), and other organizations have examined the chemical characterization of coal combustion wastes. Table 3.21 lists major studies funded by government agencies or EPRI. These have focused on wastes generated by SO_2 removal systems (with or without simultaneous fly ash removal). In addition, a number of private organizations active in commercial fixation of FGC wastes and in the marketing of FGC systems, as well as the utilities, have valuable in-house data, much of which is not available in the open literature.

3.7.2 Physical Characterization of Coal-Fired Utility Wastes

Physical properties that have been studied for coal combustion wastes include index properties, consistency-water retention, viscosity versus water content, compaction behavior, dewatering characteristics, strength parameters, permeability, and weathering. EPRI and EPA have sponsored several studies concerning the physical characterization of FGC wastes and coal cleaning wastes. Table 3.22 gives a partial listing of investigators who have performed physical tests on FGC wastes and indicates the types of tests performed. In addition to the projects listed in Table 3.22, many studies are being conducted by utility organizations, individual utilities, and agencies that furnish waste fixation processes and expertise.

3.7.3 Field Studies

EPA, EPRI, DOE, TVA, and others have undertaken several FGD waste disposal studies, as indicated in Table 3.23.

TABLE 3.22

SUMMARY OF PHYSICAL TESTING - FGC WASTES

Waste Type	Physical Tests	Investigators[a]
Sulfite-Rich ($CaSO_x \cdot 1/2H_2O$)	Grain-Size Analysis	ADL, Aerospace, Dravo, FMC, UL, WES
	Atterberg Limits	DRAVO, FMC, UL
	Proctor Compaction	ADL, FMC, UL, WES
	Permeability	ADL, Aerospace, UL, WES, Radian
	Consolidation	DRAVO, FMC, UL
	Unconfirmed Compression	ADL, Radian
	Triaxial Compression	FMC, UL Radian
	Dynamic Loading	UL
	Dewatering-Viscosity	ADL, Aerospace, UL
	Field Compaction	SCS
Mixed Sulfite/Sulfate ($CaSO_x \cdot 1\ 2H_2O$ + $CaSO_4 \cdot 2H_2O$)	Grain Size Analysis	Aerospace, H&L, K&D, UL, WES
	Atterberg Limits	H&L, K&D, UL
	Proctor Compaction	H&L, K&D, UL, WES
	Permeability	Aerospace, K&D, WES
	Consolidation	UL
	Unconfined Compression	H&L, K&D
	Triaxial Compression	H&L, K&D
	Dewatering-Viscosity	ADL, Aerospace, Dravo

(continued)

TABLE 3.22 (continued)

Sulfite-Rich ($CaSO_4 \cdot 1/2H_2$ + or $CaSO_4 \cdot 2H_2O)^2$	Grain-Size Analysis	ADL, Aerospace, UL, WES, Radian
	Atterberg Limits	UL
	Proctor Compaction	ADL, TCT, UL, WES
	Permeability	ADL, Aerospace, WES, Radian
	Consolidation	UL
	Unconfined Compression	ADL, TCT, Radian
	Triaxial Compression	UL, Radian
	Dewatering-Viscosity	ADL, Aerospace,
Other (mixed)	Liquefaction	TVA

Notes:

[a]ADL - Arthur D. Little, Inc.
Aerospace - Aerospace Corporation
Dravo - Dravo Corporation
FMC - FMC Corporation
H&L - Haas and Ladd
K&D - Klynn and Dodd, Ontario Hydro
SCS - Southern Company Services
TCT - Twin City Testing
UL - University of Louisville
WES - U.S. Army Waterways Experimental Station
Radian - Radian Corporation
TVA - Tennessee Valley Authority

TABLE 3.23

RECENT FIELD TESTING PROJECTS - FGC WASTES - 1982

Basis: 1. Only recently completed, ongoing or planned projects are mentioned.
2. Projects involving paper studies or engineering/economic assessment with no characterization or monitoinr are also included.

Number	Sponsor[a]	Principal Contractor[a]	Type of Waste	Form of Waste	Disposal Mode	Test Area	Comments
LAND DISPOSAL							
1.	EPA	ADL	Many	Many	Many	All over the U.S.	This project was initiated in late 1979.
2.	EPRI	MBA	Many	Many	Many	All over the U.S.	Eight-site engineering/economic assessment of projected solid waste disposal practices.
3.	EPA/EPRI	CEA/ADL	Dual Alkali, Sulfite-rich	Filter Cake	Dry Impoundment	Several acre sites at Plant Scholz of Gulf Power	Completed.
4.	EPRI	CIC/Radian	Gypsum	Thickened Slurry	Gypsum Stacking	One acre site at Plant Scholz of Gulf Power	Results appear encouraging.
5.	EPRI	MBA/Battelle	Thiosorbic Lime based FGD wastes	Stabilized by CSI and as filter	Dry Impoundment	Several cells at Conesville Plant of Columbus and Southern Ohio Electric	Phase I report published. Tests continuing.
6.	EPA	Bechtel	Dual Alkali Sulfur rich	Stabilized and as filter cake	Dry Impoundment	Wet and dry impoundments (<0.1 acre each) at Cane Run Plant, Louisville Gas & Electric	Completed.
7.	EPA	TVA/Bechtel/Aerospace	Lime & Limestone FGD Systems; forced oxidation units	As cake and as slurry	Dry Impoundment	Four Pts. at Shawnee Plant, TVA	Completed.
8.	DOE	UND	Alkaline Ash based FGD system waste	Filter cake and as slurry	Surface Mine Disposal	Sections of mine at Milton Young Plant of Minnkota Power	Originally funded by EPA and now continued by DOE.

(continued)

TABLE 3.23 (continued)

Number	Sponsor[a]	Principal Contractor[a]	Type of Waste	Form of Waste	Disposal Mode	Test Area	Comments
9.	DOE	Engineering Science	Many	Many	Many	All over the U.S.	Engineering/economic study of sites. No characterization or monitoring.
OCEAN DISPOSAL							
10.	DOE/EPA EPRI/ NYERDA/	SUNY/CSI	Thiosorbic lime-based FGD wastes	Stabilized by CSI and as bricks	Reef Construction	Off Long Island	Work is continuing.

NOTES: [a]ADL - Arthur D. Little, Inc.
CEA - Combustion Equipment Associates
CIC - Chiyoda International
DOE - Department of Energy
EPA - U.S. Environmental Protection Agency
EPRI - Electric Power Research Institute
CSI - Conversio Systems, Inc.
NYERDA - New York State Energy Research & Development Agency
PASNY - Power Authority of the State of New York
SUNY - State University of New York
TVA - Tennessee Valley Authority
UND - University of North Dakota
NEA - New England Aquarium
MBA - Michael Baker Associates

Source: Arthur D. Little, Inc.

SECTION 4.0

APPROACH

4.1 BACKGROUND

The environmental effects of FGC waste disposal and any potential threat to human health or the environment are influenced by three factors:

- type of waste generated (physical and chemical characteristics);
- disposal method used (ponding, landfilling, or others); and
- disposal site characteristics (soil type, hydrogeology, climate, etc.).

In this project, a mix of waste types, disposal modes, and site characteristics were selected to provide the broadest possible range for the environmental assessment.

Criteria and planning for this project were organized to reflect the priorities of the various potential impacts under the Resource Conservation and Recovery Act (RCRA). Highest priority was given to subject areas that both are characteristically important for utility solid waste disposal and reflect principal regulatory concern under RCRA:

- groundwater quality;
- surface water quality from non-point sources; and
- use of potentially mitigative design management or control practices.

Within this context, the overall approach is described below. It consisted of eight major areas of effort -- site selection, test plan preparation, site development, physical and chemical sampling and analysis, preparation of engineering cost information, site-specific environmental assessment, generic environmental assessment, and development of a decision methodology.

4.1.1 Site Selection

Site selection was a two-step process. First was the preliminary evaluation of available data from all coal-fired power plants in the United States. This information was used to select 18 candidate and eight backup sites.

Sources included a precursor EPA study (36), together with a large data base resulting from efforts by EPA, EPRI, TVA, DOE and others.

In the second site selection step, the candidate sites were evaluated more closely through site visits, preliminary testing of grab samples of wastes, and detailed geotechnical and hydrogeologic evaluations. A continuous iterative process, based on several technical factors and the geographic distribution of sites, led to the final selection of the six sites (Appendix A).

4.1.2 Site Development

Site development was undertaken according to the overall procedures defined in the Hydrogeologic and Geotechnical Procedures Manual (Appendix B). It involved preliminary site visits, research of available information, development of a test plan, and actual site evaluation and sampling. The test plans were developed to provide background information on each site, and to guide the program of site development, physical and chemical sampling and analysis, and assessment of engineering costs. The test plan was a detailed account of the work to be done at each site. Each test plan was reviewed by EPA and the utility involved.

4.1.3 Physical and Chemical Sampling and Analysis

Many waste, soil, and water samples were gathered during site development. Sampling and analysis teams also visited the sites periodically for about one year to gather appropriate samples and field data. All samples were subjected to a comprehensive program of physical and chemical evaluations, as described in the Sampling and Analysis Procedures Manual (Appendix C).

4.1.4 Engineering and Cost Assessment

Based on site visits and information supplied by the utilities, process flow diagrams, equipment lists and equipment specifications were developed for the waste handling and disposal systems at each site. These were used as the basis for costing after they had been reviewed by the utilities. Capital and annual costs were then developed for each site and adjusted to late-1982 dollars.

4.1.5 Environmental Assessment

The environmental assessment of each site started as soon as initial data became available from the site development and sampling and analysis programs. As the data were gathered, preliminary assessments of the effects of waste disposal at each site were developed. These assessments were modified as additional data became available.

4.1.6 Generic Engineering, Cost and Environmental Assessment

In both the environmental evaluations and engineering cost assessments, the data and findings of the six-site study were incorporated into a larger data base. This effort took into account not only the data from the six sites but other studies sponsored by EPA, EPRI, TVA, DOE, and others. These combined results led to the generic evaluation summarized in Sections 6 and 7, a generic engineering and cost data base and an environmental assessment, respectively, for a broad matrix of waste types, methods of disposal, and site characteristics.

4.1.7 Decision Methodology

As part of this study, a decision methodology tool was developed. Its purpose is to permit state and local planning officials and the utility industry plan new waste disposal facilities or modify or expand existing ones. Details on the decision methodology are outlined in Section 8.0.

4.2 SITE SELECTION PROCESS

4.2.1 Overview

The overall objective of the site selection process was to choose sites that would include both prevalent disposal methods used by industry today and those with future potential. For example, in the future, dry disposal of coal ash and FGD wastes (that is, as moist soil-like materials) in managed fills is likely to be encouraged. Similarly, use of coal in western plants is likely to grow. The site selection process was a major effort and is described in detail in Appendix A. It involved two major tasks -- selection of candidate sites and selection of final sites, as described briefly below.

4.2.2 Selection of Candidate Sites

The goal of the candidate site selection process was to evaluate available data on coal-fired power plants and recommend an initial pool of 18 candidate sites and a smaller (but unspecified) number of backup sites.

The first step was to divide the contiguous 48 states into 14 physiographic regions. The plants in each region were screened to develop a list of those that could be considered as candidate and backup sites. The total number of candidate sites was to be 18 to ensure enough redundancy. A smaller number of backup sites was also desired, for a total target of 25 to 30 candidate and backup sites. Present and projected coal ash and FGD waste disposal practices (described in Section 3) were assessed to determine the best regional distribution of the sites. The attempt was to choose desirable plants in as many regions as possible. A total of 26 plants in all the regions passed through this screening process. These 26 plants were then ranked, and 18 were nominated as candidate sites, with the rest as backup sites. This process is described in more detail below, along with the selection criteria that were used.

4.2.2.1 Initial Screening for Sites--
The selection criteria used to screen sites were based on the need to study the effects of disposal in three areas that are important issues for solid waste disposal and have been priority concerns under RCRA:

- impact on groundwater quality;
- impact on surface water quality from non-point sources; and
- use of mitigative design, control, or management practices.

Engineering/technology-related screening criteria were developed to assess a plant's disposal operations. These included factors related to waste variability, site age, FGD system, and application of mitigative engineering practices. The engineering/technology criteria were applied as first-level screens.

Hydrogeologic criteria were also used in the site selection process. These concerned site bedrock geology, surficial soil characteristics, groundwater flow conditions, and climate. The intent was to select sites where data from about one year of environmental monitoring could be used for assessment with reasonable confidence.

Other site selection criteria were developed to reflect the overall objectives of RCRA. These rating factors fell into two basic categories: (1) regional/general factors, such as climate, regional soils, and critical regions for groundwater and surface water utilization; and (2) site-specific factors, such as site settings (substrate and proximity to surface water), mitigative controls, complicating factors (such as other external influents to an ash pond), availability of baseline environmental information, and other study opportunities. (These factors only illustrated potential opportunities to study various types of environmental impacts. No attempt was made to select preferentially sites with high or low expected effects.)

The screening criteria (engineering/technologic, hydrogeologic and other site selection factors) were used to obtain a preliminary list of sites where data obtained from about one year of monitoring could be reasonably assessed. Very complex sites where reliable data interpretation was not possible (on technological or hydrogeologic grounds) were eliminated from further consideration. Even so, the overall plan for characterization and environmental monitoring at the final selected sites was designed to accommodate complex sites, complex waste types, and complex methods of disposal.

4.2.2.2 Ranking Used to Select Candidate and Back-Up Sites--

The initial list of sites was evaluated in an iterative manner. This evaluation process focused on three types of variables:

- Waste Type. Available information indicated that six categories of waste constitute the vast majority: fly ash, bottom ash, combined fly and bottom ash, FGD waste alone, FGD waste and fly ash, and chemically treated FGD waste. These categories will likely remain the only major options in the future.
- Method of Disposal. Ponding and landfill-type operations are practicable for many wastes. FGD wastes, when disposed of alone, are usually disposed of by ponding. However, disposal of treated FGD wastes as

moist soil-like materials in landfills is likely to be a future trend. In the future, with forced oxidation methods, FGD waste disposal by itself in the form of gypsum stacks may also be feasible, although such disposal practices do not now exist. Mine disposal, another special subcategory of landfill-type disposal, was also considered.

- General Location. While the initial screening was based on 14 physiographic regions, for the final ranking, the United States was divided into three basic types of environmental settings: Coastal, Interior, and Western. Plants within a few miles of Atlantic and Gulf coasts were grouped as Coastal plants. Plants in or west of Montana, Wyoming, Colorado, and New Mexico were considered Western plants. The remainder of the contiguous 48 states was considered Interior.

The ranking process began by listing all sites with a particular mix of waste type, method of disposal (e.g., fly ash ponding) and general setting. The sites were compared, and the more promising ones were recommended as candidate sites, with the others as backups. Results are shown Table 4.1, which categorizes the recommended candidate and backup sites by waste type, disposal mode, and region. For many disposal modes there were no candidate or backup sites in some regions of the country. Usually this was because such practice either was not very common in that particular region or not used at all. For example, separate fly ash ponding is not practiced in the Coastal zone. Similarly, the separate landfilling of fly ash in the Coastal zone had no candidate, since it is not typical of this region.

4.2.3 Selection of Final Sites

The candidate and backup sites listed in Table 4.1 were next subjected to more detailed evaluation, including one or more detailed site visits by appropriate engineering, and environmental and hydrogeologic specialists.

Based on the overall site selection effort, six sites were selected for evaluation, as shown in Table 4.2. All these sites were developed for evaluation during 1981. Figure 4.1 gives the locations of these sites.

During the selection process, the distribution of the sites was continually assessed in terms of coal rank, particulate control systems and sulfur controls. The intent was to provide a reasonable mix of these features. Individual sites from major participating utilities, notably TVA, were also evaluated. In addition, the utility industry wished to include a site west of the Continental Divide, in the relatively arid part of the country. Apache Plant of Arizona Electric Power Cooperative was nominated as a seventh site but but could not be evaluated because of budget and time constraints.

Industry representatives pointed out that the engineering/cost impacts of coal ash and FGD waste disposal at small plants (less than 200 MW) could be much different from the impacts at larger plants. Several attempts were made to locate a suitable small plant for study, but many of the smaller plants practiced disposal of these wastes along with other types of wastes that were

TABLE 4.1

RECOMMENDED CANDIDATE AND BACKUP SITES - OVERVIEW

No.	Plant Name	Utility Name	Location: County	Location: State	Nameplate Generating Capacity (MW)	Startup Date[a]	Disposal	Region
1	Allen	Duke Power	Gaston	NC	1156	-/57	Combined fly and bottom ash to an unlined pond.	Interior
2	Arapahoe	Public Service of Colorado	Denver	CO	250	-/50	Combined fly and bottom ash to an interim pond and then to a landfill.	West
3	Clifty Creek	Indiana-Kentucky Electric	Jefferson	IN	1303	2/55	Fly and bottom ash to separate clay substrate lined ponds.	Interior
4	Colstrip	Montana Power	Rosebud	MT	720 (720 on FGD)	11/75	Fly ash/FGD wastes to a clay substrate lined interim pond and then to an unlined final pond. Bottom ash to separate clay substrate lined pond and then to the same final pond.	West
5	Columbia I	Wisconsin Power & Light	Portage	WI	556	5/75	Fly and bottom ash to separate unlined ponds.	Interior
6	Drake	Colorado Springs Dept. of Public Utilities	El Paso	CO	282	-/62	Combined fly and bottom ash to a clay substrate lined landfill.	West
7	Elrama	Duquesne Light & IU Conversion Systems	Washington	PA	510 (510 on FGD)	6/52 (FGD in 10/75)	FGD wastes stabilized and disposed in an off-site landfill. Combined fly and bottom ash to an unlined interim pond and then to the same landfill.	Interior
8	Dave Johnston	Pacific Power & Light	Converse	WY	750	-/59	Fly ash to an unlined landfill. Combined fly and bottom ash to a clay substrate lined interim pond and then to the same landfill. Bottom ash to an unlined interim pond and then to the same landfill.	West
9	Keystone	Pensylvania Electric	Armstrong	PA	1872	1/67	Fly ash to an unlined landfill. Bottom ash to an unlined interim pond and then to the same landfill.	Interior

(continued)

TABLE 4.1 (continued)

No.	Plant Name	Utility Name	Location County	Location State	Nameplate Generating Capacity (MW)	Startup Date[a]	Disposal	Region
10	A.S. King	Northern States Power	Washington	MN	598	-/68	Combined fly and bottom ash to an unlined landfill.	Interior
11	Powerton	Commonwealth Edison	Tazewell	IL	1785	-/72	Fly ash to an artificially lined landfill. Bottom ash to the same landfill. Landfill is off-site.	Interior
12	Presque Isle	Upper Peninsula Generating	Marquette	MI	301	9/55	Fly ash to an unlined landfill. Bottom ash to an unlined interim pond and then to the same landfill.	Interior
13	Sherburne County	Northern States Power	Sherburne	MN	1440 (1440 on FGD)	5/76	Fly ash/FGD wastes to a clay substrate lined pond. Bottom ash to an interim pond and then sold.	Interior
14	Smith	Gulf Power	Bay	FL	340	6/65	Combined fly and bottom ash to an unlined pond.	Coastal
15	Southwest	Springfield City	Greene	MO	194 (194 on FGD)	6/76 (FGD in 4/77)	Fly ash/FGD waste to an artificially lined landfill. Bottom ash to an artificially lined interim pond and then to the same landfill.	Interior
16	Tombigbee	Alabama Electric Coop.	Washington	AL	585 (385 on FGD)	6/69 (FGD in 9/78)	FGD wastes to a lined pond.	Interior
17	Widows Creek	Tennessee Valley Authority	Jackson	AL	1977 (550 on FGD)	7/52 (FGD in 1/78)	FGD wastes to an unlined pond. Combined fly and bottom ash to an unlined pond.	Interior
18	Winyah	South Carolina Public Service Authority	Georgetown	SC	630 (140 on FGD)	5/75 (FGD in 7/77)	FGD wastes to an unlined pond. Combined fly and bottom ash probably ponded.	Coastal
	BACKUP SITES							
19	Big Brown	Texas Power & Light	Freestone	TX	1186	12/71	Fly ash to a clay substrate lined landfill. Bottom ash to clay substrate lined pond.	Interior
20	Jim Bridger	Pacific Power & Light	Sweetwater	WY	1525	9/74	Combined fly and bottom ash to a landfill which is a mine.	Interior

(continued)

TABLE 4.1 (continued)

No.	Plant Name	Utility Name	Location: County	Location: State	Nameplate Generating Capacity (MW)	Startup Date[a]	Disposal	Region
21	Comanche	Public Service of Colorado	Pueblo	CO	77	-/73	Fly ash to a landfill. Bottom ash to an interim pond and then to the same landfill.	West
22	Duck Creek	Central Illinois Light	Fulton	IL	441 (416 on FGD)	6/76 (FGD in 9/76)	Fly ash/FGD wastes to an unlined pond. Bottom ash to an unlined pond.	Interior
23	Huntley	Niagara Mohawk Power	Erie	NY	828	-/42	Fly ash to an unlined landfill. Bottom ash to unlined and lined interim ponds and then to the same landfill.	Interior
24	George Neal	Iowa Public Service	Woodbury	IA	96	-/64	Combined fly and bottom ash to an unlined pond.	Interior
25	Sporn	Central Operating	Mason	WV	1105	-/50	Fly ash to an unlined pond. Bottom ash to an unlined interim pond and then sold.	Interior
26	Sutton	Carolina Power & Light	New Hanover	NC	671	8/54	Combined fly and bottom ash to an unlined pond.	Coastal

Notes:

[a]Original startup date of plants' first coal-fired unit.

TABLE 4.2

SELECTED SITES

Plant	Utility	Location: State	Location: County	Capacity (MW): Nameplate Generating	Capacity (MW): FGD Unit On	Startup Date (mo/yr): Plant	Startup Date (mo/yr): FGD	Waste Site Under Study: Waste Type	Waste Site Under Study: Disposal Method[a]	High Priority Issues Under Study: Ground-water Quality	High Priority Issues Under Study: Surface-water Quality	High Priority Issues Under Study: Employment of a Potentially Mitigative Practice
Allen	Duke Power	NC	Gaston	1155	-	-/57		Combined fly and bottom Ash	Pond (UL)	x	x	x
Elrama	Duquesne Light[b]	PA	Washington	510	510	6/52	10/75	Stabilized FGD waste Combined fly and bottom ash	Landfill (UL; offsite) Landfill (UL)	x	x	x
Dave Johnston	Pacific Power & Light	WY	Converse	750	-	-/57	-	Fly Ash	Landfill (UL)	x	-	x
Sherburne County	Northern States Power	MN	Sherburne	1458	1458	5/76	5/76	Fly ash/FGD	Pond (AL)	x	-	x
Powerton	Commonwealth Edison	IL	Tazewell	1786	-	-/72	-	Combined fly and bottom ash	Landfill (AL)	x	x	x
Smith	Gulf Power	FL	Bay	340	-	6/65	-	Combined fly and bottom ash	Pond (UL)	x	x	x

Notes:
[a]UL - Unlined
AL - Artificially Lined

[b]Disposal site operated by Conversion Systems, Inc.

Source: Arthur D. Little, Inc.

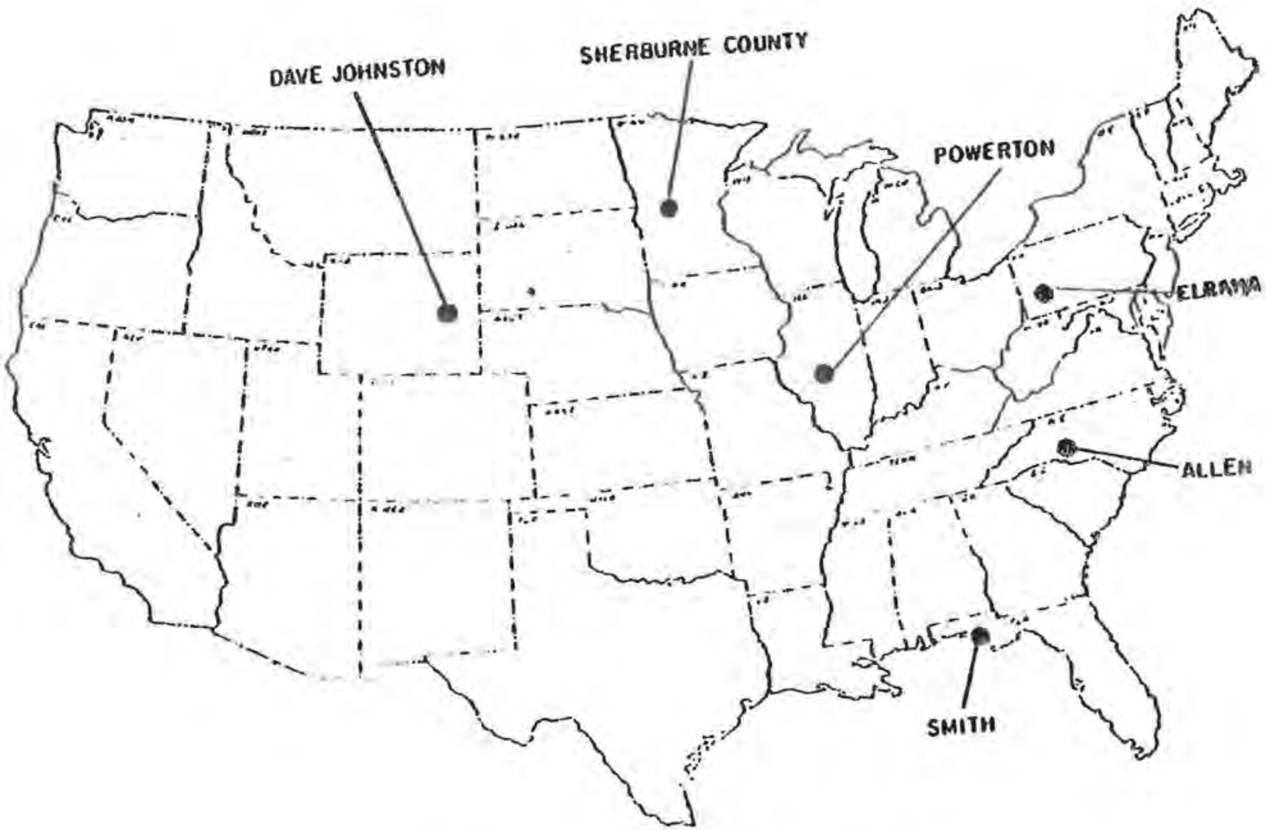


FIGURE 4.1 SELECTED SITES FOR EVALUATION

outside the scope of this study. Hence, no suitable small plant was available for this project.

4.3 SITE DEVELOPMENT

The term "site development" refers to those activities associated with the design and installation of the sampling infrastructure at each site. Site development field activities consisted of:

- preliminary visit by the site selection team;
- initial hydrogeological/geotechnical site reconnaissance;
- research of available information;
- development of a Site Evaluation Plan (Test Plan) for each site;
- actual site evaluation; and
- selective, long-term well sampling.

The Test Plan summarized the regional and local hydrogeologic and geotechnical conditions, detailed the approximate locations, numbers, and depths of samples, and described the types of explorations and instrumentation for the selected site. It also summarized plant background data, the various sampling and analytical procedures, site evaluation costs, and schedule of activities. The site-specific evaluation plans were then reviewed by all participating parties, including EPA and the utilities.

Since the various selected sites were widely spread throughout the contiguous United States, a variety of firms specializing in subsurface explorations participated in the field evaluation phases of the project. Also, because of major variations in hydrogeological conditions and site access, a range of equipment and technical procedures was used to accommodate local conditions.

A manual was prepared to describe the hydrogeologic and geotechnical procedures used during the site development (Appendix B). The purpose of this manual was to ensure that the field work would be accomplished efficiently and on a consistent basis. The intent was to make all the data acquisition and management as similar as possible. The Hydrogeologic and Geotechnical Procedures Manual describes the field procedures in detail, including:

- procedures used for boring, well and piezometer installations, performance of field permeability tests, soils classification, and test pit preparation;
- procedures for sampling wastes and soils; and
- formats used for reporting data obtained during the various site development activities -- daily test borings, test pits, groundwater observation wells, groundwater monitoring piezometer installation, borehole sealing, and field permeability and subsurface exploration.

Although the methods of advancing and stabilizing the boreholes varied from site to site, the methods used to obtain the various samples at all sites was in accordance with the American Society for Testing and Materials (ASTM) procedures. The two primary sampling devices consisted of the 2-inch diameter split-spoon sampler (ASTM D1586) and the 3-inch diameter thin-wall "Shelby" tube sampler (ASTM D1587). These samplers gave detailed information on site stratigraphy. Selected samples were preserved for additional geotechnical and chemical laboratory testing. Other details regarding technical procedures, equipment and methodology are outlined in Appendix B. Information on the site-specific exploration program, samples obtained, in-situ tests and instrumentation installed, is summarized in Sections 4.4, 4.5 and in Section 5.

4.4 PHYSICAL SAMPLING AND ANALYSIS

4.4.1 General

This section briefly summarizes the standard procedures for physical sampling and analysis that were used during this project. The actual data from these efforts are available in Appendix E, Physical Sampling and Analysis Data.

Physical sampling and analysis were conducted on this project to:

- establish geologic profiles for estimating water/contaminant movement patterns;
- establish waste deposit distribution data by waste type;
- develop field and laboratory data on physical properties (e.g., permeability, moisture content, etc.) to assist in water balance and containment movement evaluations.

Borings were drilled through the waste deposits in order to determine waste deposit boundaries and physical properties and to sample for chemical and physical laboratory testing. Selected borings were extended beneath the waste deposits to assess the nature and characteristic of the underlying natural soil and/or liner material. Borings were advanced through landfills of FGC waste by truck-mounted drilling rigs equipped with both hollow stem augers and flush joint casing; borings were advanced through ponded FGC waste deposits by using portable equipment mounted on a barge to drive a 2.5-inch O.D. (BX) casing. Detailed descriptions of the drilling techniques are available in Appendix B, Hydrologic and Geotechnical Procedures Manual.

4.4.2 Sampling Procedures

Disturbed and relatively undisturbed samples of the appropriate FGC wastes were obtained in accordance with ASTM D 1586 (Penetration Test and Split Barrel Sampling) and ASTM D 1587 (Thin Walled Tube Sampling of Soils), respectively. Samples were generally obtained at intervals of less than 5 feet (measured from center-to-center of samples). Detailed descriptions of the sampling procedures are available in Appendix B, Hydrogeologic and Geotechnical Procedures Manual, and Appendix C, Sampling and Analysis Procedures Manual.

At one site, Sherburne County, different sampling procedures were required. This site was unique in that it involved disposal in a lined pond. The sampling procedure, described below, was used to ensure that when the liner was pierced, minimal leakage would occur.

Sampling within the scrubber sludge waste basin at the Sherburne County plant was accomplished with site-specific, predetermined procedures for penetrating the cohesive soil liner beneath the bottom of the basin. Continuous split-spoon samples (ASTM D 1586) and Shelby tube samples (ASTM D 1587) of the waste were taken throughout the depth of each boring. After a sample had been obtained, the boring was advanced by driving BX casing through the waste to the level which had been previously sampled; any material which remained within the casing was removed with the split-spoon sampler. Immediately after the liner had been encountered, as determined from a marked increase in blow counts, the BX casing was driven approximately halfway through the liner. Clear pond water was then pumped through a line leading to the bottom of the casing to flush any sludge out the top of the casing. Water was bailed out of the casing, and a recovery permeability test was performed to verify that the casing was properly sealed. Afterwards, the casing was driven completely through the liner. The cohesive soil (liner) that remained in the casing was then sampled as previously described. The natural sand underlying the liner was then sampled using the split-spoon sampler.

4.4.3 Physical Testing Procedures

This section summarizes the field tests, laboratory tests, and quality assurance/quality control activities of the physical testing program. The results of these efforts are available in Section 5 and Appendix A.

4.4.3.1 Field Tests--

Field testing of the FGC wastes consisted of standard penetration tests (ASTM D 1586), field permeability tests, vane shear tests (ASTM D 2573), and down-hole nuclear density tests. Specific procedural details for these tests are described in Appendix B.

4.4.3.2 Laboratory Tests--

Laboratory testing of the wastes consisted of:

- natural moisture content determinations (ASTM D 2216);
- index tests (ASTM D 422, ASTM D 423, ASTM D 424, ASTM D 857);
- moisture-density relationship determinations (ASTM D 698);
- permeability tests (ASTM D 2434);
- consolidation/Permeability tests; and
- strength tests (ASTM D 2166).

Where applicable, the laboratory tests were performed according to ASTM procedures. If no ASTM procedures existed, the tests were based on procedures developed for this project as described in Appendix C, Sampling and Analysis Procedures Manual.

4.4.4 Quality Assurance/Quality Control Activities

Project personnel from the University of Louisville and Geologic Associates served as QA/QC coordinators for the physical testing program. Early during the testing program, QA/QC personnel reviewed the testing procedures and observed testing activities. Since procedures for most of the physical tests were defined by ASTM, the QA/QC program was developed to verify only the permeability tests. In addition, field permeability test results were performed for comparison with results of laboratory permeability tests. The quality control program also called for tests on nearby samples (not quite duplicate samples) to examine the repeatability of the physical test data. This gave additional results that enlarged the data base for the project. More information on the QA/QC activities is available in Appendix I, Quality Assurance/Quality Control Testing Program: Physical and Chemical Sampling Analysis.

4.5 CHEMICAL SAMPLING AND ANALYSIS

4.5.1 General

Chemical sampling and analysis were conducted to:

- characterize the chemical concentrations of species of interest in waste solids, background soils, groundwater and surface water;
- identify potential waste-related chemical "tracers," i.e., those chemicals whose elevated concentrations in the waste and relative absence in background samples made them candidates for use in mapping the extent of waste-related contamination;
- map chemical concentration gradients related to the waste deposits; and
- provide data to structure and test hypothesis to explain phenomena suspected to occur at the site (e.g., soil attenuation of trace metals).

4.5.2 Sampling

4.5.2.1 Waste and Soil Samples--

Shelby tube and split-spoon sampling techniques were used during site development to obtain all waste and soil samples (including pond liner samples). The Shelby tube samples were shipped "as is" in tubes to the laboratory. The split spoon samples were transferred to precleaned glass mason jars and then shipped. Some waste samples were also collected during the subsequent sampling and analysis trips. These samples (mostly liquids and slurries) were obtained by grab sampling with a plastic bucket.

4.5.2.2 Groundwater and Surface Water Samples--

Samples were collected from groundwater monitoring points and several types of surface water sources. Sample types included saturated zone groundwater samples from wells and piezometers, unsaturated zone groundwater samples from lysimeters, and samples of surface water (i.e., ponds, lakes, rivers, streams, swamps and tidal basins). Collected samples were split into two fractions, one for metal analysis and one for anion analysis. The metals fractions recovered were preserved with nitric acid as per pertinent DOT/EPA regulations, while the anion fractions were preserved by packing in ice. A comprehensive chain of custody record system adapted from NEIC (National Environmental Investigation Center) protocol was imposed on all field samples collected. Table 4.3 summarizes the sampling equipment used. Figure 4.2 is a schematic of the pneumatic pumping system used to sample groundwater.

Certain sampling and analysis procedures deviated from those described in Appendix C. These are described below.

4.5.2.2.1 Groundwater Well/Piezometer Sampling (Saturated Zone) -- The intended procedure at the beginning of this project was to remove three to five well volumes before sample collection, as described in Appendix C. This proved to be impractical because of time limitations during sampling trips. The following procedure was developed instead. It saved time and provided the appropriate samples.

In determining the procedure used to collect a sample from a groundwater well, some assumptions were made about the water column in a well. Any water above the screened section of a well was considered stagnant with respect to the water in the screened section. This is because the water in the screened section is constantly being replaced with water from the aquifer and so has been more recently exposed to the geological formations that are outside of the well casing. Water contained above the screened area is trapped, with possible changes in its composition because of prolonged exposure to the atmosphere and to well casing materials. Therefore, the sample should contain a minimal amount of stagnant water. To achieve this, the sample should be withdrawn from below the fresh/stagnant water interface, with care to prevent any stagnant water from contaminating the sample. The following procedure was used:

1. Groundwater depth was measured to calculate the overall well volume and volume of stagnant water in the well (the well diameter was known). Before the sample location was assessed, data were gathered as to the well diameter, screen volume (screen length times well cross-sectional area), screen/upriser interface depth (see Figure 4.2), and overall well depth.

2. One well volume (overall well depth minus depth to water times well cross-sectional area) was removed from a location in the well that was as high above the fresh/stagnant water interface as possible. The fresh/stagnant water interface was assumed to coincide with the upper elevation of the screened section of the well. The point from which the initial well volume was removed was determined by the individual characteristics of each well, including factors such as well depth,

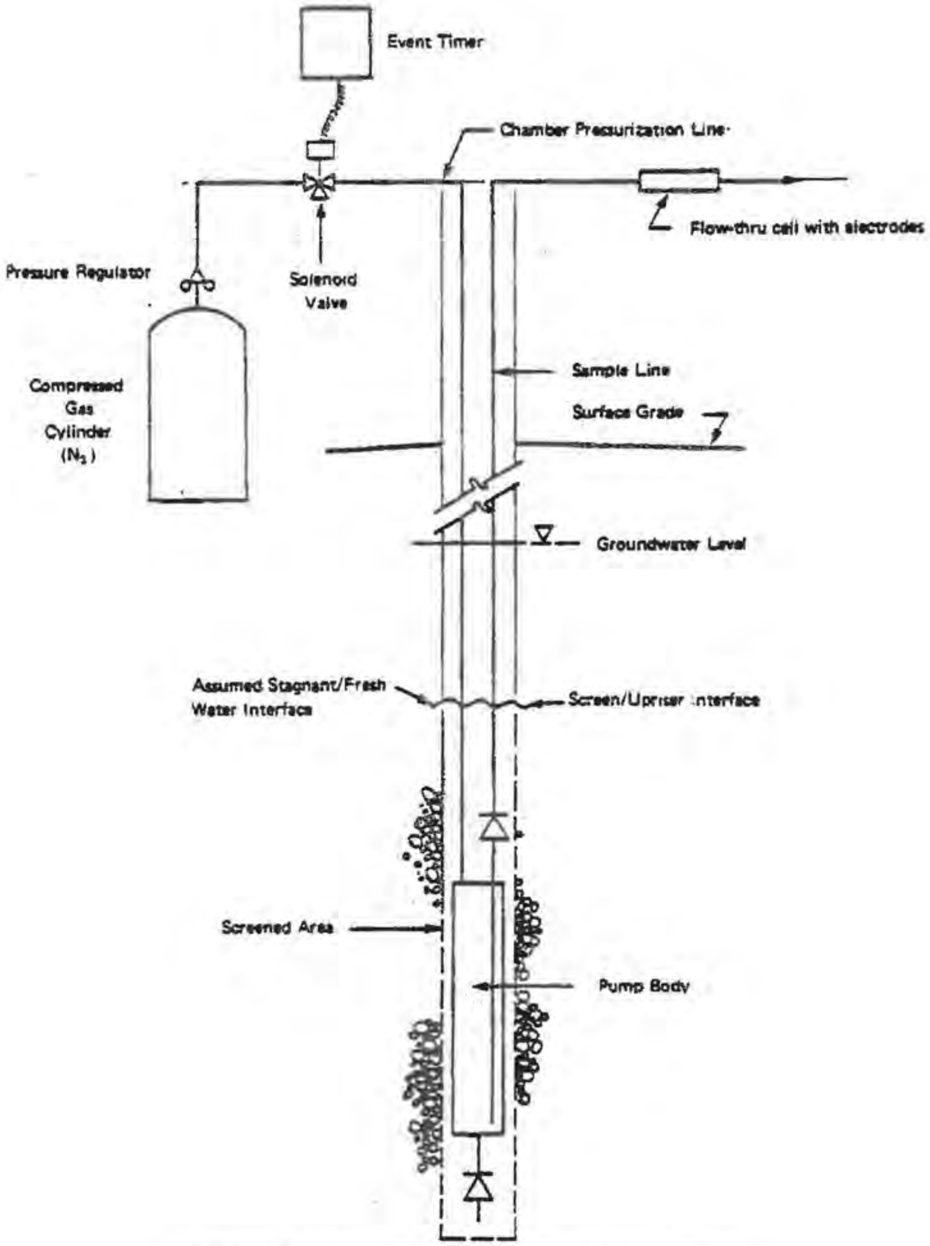


FIGURE 4.2 SCHEMATIC OF PNEUMATIC PUMPING SYSTEM

TABLE 4.3

CHEMICAL SAMPLING EQUIPMENT

PUMPS:		
Peristaltic Pump	-	Master flex portable sampling pump Horizon Ecology Co.
Pneumatic Pump	-	Designed and built at Arthur D. Little, Inc. The pump body consists of PVC pipe (1½", schedule 80 PVC), a check valve on the bottom to allow water to flow in, and a check valve at the top to prevent water from flowing back into the pump body once the pressure is released. Figure 4.2 shows the pump body along with the ancillary equipment needed for sample collection.
INSTRUMENTS:		
pH Meters	-	Horizon Ecology Co. (Type 5995) portable pH meter and a Beckman portable field (Model Monitor II system).
Dissolved Oxygen Meter	-	YSI Model 57 with built-in temperature probe.
Conductivity Meter	-	Chemtax, Inc., Type 70.
FILTER HOLDER:	-	Millipore 316 stainless sanitary XY3024236
FILTERS:	-	Millipore 0.45 HAWP14250
	-	Millipore prefilter AW0614250
GRAB BUCKET:	-	Polyethylene
SAMPLE CONTAINERS:	-	Polyethylene
TUBING:	-	All sampling lines in the wells were polyethylene tubing.
	-	Surface water samples were collected through Tygon® tubing.
PNEUMATIC FLUID:	-	Nitrogen

groundwater depth, and the rate of well recharge. If the well did not recharge as quickly as the water was removed, the location of the sampling point was positioned at or just below the fresh/stagnant water interface. Once the stagnant water was removed, the sampling location was dropped to a point near the bottom of the screened section.

3. Successive screen volumes of water were removed from the bottom of the well and pumped through a flowthrough cell equipped with electrodes to measure chemical parameters of the flowing water. Conductivity, pH, dissolved oxygen (D.O.), and temperatures were measured. Stabilization of these measurements indicated that the well water composition had reached equilibrium (minimal changes with successive pumping). When two consecutive parameter readings fell within the allowed tolerances (the allowed tolerances were pH ±0.3 units, conductivity ± 10% relative; D.O. readings relatively consistent), the well was sampled.

4. Actual sample collection involved removing and filtering the appropriate volume of water (typically liters), splitting the sample into anion and metal fractions (for analysis purposes), and preserving these fractions.

This type of multilevel sampling approach greatly reduced the time required to sample each well by decreasing the volume of water that had to be removed before sample collection.

Two kinds of pumps were used to evacuate the wells, pneumatic pumps and peristaltic pumps. The pneumatic pump was used when the water level in the well was below the suction lift capacity of the peristaltic pump. The pumping sequence and the volumes of water removed were the same for both types of pumps. One difference in procedure between the two pumps was that two separate tubes were placed in the well at the desired depths when the peristaltic pump was used. The peristaltic pump was connected to the appropriate tube to remove stagnant or fresh water. The pneumatic pump, however, was physically raised or lowered to locations above or below the screen/upriser interface to remove the desired type of water from the well.

Two types of duplicate samples were removed from the wells to check on different aspects of the sampling and analysis procedure. These were:

- Well duplicates obtained by using the same pump. These were collected by first completing one full sampling sequence, then repeating the sequence from the beginning of the entire sampling procedure. This type of sample duplicate was taken to determine: (1) if the well had actually reached the equilibrium state identified during the initial sampling process and (2) if by removing more water prior to sample collection, a different quality water would be sampled.

- Well duplicates obtained by using the two different types of pumps. This type of duplicate was taken exactly the same as the well duplicate above except that the second sequence was carried out with a different pump. This procedure indicated whether the two pumping systems produced the same quality sample.

The results of these well duplicates are available in Appendix I, Quality Assurance/Quality Control Testing Program: Physical and Chemical Sampling and Analysis (Table 7). The small variations observed in the concentration of analytes in the sequential samples showed that even after at least two times the minimum volume required before sampling had been removed, the quality of the water being sampled was (with regard to the measured parameters) the same as the quality obtained when only the original procedure was used. This indicated that the procedure for collecting the initial sample was adequate to collect a representative sample. Results from a series of well duplicates collected with the two different types of pumps, peristaltic and pneumatic, also supported this conclusion.

4.5.2.2.2 Lysimeter Sampling (Unsaturated Zone) -- Lysimeters located in the unsaturated zone were sampled by a pressure-vacuum hand pump. The lysimeter was pressurized and evacuated of the accumulated standing water. A vacuum was applied to the lysimeter for six hours. The water collected in the lysimeter after this period was pumped into a container, and chemical parameters (pH, conductivity) were measured on a small aliquot of the unfiltered sample. The water was then filtered and preserved according to the protocol described previously.

4.5.2.2.3 Surface Water Sampling -- Surface water samples were collected with a peristaltic pump or a grab bucket. With the pump method, the pumping sequence applied was similar to the one used in sampling the groundwater wells. A volume of water (~1000 mls) was pumped from the surface water source, and then successive volumes (3500 mls) were removed. Chemical parameters were measured (in the sampling stream) on each successive volume. A sample was taken after two consecutive parameter readings fell within the allowed tolerances. The sample volume was removed, filtered, split into anion and metal fractions, and preserved.

The grab bucket method was used at locations where it was impractical to collect surface water samples with the pump. In this approach, a volume of water was collected, and the sample was filtered split, and preserved. The excess unfiltered sample was used for measuring chemical parameters.

4.5.2.2.4 Quality Control Samples (Field) -- In addition to surface and groundwater samples, a number of quality control samples were collected during each site visit as part of an overall Quality Assurance/Quality Control (QA/QC) plan. These are described in Section 4.5.6.

4.5.3 Sample Log-In and Distribution

Solid samples (wastes and solids) obtained during site development were assigned an F number (F followed by a number from 0 to 9999). The liquid samples collected in subsequent sampling trips were placed in insulated boxes that contained a mixture of ice and water in which a plastic bag containing the plastic bottles had been immersed.

Samples were checked for: (1) integrity of the seal placed on each bottle cap; (2) the presence of solid precipitates which sometimes formed during sample transport; and (3) pH (for the acidified samples). If a sample did not conform to the required condition, a remedial action was taken, such as adding nitric acid to dissolve solids or to lower the pH. Non-acidified samples containing particulates were filtered. Any manipulation of the samples was noted. If problems had been encountered with any field pH or conductivity equipment, a value for these parameters was obtained in the lab at this time.

The acidified water samples were then assigned "MF numbers" (M for metals fraction), and the unacidified fraction of the same sample assigned an "ICF number" (IC for ion chromatography) number. The ICF samples were stored in the refrigerator until aliquoted for analysis. Metal samples were stored at room temperature, as were soil samples and wastes. A list of sample numbers and a description of each sample were prepared for each batch of samples received (generally representing a particular sampling period for a particular site).

At this point, laboratory QC samples were prepared. These included laboratory splits, blind standards, and laboratory blanks. Liquid samples were then aliquoted into three plastic bottles (30 ml) and distributed as follows. A complete set of MF samples (including splits and blind standards) was sent to Barringer Magenta, Ltd. (Toronto, Canada) for inductively coupled argon plasma (ICAP) analysis. Another set was reserved for metals analysis in-house (As and Se) on selected samples. A complete set of ICF samples was provided for in-house IC analysis.

Waste and soil samples were distributed after the site development boring logs had been reviewed and the particular samples designated for further chemical analysis had been identified.

4.5.4 <u>Preparation of Samples for Analysis</u>

4.5.4.1 Liquid Samples--

The ICAP and IC liquid samples required no preparation (other than dilution) before they were introduced to the ICAP spectrometer or ion chromatograph. Analyses of As and Se based on hydride evolution were performed on as-received water samples. In cases where the presence of organics was suspected, e.g., extracts of soils, samples were digested with HNO_3 and $HClO_4$, as explained in Appendix C. A check on a cross section of groundwater samples from the various sites showed, in general, small differences between digested and undigested samples.

4.5.4.2 Solid Samples--

Solid samples of wastes and soils were freeze-dried under vacuum before they were shipped for analysis. The analysis, performed by Barringer Magenta, Ltd., involved a "total" digestion of the solids with a mixture of $HF/HNO_3/HClO_4$ before ICAP analysis.

Solid samples for As and Se analysis were digested with $HNO_3/HClO_4$ before the AA/hydride evolution analysis of the digest.

4.5.4.3 Pore Liquid Samples--

Pore liquids were obtained from moist or saturated waste solid and soil samples by the pressing technique described in Appendix C. Waste and liner samples were pressed under N_2 to obtain samples of the liquid phase which were then passed through a 0.45-inch filter. Portions of the liquid were then acidified for metals analysis, and a portion was cooled for anion analysis.

4.5.4.4 Extracts--

In cases where the pressing technique did not produce any liquid for analysis, a water extract was obtained by mixing distilled water with the solid and agitating the slurry in a shaker for one hour. The extract was separated from the slurry by filtration through a 0.45-inch filter.

4.5.5 Analytical Methodology

4.5.5.1 Inductively Coupled Argon Plasma Spectroscopy--

Inductively coupled argon plasma (ICAP) spectroscopy was performed by Barringer Magenta, Ltd. (Toronto, Canada) (37). The ICAP unit was a model QA-137 Applied Research Laboratories spectrometer with a 1920 rulings/mm grating. Reciprocal linear dispersion detectors (0.48-0.52/mm, first order R300) from Hamamatsu Corp. were used. The plasma observation height was 16 mm above load coil, 4-mm vertical section. Sample uptake was 2-2.5 ml/min by a cross-flow pneumatic nebulizer with Scott chamber. A Jarrel-Ash monochromator (1/2 M Ebert) and a R787 Hamamatsu Corp. photomultiplier were used. Generator output was 1600 W was at 27.12 MHz.

The ICAP analysis is performed by aspirating the undiluted sample. This analysis provides emission data for trace components as well as major species (up to 1000 ppm). A computer-based program, which corrects for interelement spectral interferences, is used to quantify trace elements. The major species (>100 ppm) are quantitated by diluting the original sample and reanalyzing it. These reanalyzed values are used as input concentrations for major species in the interelement computer program.

The following elements were analyzed simultaneously for liquid samples: Ag, Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Si, Sr, Th, Ti, V, Zn, Zr. In the case of solid samples that had been digested with a mixture containing HF, the ICAP reports did not contain data for B and Si, which are at least partially lost due to formation of volatile fluorides. Data for Ba also were not available because of erratic results, probably due to formation of insoluble sulfate.

Barringer Magenta, Ltd. has an extensive in-house QC program, as described in Section 4.5.6. More details on this analysis are available in Appendix C and in Reference 38.

4.5.5.2 Ion Chromatography--

Ion chromatography (IC) was performed on liquid samples with a Dionex Model 10 ion chromatograph equipped with a Varian autoinjector (Model 805500). The anion analysis system consisted of a precolumn, anion separator column, and a suppressor column followed by conductivity detector. Conditions for performing the analysis with $NaHCO_3/Na_2CO_3$ eluent were as specified in the instrument operator manual. Appendix C provides further details.

Analytes quantitated were F^-, Cl^-, NO_3^-, and $SO_4^=$. Chromatograms were also reviewed for the presence of Br^- and $PO_4^{\equiv}$, and these were noted if detected.

4.5.5.3 Atomic Absorption Measurements--

Atomic absorption (AA) measurements were performed for As, Se and Pb. Arsenic and selenium were analyzed by Arthur D. Little, Inc. The method was to use the hydride evolution technique on a Perkin Elmer Model 503 spectrometer equipped with an Instrumentation Laboratory Model 440 atomic vapor accessory. The detailed procedure is described in Appendix C.

Atomic absorption was also used to quantitate Pb in various samples. This analysis was performed by Barringer Magenta, Ltd. as part of the "ICAP analysis" suite. The methodology was either flame AA (with a Varian Techtron Model AAS under conditions specified by EPA Method 239.1) or flameless AA (with a Varian Techtron Model 475 and a Perkin- Elmer Model HGA 2100 furnace under conditions specified in EPA Method 239.2).

4.5.5.4 Other Procedures--

4.5.5.4.1 Total Organic Carbon -- Total organic carbon in soils was determined by Barringer Magenta, Ltd., with a LECO induction furnace Model 521-000 used according to manufacturer specifications. Sulfurous acid was added to remove inorganic carbonate and the sample was then dried. The dried sample was combusted under O_2, and the CO_2 produced was absorbed in KOH. The change in gas volume was measured volumetrically.

4.5.5.4.2 Silicon in Solids -- Silicon in soils was determined by $LiBO_3$ fusion, dissolution of the solid residue in 10% HNO_3, and determination of Si in the solution by ICAP analysis (performed by Barringer Magenta, Ltd.).

4.5.5.4.3 Bromate Analysis -- Bromate analysis of boiler cleaning samples was performed by adding an aliquot of the sample (5-25 ml) to 10 ml of 2N hydrochloric acid (HCl) and 5ml of 0.5N potassium iodide (KI) solution, with a few drops of ammonium paramolybdate solution to catalyze the reaction. The iodine (I_2) produced was titrated with standardized sodium thiosulfate. Starch was the end point indicator.

4.5.5.4.4 Other Solid Waste Characterization -- Measurement of total oxidizable sulfur (S), sulfate ($SO_4^=$), acid insolubles, slurry pH, and % solids were made on selected FGD solid waste samples, as described in Appendix C. Solid samples were freeze-dried to constant weight to determine % solids before other analyses were carried out.

A summary of the sampling dates, number of samples, number of sample locations, and type of chemical data available for each site is given in Tables 4.4 to 4.9.

4.5.5.5 Soil Attenuation Studies--

Soil samples from each site were analyzed to determine the extent of attenuation of certain major and trace elements. Two leachate solutions (one from the Allen site and one from the Sherburne County site) were contacted with nine different soils from the various sites. These two solutions were "spiked"

TABLE 4.4

SUMMARY OF CHEMICAL S/A PROGRAM – ELRAMA PLA[illegible]

Sampling Trips: Site Development – 3/31/81
1st S/A 4/27/81
2nd S/A [illegible]/25/81
3rd S/A 11/02/81

Samples Obtained:[a] Site Development 85 Solids and Liquids
1st S/A – 35 liquids
2nd S/A 37 liquids
3rd S/A [illegible]6 liquids

Analysis Peformed (Locations)[c]

	Anions	ICAP Metals	As[b]	Se[b]	Field Data	Solid Extract Anions	Other
Site Development –							
– 21 Groundwater and Waste Liquids	x	x	x	x			
– 7 Wastes		x	x	x		x	x[d]
– 1 Soil		x	x	x			
Trip 1 – 23 Liquids	x	x	x	x	x		
Trip 2 – 25 Liquids	x	x	x	x	x		
Trip 3 – 27 Liquids	x	x			x		
Attenuation Studies – 1 Soil		x	x	x			

NOTES:

[a]Includes QA/QC

[b]Selected Number

[c]Does not include QA/QC

[d]TOS, SO_4, pH Slurry, Acid Insolubles, % Solids

TABLE 4.5

SUMMARY OF CHEMICAL S/A PROGRAM - ALLEN PLANT

Sampling Trips: Site Development - 12/8/81
1st S/A - 2/23/81
2nd S/A - 3/23/81
3rd S/A - 7/14/82

Samples Obtained:[a] S.D. - 88 Solids and Liquids
1st S/A - 39 Liquids
2nd S/A - 30 Liquids
3rd S/A - 35 Liquids
Other - 9 Boiler Cleaning

Analysis Performed (Locations):[c]

	Anions	ICAP Metals	As[b]	Se[b]	Field Data	Other
Site Development						
- 6 Well Samples	x	x				
- 6 Solid Ash		x	x			
- 8 Interstitial Ash Liquors	x	x	x	x		
- 17 Soils		x	x			
Trip 1 - 21 Groundwaters and Others	x	x	x	x	x	
Trip 2 - 18 Groundwaters and Others	x	x	x	x	x	
Trip 3 - 25 Groundwaters and Others	x	x	x	x	x	
Boiler Cleaning - 8 liquids		x				Bromate, pH
Attenuation Studies - 3 Soils		x	x	x		

NOTES:

[a]Includes QA/QC Samples

[b]Selected Number

[c]Does not include QA/QC samples

TABLE 4.6

SUMMARY OF CHEMICAL S/A PROGRAM - DAVE JOHNSTON PLANT

Sampling Trips: Site Development - 5/20/81
1st S/A - 7/06/81
2nd S/A - 10/20/81
3rd S/A - 5/18/82

Samples Obtained:[a] S.D. - 10 Liquids
1st S/A - 19 Liquids
2nd S/A - 22 Liquids
3rd S/A - 19 Liquids

Analysis Performed (Locations):[c]

	Anions	ICAP Metals	As[b]	Se[b]	Field Data	Extracts (Anions)
Site Development -						
- 10 Liquids	x					
- 6 Waste Solids		x	x	x		x
- 5 Soils		x				
1st S/A - 11 Liquids	x	x	x	x	x	
2nd S/A - 13 Liquids	x	x	x	x	x	
3rd S/A - 11 Liquids	x	x			x	
Attenuation Studies - 1 soil		x	x	x		

NOTES:

[a]Includes QA/QC

[b]Selected number

[c]Does not include QA/QC

TABLE 4.7

SUMMARY OF CHEMICAL S A PROGRAM - SHERBURNE COUNTY PLANT

Sampling Trips: Site Development - 8/21/81
1st S/A - 10/06/81
2nd S/A - 5/10/82
3rd S/A - 6/10/82

Samples Obtained:[a] S.D. - 113 Solid and Liquids
1st S/A - 10 Liquids
2nd S/A - 24 Liquids
3rd S/A - 23 Liquids

Analysis Performed (Locations):[c]

	Anions	ICAP Metals	As[b]	Se[b]	Field Data
Site Development					
- 10 Liquids (wells/surface)	x	x			
- 8 Interstitial Waste Liquids	x	x	x	x	
- 8 Waste Solids		x			
- 2 Liner Solids		x			
- 4 Intestitial Liner Liquids/Extracts	x	x			
- 7 Intestitial Soil Liquids/Extracts	x	x			
- 4 Soil Solids		x			
Trip 1 - 9 Liquids	x	x	x	x	x
Trip 2 - 14 Liquids	x	x			x
Trip 3 - 11 Liquids	x	x			x
Attenuation Studies - 1 Soil and 1 liner solid		x	x	x	

NOTES:

[a]Includes QA/QC

[b]Selected Number

[c]Does not Include QA/QC

TABLE 4.8

SUMMARY OF CHEMICAL S/A PROGRAM - POWERTON PLANT

Sampling Trips: Site Development - 11/23/81
1st S/A - 12/14/81
2nd S/A - 4/19/82
3rd S/A - 8/02/82

Samples Obtained:[a] S.D. - 50 Solids and Liquids
1st S/A - 21 Liquids
2nd S/A - 22 Liquids
3rd S/A - 21 Liquids

Analysis Performed (Locations)[c]

	Anions	ICAP Metals	As[b]	Se[b]	Field Data
Site Development					
- 2 Liquids	x	x			
- 10 Waste Solids		x			
Trip 1 - 12 Liquids	x	x	x	x	x
Trip 2 - 12 Liquids	x	x	x	x	x
Trip 3 - 12 Liquids	x	x	x	x	x
Attenuation Studies - 1 Soil		x	x	x	

NOTES:

[a] Includes QA/QC

[b] Selected Number

[c] Does not Include QA/QC

TABLE 4.9

SUMMARY OF CHEMICAL S/A PROGRAM - SMITH PLANT

Sampling Trips: Site Development - 12/02/81
1st S/A - 2/02/82
2nd S/A - 3/22/82
3rd S/A - 8/23/82

Samples Obtained - S.D. - 59 Liquids and Solids
1st S/A - 53 Liquids
2nd S/A - 46 Liquids
3rd S/A - 50 Liquids

Analysis Performed (Locations)[c]

	Anions	ICAP Metals	As[b]	Se[b]	Field Data
Site Development -					
- 3 Waste Solids		x			
- 3 Waste Interstitial Solids	x	x			
- 1 Soil Solid		x			
- 1 Interstitial Solid		x			
- 1 Interstitial Soil Liquid	x	x			
Trip 1 - 38 Liquids	x	x	x	x	x
Trip 2 - 33 Liquids	x	x	x	x	x
Trip 3 - 39 Liquids	x	x	x	x	x
Attenuation Studies - 1 soil		x	x	x	

NOTES:

[a]Includes QA/QC

[b]Selected Number

[c]Does not include QA/QC

with Cd^{+2}, CrO_4^{-2}, Cu^{+2}, Pb^{+2}, and SeO_2^{-2}. (Spiking, the addition of a substance in known concentrations to a solution, is used when the original concentrations may be below detection limits. The procedure establishes measurable baseline concentrations that can be observed for changes when samples are then added to the solution.) A constant volume of spiked solution (50 ml) was mixed with various amounts of as-received soil (0.05, 0.5, 5 and 25 g). The resultant slurries were mixed for 24 hours in a rotary shaker. The slurry was then passed through a 0.45-μm filter, and the aqueous phase was preserved by addition of nitric acid and analyzed for pH, As, Se, and a suite of metals via ICAP analysis. A limited number of unacidified extracts were subjected to ion chromatography to determine anions present. Calculations of the amount of analyte sorbed (removed from solution) onto the soil were based on the difference in concentrations in the starting solution and the solution equilbrated with the soil. A t-test (90% confidence level) was performed to determine if this difference in solution concentrations was significant. More information on those procedures and their results is given in Appendix F, Chemical Sampling and Analysis Data.

4.5.5.6 Extraction Procedure and Radioactivity Measurements--

Twenty-three waste samples (fly ash and FGD wastes) were obtained from 18 utilities and subjected to the EPA Extraction Procedure (EP) (8). Samples were used as-received, without drying or grinding. About 100 g of sample were extracted at pH 5.0± 0.2 for 24 hours. The separated aqueous phase was stabilized with nitric acid and analyzed for Ag, As, Se, Hg, Cr, Cd, Pb, and Ba. As and Se were analyzed by hydride-evolution AA. Hg analysis was conducted with the cold vapor atomic absorption method. Graphite furnace AA techniques (39) were used to analyze all other elements.

Radioactivity measurements were made on 34 waste samples (fly ash, bottom ash, FGD, and boiler slag wastes) from 18 utilities. Gamma-ray spectroscopy (40) was applied to analyze these samples for radium-226. Gamma ray energies in the 0 to 2 MeV were screened, and emitting nuclides were identified by the characteristic energies of the gamma rays. Several samples were analyzed for radium-228, thorium-228, potassium-40, uranium-238, total uranium and radon emanation.

Appendix D, Application of the EPA Extraction Procedure and Radioactivity Measurements to Coal-Fired Utility Wastes, provides further information on these experiments and their results.

4.5.6 <u>Data Management and Reporting Formats</u>

4.5.6.1 Data Management--

After each sampling trip, a memo was prepared to summarize the field data obtained. This data included groundwater levels (relative to top of casing) for the wells, temperature, pH, conductivity and dissolved oxygen in water samples. The memo also described all samples taken and summarized any other observations. These field sample descriptions were assigned numbers in the laboratory. The analytical results obtained from Barringer Magenta, Ltd. (ICAP) were received in the form of computer printouts. These listed sample numbers (e.g., MF XYZ) and concentrations (ppm) for the appropriate analytes. The analytical results for the IC data and AA data were similarly summarized by sample number after completion of the analysis. All analytical data were input into a computerized system designed to store the analytical information. A description of each sample was also entered. The computer could then summarize all stored information in each of a number of formats, as described below.

Format 1. Sample listing description by sequential F number:

F768	2/3/82	09SW19	SEEP EAST
(sample no.)	(date collected)	(location)	(description)

A B F
(type of data available)

Location 09SW19 indicates site 9, surface water, location 19. A, B, and F indicate ICAP, IC, and monitoring data available.

Format 2. A site report describing which sample data are printed relative to a described location:

SEEP:	12/20/81	
	9-9 (EAST)	F768

This report indicates that the data for sample F768 were printed next to location 9-9 under SEEPS. Each site report contains data for one specific analyte for all sampling trips and locations.

Format 3. A sample report which provides all analytical data for a particular sample:

	F768
2 Chloride (ppm)	1570
4 Sulfate (ppm)	699
32 Zirconium (ppm)	<0.05

The values before the analytes are identification numbers for each analyte. The data on the right side are concentrations obtained for the particular analyte for sample F768.

Format 4. Quality Control Reports for blanks, field replicates, laboratory replicates, sequential samples and standards:

Blanks were generally reported in a format to highlight the analytes that were above detection limit. Replicate and sequential samples were reported in terms of the % relative standard deviation change between the samples. Standards were reported with a column for reference values and calculated recovery data.

4.5.6.2 Reporting Formats--

The results of the chemical sampling and analysis program are provided in Appendix F. This data is reported by analyte for each site in the form of "site reports." Table 4.10 lists the analytes and their respective assigned identification numbers. Section 5 explains where liquid and solid samples were obtained and the reporting format for each site. The locations are also identified in site maps provided in Appendix F.

4.5.7 Quality Assurance/Quality Control (QA/QC) Activities

4.5.7.1 Overview—

A brief summary of QA/QC activities is given below. More detailed information is available in Appendix I, Quality Assurance/Quality Control Testing Program: Physical and Chemical Sampling and Analysis.

4.5.7.2 Field Activities—

A field activities plan, prepared before each sampling trip, described the methods to be used as well as the samples to be obtained, including quality control samples. Quality control samples obtained during each trip were generally as follows:

- Acid Blank - distilled water containing the exact amount of acid (HNO_3) used to stabilize samples for metals analysis.
- MilliQ® Blank - distilled water with no additives to serve as a blank for anion analyses.
- Field Blank - distilled water passed through the sampling devices (pneumatic pump, peristaltic pump) and filtration apparatus to check for equipment contamination.
- Field Duplicate - split of a sample obtained from a well or a surface water location after all field manipulation had been completed but just before placing in the sample bottle for transport to the laboratory.
- Sequential Well or Surface Duplicates - sequential samples obtained from a well or a surface water location after the location had been sampled with the standard sampling procedure.
- Other Blanks - samples of water obtained on or near the site that had been used to wash equipment.

In addition to these check samples, QC activities were performed to calibrate and verify the accuracy of the instruments used to obtain field data (dissolved oxygen, conductivity, pH). Standards used to calibrate and monitor performance of the instruments were:

- Dissolved Oxygen. The response in air and to a sodium sulfite (D.O. = 0) were measured. This was performed at the beginning and end of each day's sampling.
- Conductivity. Standard KCl solutions (0.1, 0.029 and 0.001 N) were measured before and after sampling each day.

TABLE 4.10

ANALYTES, ANALYTE NUMBER
DESIGNATION, AND ABBREVIATIONS

Liquids

1	Fluoride	F
2	Chloride	CL
3	Nitrate	NO_3
4	Sulfate	SO_4
5	Phosphate	PO_4
6	Bromide	BR
7	Silver	AG
8	Aluminum	AL
9	Boron	B
10	Barium	BA
11	Beryllium	BE
12	Calcium	CA
13	Cadmium	CD
14	Cobolt	CO
15	Chromium	CR
16	Copper	CU
17	Iron	FE
18	Potassium	K
19	Magnesium	MG
20	Manganese	MN
21	Molybdenum	MO
22	Sodium	NA
23	Nickel	NI
24	Phosphorus	P
25	Lead	PB
26	Silicon	SI
27	Strontium	SR
28	Thorium	TH
29	Titanium	TI
30	Vanadium	V
31	Zinc	ZN
32	Zirconium	ZR
33	Arsenic	AS
34	Selenium	SE
37	pH Lab	pH-L
38	pH Field	pH-F
39	Conductivity Lab	C-L
40	Conductivity Field	C-F
41	Groundwater Level	GRW
42	Dissolved Oxygen	DO
57	Bromate	BrO_3
60	Lead Graphite Furnace	PB-GR

Solids

7	Silver	AG
8	Aluminum	AL
11	Beryllium	BE
12	Calcium	CA
13	Cadmium	CD
14	Cobolt	CO
15	Chromium	CR
16	Copper	CU
17	Iron	FE
18	Potassium	K
19	Magnesium	MG
20	Manganese	MN
21	Molybdenum	MO
22	Sodium	NA
23	Nickel	NI
24	Phosphorus	P
25	Lead	PB
27	Strontium	SR
28	Thorium	TH
29	Titanium	TI
30	Vanadium	V
31	Zinc	ZN
32	Zirconium	ZR
43	Arsenic	AS
44	Selenium	SE
45	TOS (Sulfite)	TOS
46	Sulfate	SO_4
47	pH-Slurry	pH
48	Acid Insolubles	AI
49	Solids (%)	% SOL
50	F (Extractable)	F
51	CL (")	Cl
52	NO_3 (")	NO_3
53	SO_4 (")	SO_4
54	CO_4 (")	CO_4
55	Alkalinity (OH)	OH

- pH Buffers (pH 4, 7, 10) were checked at the beginning, end, and at least two other times during each sampling day.

- Temperature. Checks were made of the instrument with a mercury thermometer at the beginning and end of each sampling day.

4.5.7.3 Laboratory Activities--

Laboratory QC activities included inserting "blind" quality control samples into each batch of samples to be analyzed. In addition to this level of QC, ICAP analyses performed by Barringer Magenta, Ltd., were subject to that organization's internal routine laboratory QC program.

The following quality control samples (in addition to the field QC samples) were generated in-house:

- Laboratory Duplicate - a split of the field duplicate sample was made upon receipt of samples in the laboratory.

- Blind Standards - a triplicate set of blind standards was inserted routinely into each batch of samples. For larger batches, two triplicate sets were included.

- Digestion Blanks - for samples requiring in-house digestion, a blank was carried along with each batch.

- Spiked Samples - known amounts of standard solutions were added to the various liquid matrices observed during the project.

A quality control procedure was practiced by Barringer Magenta, Ltd., during this ICAP analyses. In it, every 10th sample in a batch represented a quality control check sample in the form of a blank, repeat, or certified standard. If the sample was digested before analysis (e.g., solids), reagent blanks, repeat digestions, and appropriate certified solid samples were run. In addition, a drift standard was run after every 10th sample to check instrument stability (37).

The types of reference standards used throughout this project for liquid samples were Environmental Resource Associates (ERA, Chicago, Illinois) water quality control samples from various lots (MINERALS WasteWatR^tm, HARDNESS WasteWatR^tm, DEMAND WasteWatR^tm, NUTRIENTS WasteWatR^tm, TRACE METALS WasteWatR^tm). In addition, National Bureau of Standards (NBS) Trace Elements in Water reference standard (1643a) was routinely used. High concentration standards of certain elements (e.g., Si) were prepared from atomic absorption standards (Fisher Scientific).

For solid samples, the reference standards were National Bureau of Standards (NBS) fly ash (1633 and 1633a) as well as River Sediment (1645).

4.5.7.4 QC Data--

The quality control data were reported and reviewed for individual sites and for the overall program. Data were reviewed for the following individual site samples:

- concentrations of analytes in blanks where levels exceeded detection limits;
- concentrations of all analytes in duplicates and relative standard deviation between replicates;
- recovery of blind standards and reproducibility of these results; and
- recovery of spiked samples and reproducibility of these results.

For the overall program, the following data were reviewed:

- values of all blanks that were above detection limits;
- composite values for relative standard deviations of all field, laboratory duplicates and well or surface water duplicates;
- average recovery for each element for the complete program for blind standards; and
- average recovery for each element in "spiked" samples.

4.6 ENGINEERING AND COST ASSESSMENT

4.6.1 Overview

The purpose of the engineering and cost assessment was to develop conceptual engineering designs and corresponding capital and annual costs for generic waste handling and disposal operations. This information was prepared in a form that would enable it to be used as a decision-making tool for preliminary waste management planning purposes. The engineering/cost data are provided in Section 6. The data were developed so that they could be used, together with other information (waste characteristics, environmental setting, etc.), by local permitting officials or utility planners to define, evaluate and select appropriate waste management scenarios for new coal-fired power plants. Variations in waste type and in the collection handling, processing, storage, transport and disposal of these wastes call for different waste management practices. The engineering data presented in this report provide design options for each type/waste management activity combinations. In addition, the cost data base found in Section 6 gives estimates for the capital and annual costs associated with each possible waste management design option. This engineering/cost data base fulfills one of the several information requirements necessary to apply the overall decision methodology for proper waste management options. (See Section 8.)

Site-specific engineering and cost data were developed for the solid waste handling and disposal operations at the six study sites based in information supplied by the participating utilities and data developed during this project. The detailed procedures for the site-specific engineering and cost assessments are provided in Section 4.6.2. The results of this effort (summarized in Section 5.1), along with engineering and cost data developed for other pertinent studies, were adjusted and refined to produce the generic engineering and cost data base presented in Section 6. The approach for developing this generic engineering and cost data is described in Section 4.6.3.

4.6.2 Site-Specific Engineering and Cost Assessments

The site-specific engineering and cost assessment involved developing conceptual engineering designs and cost (capital and annual) estimates for the solid waste handling and disposal operations at the six study sites. This effort called for several major work products:

- Preliminary conceptual engineering designs for the solid waste handling and disposal systems at the six study sites, based on data provided by the participating utilities and engineering data developed as a result of a preliminary plant visit.
- Finalized conceptual engineering designs for the solid waste handling and disposal systems of the six study sites, based on revisions to the preliminary design, as provided by the utilities, and data developed during a final plant visit (if such a visit was necessary).
- Capital and annual cost estimates for the systems specified in the final engineering design.

Final, site-specific engineering/cost packages consisting of the conceptual engineering process designs and cost estimates developed.

Figure 4.3 shows the relationship of these various work products. A more detailed discussion is given below.

4.6.2.1 General Approach for the Site-Specific Engineering and Cost Assessments--

The site-specific engineering and cost evaluations of the coal combustion coal-fired utility solid waste handling and disposal operations at all six sites were conducted in the same manner. For each site, the approach to the first phase of the assessment required identifying the waste types and process systems of interest. Three major utility coal combustion wastes were taken as the primary focus: fly ash, bottom ash or boiler slag, and FGD waste.

Fly ash was viewed in this study as any particles collected from the flue gas, including economizer and air heater ash, as well as fly ash collected in air pollution control devices. Waste materials rejected by coal pulverizers (i.e., mill rejects or pyrites) are typically handled and transported in consolidated systems with bottom ash or slag. For this reason, these materials were placed in the same waste type category as bottom ash/boiler slag.

After the waste types to be considered on a site-by-site basis had been identified, the battery limits of the waste handling and disposal system were established. In the case of FGC wastes, the systems to be considered began at the point of discharge from the various particulate and/or sulfur oxides collection devices. In systems where fly ash or FGD wastes were collected in dry form, this was the discharge of the hoppers below the electrostatic precipitator (ESP), bag filter, or mechanical collectors. For fly ash or FGD

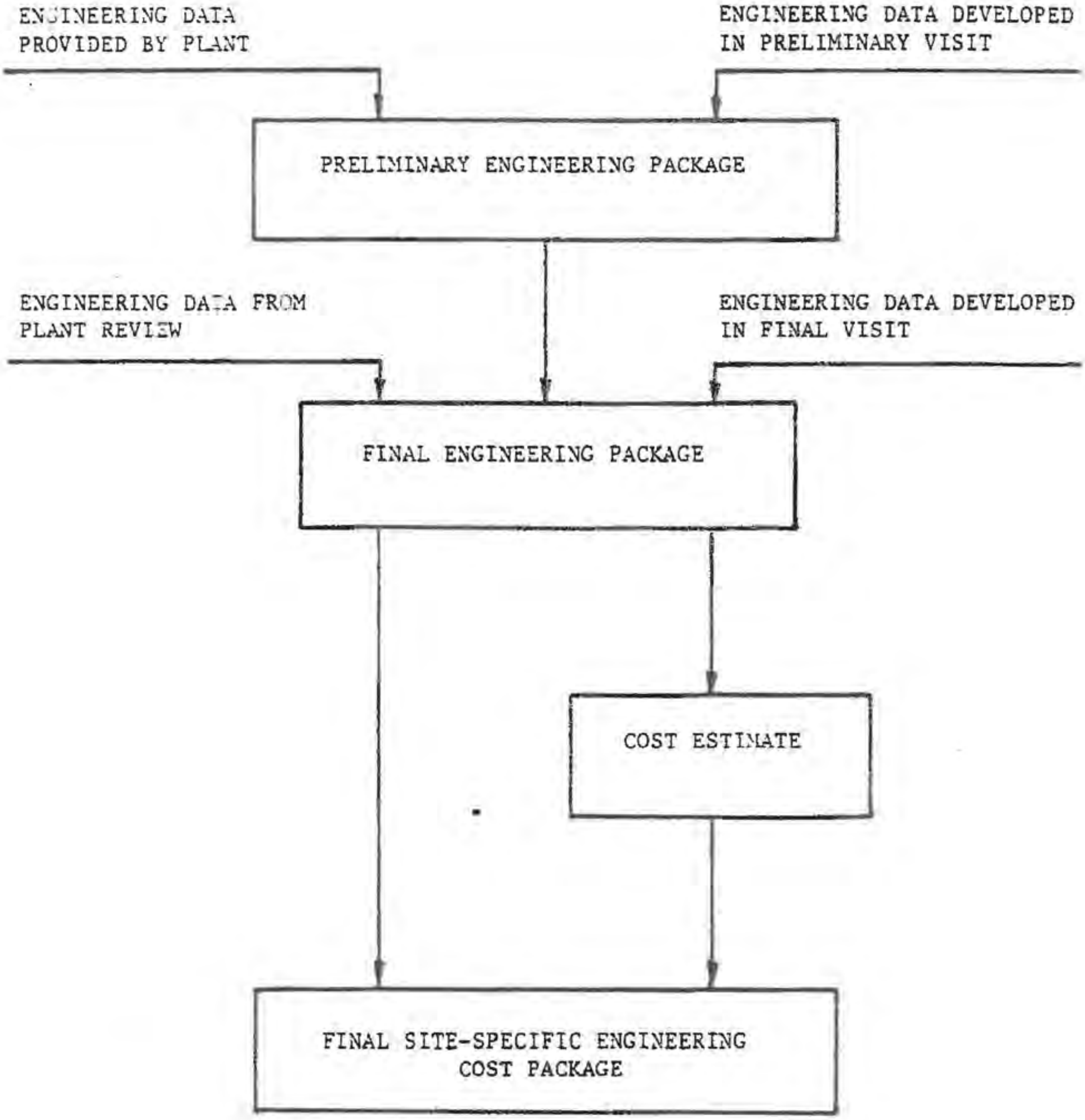


FIGURE 4.3 SITE-SPECIFIC ENGINEERING AND COST ASSESSMENT APPROACH

Source: Arthur D. Little, Inc.

waste collected in wet scrubbers, the system under assessment began at the discharge from the scrubber. For bottom ash or slag, the pertinent system for this study started at the discharge of the bottom ash/slag hopper. In every case, the operation under consideration included all waste handling, processing, storage, transport and disposal activities, up to and including disposal site reclamation.

It is difficult to separate completely solid waste handling and disposal systems from other waste streams in the plant. Such streams include coal pile runoff, wastes generated in boiler cleaning operations, and other, similar plant wastes. Thus, broad process specifications were developed for auxiliary systems -- those handling wastes, other than coal ash and FGD wastes, that enter the solid waste handling and disposal system.

After the waste types and solid waste handling and disposal operations had been identified, the system was divided into modules. Up to five modules were considered for the management at any particular waste type:

- raw materials handling and storage;
- waste processing and handling;
- waste storage;
- waste transport; and
- waste placement and disposal (including site monitoring and site reclamation).

All five specified system modules did not necessarily exist at every coal-fired utility plant for each of the waste types of interest.

This modular approach to the engineering and cost evaluation was valuable for many reasons. It ensured consistency in the assessments for all six sites. It also allowed easier cost comparisons to be made between individual modules and systems at different plants. This approach also facilitated identification of the various cost elements within the solid waste handling and disposal systems. The ultimate benefit of the modular approach was in the development of engineering and cost data for generic solid waste disposal and handling modules. The generic modules can be viewed as building blocks which may be combined and interchanged to obtain generic engineering designs and capital and annual costs for any number of generic solid waste handling and disposal schemes.

4.6.2.2 Methodology for the Site-Specific Engineering Assessment—
As the first step in developing conceptual engineering designs for the systems of interest, a questionnaire was distributed to each utility that participated in the project. Table 4.11 shows the questionnaire format. Much of the information requested was gathered during the site selection process. To minimize any inconvenience to utility personnel, this information was placed on the questionnaire before it was sent. The utility was asked to verify this

TABLE 4.11

FORMAT FOR REQUESTING INFORMATION ON DISPOSAL METHODS

I. GENERAL PLANT INFORMATION

A. Plant Name:
B. Utility Operating Plant:
C. Plant Ownership [Utility Name(s)]:
D. Primary Contact

1. Name:
2. Title:
3. Telephone Number:

E. Plant Location

1. Longitude/Latitude:
2. County/State:
3. Geographic Location

a. Nearest City/Town

- Distance from Plant:
- Direction from City/Town to Plant:

b. Nearest Water Source

- Distance from Plant:
- Direction from Water Source to Plant:

F. Plant Type (i.e., Baseload or Peakload):
G. Plant Nameplate Generating Capacity (MW):
H. Plant Start-up Date (Month/Year):
I. Overall Plant Annual Capacity Factor(s) [include value(s) and year(s)]:

J. Projected Addition of New Units [include date(s), unit number(s) and nameplate generating capacity(ies)]:

II. BOILER FACILITIES

A. Boiler Type (i.e., tangentially fired, pulverized coal-fired):
B. Total Number of Units:

(continued)

TABLE 4.11 (continued)

C. Unit___Information (1 for each unit)

1. Unit Nameplate Generating Capacity (MW):
2. Unit Status (i.e., active or retired):
3. Unit Start-up Date (Month/Year):
4. Boiler Manufacturer:
5. Turbine Manufacturer:
6. Annual Average Load Factor(s) [indicate value(s) and year(s)]:
7. Boiler Cleaning Frequency:

III. SOLID WASTE COLLECTION AND HANDLING

A. Flue Gas Desulfurization (FGD) System

1. System Type (i.e., lime scrubbing):
2. System Start-up Date (Month/Year)
3. System Status (original or retrofit):
4. Design Efficiency:
5. Operating Efficiency:
6. FGC System Equipment List [include description of equipment, name of manufacturer(s) and quantity(ies) of equipment]:
7. Chemical Additives Employed:
8. Solids Content of FGC Waste Prior to Processing:
9. Primary FGC Waste Dewatering Method (i.e., thickening):
10. Solids Content of FGC Waste Following Primary Processing:
11. Secondary FGC Waste Dewatering Method (i.e., filtration or centrifugation):
12. Solids Content of FGC Waste Following Secondary Processing:

B. Particulate Removal System

1. Collection Mode (wet or dry):
2. System Type (i.e. mechanical collection or electrostatic precipitation):

(continued)

TABLE 4.11 (continued)

3. System Start-up Date (Month/Year):
4. System Status (original or retrofit):
5. Design Efficiency:

6. Operating Efficiency:

7. Chemical Additives Employed:

8. Equipment List [include description of equipment, name of manufacturer(s) and quantity(ies) of equipment]:

C. Handling of Dry Fly Ash

1. Pneumatic Conveying System

a. System Type (i.e., positive pressure or vacuum):

b. Conveying Distance:
c. Conveying Destination (i.e., storage silos):

2. Wet Handling System

a. System Type (i.e., direct slurrying or combination vacuum pneumatic/wet slurrying system):

b. Conveying Distance:

D. Bottom Ash Collection

1. Boiler Type (i.e., dry or wet bottom):

2. Processing Equipment

a. Grinding (i.e., Clinker Grinder):

b. Dewatering (i.e., Hydrobin):

3. Transport (i.e., wet sluicing or dry conveying):

E. Transport of Fly Ash

1. Truck Transport of Dry Fly Ash

a. Truck Type (i.e., conventional rear dump, semi-trailer rear dump or semi-trailer bottom dump):

(continued)

TABLE 4.11 (continued)

b. Loading Facilities (i.e., front end loaders, belt conveyors or chutes):
c. Number of Trucks Used for Fly Ash Disposal:
d. Capacity of a Truck (tons):
e. Number of Truckloads Transported Daily:
f. Distance Each Load is Transported:

2. Pipeline Transport of Fly Ash for Wet Disposal

   a. Number of Sluice Lines:
   b. Piping

      - Length of Line:
      - Size (diameter):
      - Material of Construction:
      - Frequency of Replacement:
      - Modifications:

   c. Pumping Equipment

      - Number of Pumps:
      - Pump Type(s):
      - Modifications:

   d. Slurry Solids Content:

F. Transport of Bottom Ash

1. Truck Transport of Dewatered Bottom Ash

   a. Truck Type (i.e., conventional rear dump, semi-trailer rear dump or semi-trailer bottom dump):
   b. Loading Facilities (i.e., front end loaders, belt conveyors or chutes):
   c. Number of Trucks Used for Bottom Ash Transport:
   d. Capacity of a Truck (tons):
   e. Number of Truckloads Transported Daily:
   f. Distance Each Load is Transported

2. Pipeline Transport of Bottom Ash for Wet Disposal

   a. Number of Sluice Lines:

(continued)

TABLE 4.11 (continued)

b. Piping

- Length:
- Size (diameter):
- Material of Construction:
- Frequency of Replacement:
- Modifications:

c. Pumping Equipment

- Number of Pumps:
- Type(s) of Pumps:
- Modifications:

d. Slurry Solids Content:

IV. COAL

A. Coal Consumption Data:

	1976	1977	1978	1979	1980
Coal Type:					
Coal Source(s):					
State:					
Mine:					
Coal Consumption: (thousand tons/yr)					

(continued)

TABLE 4.11 (continued)

B. Coal Composition Data:

	1976	1977	1978	1979	1980
Coal Heat Content (Btu/lb)					
Coal Sulfur Content (wt %, dry basis)					
Coal Ash Content (wt %, dry Basis)					
Coal Moisture (wt %)					

V. WASTES GENERATED

A. Coal Ash Wastes:

	Annual Tonnage (Dry Basis)				
	1976	1977	1978	1979	1980
Fly Ash Generated					
Bottom Ash Generated					
FGD Waste Generated					
Fly Ash Sold					
Bottom Ash Sold					
FGD Waste Sold					
Fly Ash Used by Plant					
Bottom Ash Used by Plant					
FGD Waste Used by Plant					
Pyrites/Mill Rejects					

(continued)

TABLE 4.11 (continued)

B. Plant Wastes:

	Annual Quantities (gallons/year)					
	1976	1977	1978	1979	1980	Indicate Where Wastes Are Sent
Boiler Blowdown						
Cooling Tower Blowdown						
Boiler Cleaning Wastes*						
Air Preheater Cleaning Wastes*						
Coal Pile Run-Off						
Surface Run-off						
Plant Sumps						
Yard Sumps						
Other (specify)						

VI. WASTE DISPOSAL METHODS

A. Brief Description of Overall Solid Waste Disposal Operation:

B. Ash Disposal Pond or Settling Pond

1. Pond Influents (waste type, volume %):

2. Present Status (active or retired):
3. Design Life:
4. Present Age:
5. Date of Construction (Month/Year):

*Indicate frequency of cleaning and what types and quantities of cleaning solutions and rinses are used.

(continued)

TABLE 4.11 (continued)

6. Construction Method:

7. Distance from Plant (miles):
8. Surface Area (acres):
9. Design Depth (feet):
10. Influent Transport Method

    a. Material(s) of Construction:

    b. Thickness
    c. Origin(s) of Material(s) of Construction:

11. Pond Overflow Discharge Destination:
12. Dredging

    a. Frequency:
    b. Disposal Site for Dredged Materials:

    c. Dredging Method Employed:

13. Proposed Modifications:

14. Past Modifications (date and description):

15. Outfall Location(s):

16. Changes in Outfall Location(s) [give date(s) and location(s)]:

C. Landfill

1. Wastes Landfilled (waste type and volume %):

2. Present Status (active or retired):
3. Design Life:
4. Present Age:
5. Date of Construction (Month/Year):
6. Construction Method:

(continued)

TABLE 4.11 (continued)

7. Distance from Plant (miles)
8. Surface Area (acres):
9. Maximum Design Placement Depth (feet):
10. Placement Depth (feet):
11. Method of Waste Transport to Landfill:

12. Spreading Method (equipment and procedure):

13. Compacting Method (equipment and procedure):

14. Run-off Control:

15. Dust Control:

16. Embankment

    a. Material(s) of Construction:

    b. Thickness:
    c. Origin(s) of Construction Material(s):

17. Excavation During Construction:

18. Landfill Slope Ratio:

19. Maximum Number of Benches:
20. Number of Benches Placed:
21. Bench Size:
22. Lift Thickness:
23. Proposed Landfill Modifications:

24. Past Landfill Modifications (date and description):

25. Planned Landfill Reclamation:

(continued)

TABLE 4.11 (continued)

VII. DISPOSAL SITE MONITORING

A. Surface Water Monitoring

1. Ash Pond Discharge Monitoring:

2. Upstream Surface Flow Monitoring:

3. Other (specify):

B. Groundwater Monitoring

1. Number of Monitoring Wells:
2. Locations and Depths of Monitoring Wells:

information and "fill in" the additional information needed. In addition to the completed questionnaire, each utility was requested to provide:

- process flow diagrams for the coal ash and, where appropriate, FGD waste handling, processing, storage and transport systems;
- process flow diagrams for the miscellaneous plant wastes handling and transport systems;
- specifications for major process and mobile equipment of the above systems;
- overall specifications for the air pollution control equipment; and
- design and operating material balances for each system.

Preliminary efforts also included a data-gathering visit to five of the six study sites. (The Powerton Plant, which had a relatively straightforward solid waste handling and disposal system, was not visited.) With the data provided as a result of these information-gathering efforts, the modular approach was used to develop preliminary engineering packages, which included process flow diagrams, equipment lists, and equipment specifications. The first step was to determine the battery limits of the systems of interest and divide these systems into appropriate modules.

A design basis was defined for each system. Of highest importance was the specification of design waste generation rates. For process equipment, the design waste capacity was assumed to be equivalent to the theoretical generation rate when the boiler operated at full electric generating capacity. For disposal areas, design waste capacity specifications were based on plant operations at a 70% load factor.

For the preliminary process flow diagrams, process flows and operations were made readily identifiable, and only the most essential details of process design were included. All major items of process equipment were shown. When two or more identical pieces of equipment were used for the same function (either in series, in parallel, or as spare equipment), only one symbol was shown on the process flow diagram. (The existence of multiple pieces of equipment was indicated by the equipment number assigned to a particular symbol, as explained below.)

Numbers were assigned to all process equipment, mobile equipment, and disposal operations for which engineering specifications and costs were developed. A number appears on or next to the appropriate equipment symbol in the process flow diagram and is referenced in all equipment lists, equipment specifications and cost estimates. Each item number consists of two, and in some cases three parts; each part is separated by a hyphen. The first part has one or more letters identifying the type of equipment or system. Process equipment is denoted by a single capital letter. Mobile equipment and disposal operations are designated two letters. In the case of mobile equipment, only the initial letter is capitalized, while both identification letters are capitalized for disposal operations. The equipment designation codes are listed in Table 4.12.

The second part of all item numbers consisted of a four digit number. The first digit represents the plant at which the equipment or disposal operation is located. (Table 4.13 lists the plants and their identification numbers.) The second digit is for the area account to which a piece of equipment or disposal operation was assigned. Area accounts were assigned after the coal ash/FGD waste handling and disposal system had been divided into modules. A module was either stipulated as an area account or broken down into two or more area accounts. In most cases, a single area account contained items assigned to only one module. A sufficient number of area accounts were established to account for all items of the waste handling and disposal operation. The remaining two digits of the equipment number indicate the number of the specific piece of equipment. For example, P-1101 indicates that the process equipment in question is located at Plant Allen, is in Area Account 1, and is designated as Pump Number 1.

A third designation is for multiple pieces of identical equipment. Two letters separated by a slash are shown. If each item represented by a symbol is assigned a consecutive letter of the alphabet, the first letter (always A) is shown to the left of the slash and the last letter assigned is placed to the right of the slash. For example, T-2101-A/B refers to a set of two thickeners in Area Account 1 at the Elrama site.

Only the most important equipment and process information was included on the process flow diagram. Table 4.14 gives the specifications which, if available, were included in the process flow diagram. A more detailed listing of equipment and specifications was developed for the cost estimating task.

All major process streams indicated on the flow diagram were assigned a number, shown on the diagram next to the stream and enclosed in a diamond-shaped symbol. A material balance referencing these stream numbers was developed and presented on the lower left corner of the process flow diagram. The material balances were developed for design (i.e., full-load) operation and were based on average daily stream flows.

An equipment list was prepared for the coal ash handling/disposal operation of each plant under consideration. Each equipment list included:

- a list of plant specific area accounts; and
- a list of equipment by type, including item numbers, descriptions, and the quantity required.

In addition to equipment lists, a more detailed listing of equipment specifications than that shown on the process flow diagrams was developed for the cost estimating task.

The preliminary engineering packages described above were submitted to the utilities for review. The utilities were requested to make corrections and to fill in any data gaps. In some cases a final plant visit was made to collect

TABLE 4.12

EQUIPMENT DESIGNATIONS USED
IN THE ENGINEERING ASSESSMENT

PROCESS EQUIPMENT	
Agitators	A
Blowers, Compressors, Fans	B
Conveyors	C
Feeders	D
Eductors	E
Filters, Centrifuges, Cyclones	F
Mixers, Pugmills	M
Pumps	P
Storage Tanks	S
Thickeners	T
Vessels, Bins, Hoppers	V
MOBILE EQUIPMENT	
Dozers	Dz
Draglines	Dl
Front End Loaders	Fl
Scrapers	Sc
Trucks	Tr
DISPOSAL OPERATIONS	
Landfills	LF
Ponds	PD

Source: Arthur D. Little, Inc.

TABLE 4.13

PLANT IDENTIFICATION NUMBERS

Plant Name	Plant Identification Number
Plant Allen	1
Elrama Power Plant	2
Dave Johnston Power Plant	3
Sherburne County Power Plant	4
Powerton Power Plant	5
Smith Power Plant	6

Source: Arthur D. Little, Inc.

TABLE 4.14

PROCESS AND MOBILE EQUIPMENT SPECIFICATIONS FOR PROCESS FLOW DIAGRAMS

EQUIPMENT	SPECIFICATIONS
Process Equipment	
Agitators	Type HP Material of Construction
Blowers, Compressors, Vacuum Pumps	Capacity (SCFM) Type Suction Pressure Discharge Pressure Material of Construction
Centrifuges	Capacity (lb/hr of wet cake) Type Size: Diameter (ϕ) x Tangent to Tangent Height (TT) Material of Construction
Conveyors, Feeders	Capacity Type Size (e.g., lift and/or length, as appropriate) Material of Construction
Cyclones, Dust Collectors, Filters	Type Flow Rate Exposed Surface Area (if applicable) Size: Diameter (ϕ) x Tangent to Tangent Height (TT) Material of Construction
Eductors	Type Inlet or Discharge Throat Diameter Supply Fluid Pressure Material of Construction
Mixers, Pugmills	Capacity Type Size: Diameter (ϕ) x Tangent to Tangent Height (TT) Material of Construction

(continued)

TABLE 4.14 (continued)

EQUIPMENT	SPECIFICATIONS
Pumps	Capacity Total Developed Head or Pressure Differential Type Material of Construction
Storage Tanks, Vessels	Capacity Size: Diameter (ø) x Tangent to Tangent Height (TT) Type Material of Construction
Thickeners	Capacity Size: Diameter (ø) x Tangent to Tangent Height (TT)
Mobile Equipment	
Dozers, Front End, Loaders, Drag Lines	Capacity Type Size:
Trucks	Capacity Type Size:

Source: Arthur D. Little, Inc.

additional engineering data. The preliminary engineering package (i.e., process flow diagrams, equipment lists and equipment specifications) was then revised and finalized.

4.6.2.3 Methodology for the Site-Specific Cost Assessment--

The finalized engineering packages were used to estimate capital and annual costs for the waste handling and disposal operations at each of the six sites. The capital costs were estimated as the replacement costs of existing facilities; first year annual costs were also developed. All cost estimates are reported in late 1982 dollars. These cost estimates are conceptual in nature, with accuracies of ±30%.

The initial plans for the cost estimating task called for obtaining actual capital and operating cost data from the utility plants themselves. A cost estimator was to visit the six plants and review as much available capital and operating cost information as possible. At the end of each visit, the estimator was to evaluate the quality of available data and its usefulness for estimating the project's cost requirements. If required, subsequent site visits were to be made to fill data gaps. At the discretion of the estimator and in the absence of sufficient utility-supplied data, estimated data from sources other than the utility were to be used.

In reality, it was not feasible to obtain actual cost data from utility sources due to the difficulties encountered in accessing these sources. Thus, cost estimates prepared for the six sites do not represent adjusted actual incurred costs, but rather were estimated based on process design data. Accepted cost estimating techniques were used.

4.6.2.3.1 Capital Costs -- The capital cost estimates were prepared from the finalized process flow diagrams, equipment lists, and equipment specifications developed for the engineering evaluation. The modular approach was applied to estimate capital costs.

Capital cost items were divided into direct costs, indirect costs and other capital costs. Direct capital costs include the costs of process equipment, piping and insulation, foundations and structural components, site preparation and earthwork, electrical requirements, process instrumentation, and site reclamation and mobile equipment. For each line item, both material and labor costs for installation were determined. In addition, the costs of services, including allocated costs from the power plant for the use of maintenance shops, stores, communications, security, offices, parking lots, walkways, landscaping, fencing, and vehicles, were also taken into account. This cost was estimated as 2% of the remaining direct capital costs, excluding mobile equipment. Current budget prices for process and mobile equipment were obtained from manufacturers or manufacturer's representatives. Direct capital cost elements are:

- Labor and Burden. Labor rates were current union labor rates for the specific site location, including fringe benefits and burden. No allowance for overtime was made.

- Material. Material prices were based on vendor budget quotations or in-house information.
- Sales Tax. This item was excluded.
- Equipment Usage. This consisted of current rental rates for construction equipment, excluding operator and oiler. An allowance for fuels, lubes and routine maintenance was included.
- Equipment. Equipment prices were based on vendor's budget quotations.

No engineering drawings or specifications were developed for structural excavation, concrete, equipment foundations, structural steel, miscellaneous steel, duct work, insulation, electrical requirements or instrumentation. The capital costs of these items were estimated as parameter costs based on equipment weight, equipment cubage, and in-house information.

Capital costs for the disposal sites were based on engineering drawings of the site, if available. For example, capital cost estimates for dike construction were based on actual dike design drawings. Unit costs for waste handling and disposal site construction are provided in Table 4.15.

Indirect capital costs include contractor's fees and profits, engineering design and supervision, architect and engineering contractor expenses, contingency allowances, allowance for startup and modification, and interest during construction. All these costs, except interest during construction, were estimated. Costs for the first five items listed were calculated as percentages of direct capital costs, as shown in Table 4.16. Allowances for startup were estimated based on in-house information.

Other capital costs include working capital and land. Working capital consists of: funds invested in raw materials and supplies; accounts receivable; cash retained for payment of operating expenses, such as salaries, wages, and raw material purchases; accounts payable; and taxes payable. For the purposes of this study, working capital was not estimated. The cost of land is highly variable throughout the country and, thus, actual land costs were not used. A unit land cost of $\$.790/m^2$ ($3,200/acre) was assumed. Land costs, however, do not represent a major contributor to the overall capital cost.

Special provisions were required to standardize the cost estimates. Equipment, material, and construction labor shortages with accompanying overtime pay incentives were not included in cost estimates. Generation facilities for electric power consumed were not included in the capital costs.

Items excluded from the developed capital cost estimates were: land right-of-way; owner's administrative costs; interest during construction; permits; soils; spare parts; working capital; and sales tax.

<u>4.6.2.3.2 Annual Costs</u> -- The modular approach described earlier was used to estimate annual costs for the coal ash and FGD waste handling and disposal activities at each of the six sites. For each site, a cost basis was developed

TABLE 4.15

UNIT COSTS FOR CAPITAL COST ESTIMATES
FOR ALL SIX STUDY FGC WASTE HANDLING AND DISPOSAL SITES

UNIT COSTS:

Item Description	Units	Unit Cost ($)
Clearing and Grubbing		
• Bushes	m^2	.205
• Medium Dense Woods	m^2	.445
• Heavy Woods	m^2	.692
Earthwork		
• Cut and Fill (balanced)	m^3	3.80 - 5.90
• Mass Excavation	m^3	1.45
• Structural Escavation	m^3	3.40 - 5.60
• Structural Backfill	m^3	4.05 - 7.85
Aggregates		
• Sand and Gravel (in place)	m^3	15.70
• Crushed Rock (in place)	m^3	19.10
• Rip-Rap (in place)	m^3	23.55-28.80
Liner		
• Bentonite Clay (installed)	m^3	5.25-13.10
• Poz-O-Pac (installed)	m^3	15.70
Dike Seeding	m^2	.70-1.20
Reclamation		
• .45 Meter Cover Soil; .15 Meter Top Soil & Seed	m^2	1.71
Access Road (dirt & some gravel)	m^2	4.80-6.60
Instrumentation		
• Monitoring Well (installed)	Each	2,800
Land Acquisition	m^2	.790

Source: Arthur D. Little, Inc. estimates.
Kaiser Engineers

TABLE 4.16

SUMMARY OF INDIRECT CAPITAL COST FACTORS

INDIRECT COST	FACTOR
CONTRACTOR'S OVERHEAD	
• Fly Ash/SO_2 Control	10% of Direct Cost
• Mobile Equipment	-
• All Other	15% of Direct Cost
CONTRACTOR'S PROFIT	
• Fly Ash/SO_2 Control	2% of Direct Cost
• Mobile Equipment	-
• All Other	5% of Direct Cost
ENGINEERING DESIGN AND SUPERVISION	
• Fly Ash/SO_2 Control	5% of Direct Cost and Contractor's Overhead and Profit
• Mobile Equipment	-
• All Other	10% of Direct Cost and Contractor's Overhead and Profit
ARCHITECT-ENGINEERING FEE	
• Fly Ash/SO_2 Control	2% of Direct Cost and Contractor's Overhead and Profit
• Mobile Equipment	-
• All Other	5% of Direct Cost and Contractor's Overhead and Profit
CONTINGENCY	30% of Direct Costs, Contractor's Overhead and Profit, Engineering Design and Supervision and Architect-Engineering Fee

Source: Arthur D. Little, Inc. estimates.
Kaiser Engineers

which included an estimate of on-stream time and annual average operating capacity. A typical operating capacity of 70% was chosen as the basis for operating cost calculations. Unit cost factors were developed for labor, materials and utilities. Table 4.17 presents the unit cost factors used for this study. All are averages typical for the industry.

Before site-specific unit costs could be calculated, it was necessary to establish site-specific operating requirements for utilities, labor, maintenance, and the like. Utilities consumption were determined from the material balance (process water and raw material requirements), mobile equipment usage (fuel and mobile equipment maintenance requirements), and horsepower of electric-powered equipment (electric power consumption). Estimates for labor requirements were based on discussions with plant personnel. Maintenance requirements for all items except mobile equipment were taken as percentages of the total fixed investment for the appropriate items. Pond and landfill maintenance were respectively estimated at 2% and 3% of the total fixed investment. Process equipment maintenance was assumed to be 4% of the total fixed investment. Mobile equipment maintenance requirements were based on manufacturers' specifications (42). Such items as lube oils, filters, grease, tires, other materials, and labor were included.

Annual costs were divided into direct and indirect operating costs for each of the specified modules. Direct operating costs consist of the costs of such items as supervision, operating labor, maintenance (labor and materials), utilities required (electricity, water, steam, etc.) and raw materials (e.g., lime or Calcilox®, a proprietary additive used for waste fixation). Direct operating costs were estimated with the unit costs and factors previously discussed.

Indirect operating costs include overhead expenses (payroll and plant), general and administrative costs, taxes, and insurance. The largest of the indirect operating costs are capital charges that depend on the capital structure of the utility. To present the findings of this study on a consistent basis, one set of capital charge values was used to determine annual costs. Capital charges for mobile equipment, which is unique in that interim replacements are required, will be relatively higher than other capital charges. Similarly, the capital requirement for reclamation, an expenditure that occurs at the end of the 30-year system life rather than at the beginning, differs from other capital charges. To provide a consistent basis between this cost estimate and other cost estimates prepared within the industry, factors for capital charges were determined with the method proposed by the Electric Power Research Institute (EPRI) as a standard for use by EPRI staff and contractors (43). With this method, the following factors for calculating capital charges were determined:

- Capital charges for the coal ash and FGD waste handling and disposal system (exclusive of mobile equipment and disposal site reclamation) were assumed to be 14.7% of total capital investment on the basis of a 30-year operating life.

TABLE 4.17

STANDARD ANNUAL COST INFORMATION SUMMARY
FOR ALL SIX STUDY SITES: FGC WASTE HANDLING AND DISPOSAL

Unit Costs:

Item Description	Units	Unit Cost ($)
Raw Materials		
• Lime	metric ton	77.15
Utilities		
• Process Water	1000 liter	.03
• Electricity	kWh	.045
• Fuel (diesel)	liter	.30
Operating Labor		
• Operator		
- Process Equipment	manhour	11.00
- Mobile Equipment	manhour	12.50
• Foreman	manhour	12.50
• Supervisor	manyear	30,000
• Sampling & Analysis	manhour	12.75
Maintenance (Materials & Labor)		
• Process Equipment (PE)	% of PE Total Fixed Inv.	4.0
• Mobile Equipment (ME)	-	Based on Ref. 7
• Pond (PD)	% of PD Total Fixed Inv.	2.0
• Landfill (LF)	% of LF Total Fixed Inv.	3.0
Subcontracted Items		
• Pond Dredging	-	Based on Ref. 8
Overheads		
• Payroll & Plant		
- Mobile Equipment	% of Maintenance (M&L)	15.0
- Mobile Equipment	% of Operating Labor	65.0
- All Other	% of Operating Labor & Maint. (M&L)	65.0
• Capital Charges		
- Process Equipment (PE)	% of PE Capital Inv.	14.7
- Mobile Equipment (ME)	% of ME Capital Inv.	28.0
- Reclamation (REC)	% of REC Capital Inv.	3.5

Source: Arthur D. Little, Inc. estimates.

- Mobile equipment capital charges were calculated to be 28.0%, based on a 10-year mobile equipment life.

Assumptions used in these calculations were that:

- The weighted cost of capital is 10% annually.
- Inflation is 6% annually.
- Depreciation is stated in terms of a sinking fund. Because of retirement dispersion, an additional allowance is added to provide sufficient depreciation reserve. (This deficiency results from the use of average life for depreciation calculations.)
- Tax preference allowances, accelerated depreciation and investment tax credits are included in the capital charges. Calculation of tax preference allowances is achieved with a flow-through method. Accelerated depreciation is determined based on the sum-of-the-years digits methods. Investment tax credit rates are 4% of the total capital investment.
- Gross receipt taxes are not universally applied to capital charges calculations and are not included in the figures presented here.
- Property taxes and insurance are 2% of the total capital investment.

Capital charges for reclamation were estimated as the annual annuity payment (assuming 10% earnings on investment) required to produce a fund sufficient to pay for reclamation costs inflated over the 30-year life of the disposal site. The annual payment was estimated at 3.5% of the total capital cost for reclamation.

Plant and payroll overhead costs and administrative costs were estimated as 50% and 15%, respectively, of the total expense for operating labor, maintenance and supervision.

4.6.3 Generic Engineering and Cost Assessment

The engineering design and economics of coal ash and FGD waste handling and disposal operations significantly affect the selection of air pollution control technologies at coal-fired utility plants. Engineering and cost data bases must be developed for these systems. These will serve as a tool in preliminary engineering and cost evaluations of potential waste management options. The generic engineering and cost evaluation was implemented in this project to provide such a decision-making tool.

The site-specific engineering and cost data developed for the six study sites, together with the engineering and cost data available in the literature, were used to develop generic capital and annual cost data for various combinations of the three waste types and five process modules. This task was complicated by the fact that most of the cost studies available in the literature did not offer detailed cost breakdown by waste type and for the specific process modules that had been identified for this project. Where practicable, cost data reported in the literature were broken down in the same manner that had been used in compiling costs for the six study sites. This involved evaluating the engineering/cost details that were provided and allocating entire cost elements or fractions of such cost elements to appropriate process modules. This was a difficult task at best, and the confidence level of the resulting data was somewhat less than desired.

Capital cost curves (capital cost vs. power plant size, MW) were developed for fly ash and bottom ash handling and disposal; similar curves (capital cost versus FGD waste generation, metric tons) were developed for handling and disposal of FGD waste. Cost curves for the handling and disposal of FGD wastes were plotted with capital cost vs. FGD waste generation rate rather than power plant size. This is because FGD waste generation rates vary widely for any given plant size. The cost of FGD waste handling and disposal is too dependent on the sulfur content of coal used for any one plant size to have a meaningful cost relationship in terms of plant size. Similarly, annual cost curves (annual cost vs. power plant size, MW, and annual cost vs. ash generation, metric tons/year) were developed for fly ash and bottom ash waste handling and disposal; in addition, cost curves (annual cost vs. FGD waste generation, metric tons/year) were developed for the handling and disposal of FGD waste. For the same reason as mentioned above, cost curves for the handling and disposal of FGD waste were not developed in terms of annual cost vs. plant size.

In preparing the generic capital and operating cost curves, it was necessary to convert all cost data to a common basis. In some cases, this required developing new cost estimates for generic engineering designs based, in part, on adjusted site specific data. For example, waste handling by truck transport varies in cost according to transport distance. It was necessary to: (1) convert all systems to a common design basis in terms of transport distance; (2) determine mobile equipment and operating requirements (e.g., fuel, labor, maintenance, etc.) for the new design basis; and (3) calculate capital and annual costs for the generic (i.e., revised) engineering design. The basic engineering design premises adopted for the generic engineering assessment are provided in Table 4.18. To arrive at common design bases, many elements in site-specific and literature engineering designs had to be adjusted, including:

- service life;
- load factor;
- fly ash/bottom ash ratio;
- coal ash content; and
- the presence of liners.

TABLE 4.18

SUMMARY OF BASIC ECONOMIC PREMISES FOR GENERIC COST CURVES:
FGC WASTE HANDLING AND DISPOSAL

Economic Premises	
Year of Capital and Annual Cost Estimates	Late-1982
Capitalization of Site Construction (Percent)	100
Capitalization of Site Reclamation (Percent)	100
Capital Charge Factors[a]	
• Process Equipment and Disposal Site	0.147
• Mobile Equipment	0.280[b]
• Reclamation	0.035
System Battery Limits	Waste Handling/Processing to Ultimate Disposal
Land Cost ($/m^2; $/acre)	0.79; 3200

[a]These capital charge factors were employed in the preparation of the first year annual costs for the six study sites and in the adjustments made to cost data found in the literature, when practicable.

[b]The capital charge factor for mobile equipment includes an allowance for interim replacement.

Source: Arthur D. Little, Inc., estimates.

In some cases, it was easier to determine the equivalent plant size that corresponded to the generic engineering design premises and for which the existing system design was appropriate, rather than to redesign completely the existing system to meet the generic premises. For example, if the bottom ash handling system at a given 500 MW plant is designed to handle bottom ash resulting from a 90/10 fly ash/bottom ash split, the system would be considered underdesigned for a 80/20 fly ash/bottom ash split. However, the same bottom ash system could handle bottom ash from a 250 MW plant generating 20% of its ash as bottom ash. Thus, rather than redesign the system to meet the engineering premises of the study, it was simpler to determine the plant size that corresponded to premises for the specified system. Of course this adjustment applied only to the plant size (MW) vs. cost determinations with respect to parameters affecting the lifetime or annual ash generation rates (i.e., service life, load factor, coal ash content and fly ash/bottom ash ratios). Differences between the design premises and actual design specifications of the remaining parameters listed required engineering design adjustments. If these adjustments were needed, corresponding capital and annual costs adjustments were made. Additionally, capital and annual costs from various studies were adjusted to the common bases shown in Table 4.19.

The least squares method of curve fitting was used to generate curves for adjusted capital costs, operating costs, and plant sizes for different combinations of coal ash types (e.g., fly vs. bottom ash) and modules. In cases of two or more distinct system variations within a given module for a given waste type,, (e.g., wet and dry transport of fly ash), two or more different cost curves were developed.

4.7 ENVIRONMENTAL ASSESSMENT

4.7.1 Overview

The environmental assessment conducted in this project emphasized three aspects of coal ash and FGD waste disposal:

- effects on groundwater quality;
- effects of non-point source drainage on surface water quality; and
- use of mitigative design, management and disposal practices.

Within this context, the assessment work was divided into two major efforts. First, individual site assessments were prepared for each of the six study sites based on available background information and on the data developed during this project. The methodology for these site assessments is described in detail in Section 4.7.2, and the assessment findings are presented for each site in Section 5.

The second major assessment effort was to use the findings from the six sites along with available information from other studies to describe the "generic" (industry-wide) effects implications of the various forms of coal ash

TABLE 4.19

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR GENERIC COST CURVES: FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES

Power Plant	
New or Retrofit	New
Plant Size (MW)[a]	200-3000
Boiler Type	Pulverized Coal-Fired Dry Bottom
Heat Rate (M joules/kWh; Btu/kWh)	12; 11,400
Location	United States
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Fly Ash/Bottom Ash Ratio	80/20
Coal Properties	
Sulfur Content (Percent)	0.5-3.5
Ash Content (Percent)	12.0-15.0
Heating Value (M joules/kg; Btu/lb)	22.0-26.7; 9,500-11,500
Air Pollution Control	
Particulate Control	ESPs
Particulate Removal (Percent)	>99
Sulfur Oxides Control	Conventional Lime Scrubber with or without Forced Oxidation
Alkali Stoichiometry	1.1
SO_2 Removal (Percent)	>70
Disposal Site	
Type	Pond/Landfill
Design Life (yr)	30
Terrain	Level
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner	None
Distance from Plant (km; miles)	1.6; 1.0

[a] Large plants employing multiple 500 MW units.

Source: Arthur D. Little. Inc. estimates.

and FGD waste disposal. The approach used for the generic or industry-wide assessment is summarized briefly in Section 4.7.3 and is presented in more detail, along with the findings, in Section 7.

4.7.2 Approach to Site-Specific Environmental Assessments

The individual site assessments were accomplished by:

- reviewing and evaluating background information on the disposal operations and setting;
- identifying and describing present disposal-related water quality effects based on evaluation of measured information developed during this project;
- postulating apparent cause/effect relationships to explain the findings at the site;
- considering potential future ranges of water quality effects (to the extent that suitable data were available); and
- summarizing the broader industry-wide implications of the findings at the individual sites

4.7.2.1 Assessment of Effects on Groundwater Quality--

4.7.2.1.1 Development of Background Information -- Background data were used in many ways. The data served as a source of information on:

- Early or pre-disposal conditions.
- Influences not related to the ash or FGD waste disposal, but still affecting the disposal site environment.
- Yearly or seasonal variability (if any). This gave a better perspective on the results from this project and provided additional information for the trend assessment.

The background data also provided a reference point that could be used to determine the reasonableness of the background sampling results obtained during this project.

Geologic and Hydrogeologic Background Information. The initial phase of site hydrogeological evaluation consisted of collecting and reviewing existing information on near-region and site-specific geologic and hydrogeologic conditions. This information was used to determine if the geologic and hydrogeologic conditions at a site would allow it to be adequately analyzed within the cost guidelines of the project. The information was collected and reviewed throughout all phases of the project, and it was used to refine or modify the assessment of a selected site.

Geologic information of interest included:

- topographic and physiographic conditions at the site;
- type of bedrock and surficial materials;
- stratigraphy and structure of geologic units;
- type and degree of site area disturbance caused by construction and mining; and
- other geologic conditions which could affect site area hydrogeology and site development for monitoring.

Hydrogeologic information included:

- proximity of major surface water bodies to the site area;
- flow characteristics of nearby streams and rivers and the potential for flooding in the site area;
- stratigraphy, pressure conditions, and hydraulic properties of aquifers underlying the site area;
- depth to the water table(s) and direction(s) of groundwater flow;
- location of nearby groundwater recharge or discharge areas and areas of artesian flow;
- aspects of the hydrologic cycle, including precipitation, evapotranspiration, infiltration, groundwater recharge, and surface water and groundwater runoff; and
- use of surface water and groundwater resources in the site area.

In the course of gathering this information, data on the chemical characteristics of surface water and groundwater were often encountered. These were catalogued and assessed in conjunction with the geologic and hydrogeologic information.

Geologic and hydrogeologic information pertaining to a particular site area were obtained from a variety of federal, state, and local government agencies; public and private organization; and knowledgeable individuals. These information sources included: U.S. and State Geological Surveys; U.S. and State Soil Conservation Surveys; U.S. and State Bureaus of Mines; National Oceanic and Atmospheric Administration; Corps of Engineers; U.S. and State Environmental Protection Agencies; and U.S. and State Bureaus of Roads. More local sources of information included the specific utilities, regional and local technical libraries, local engineers and contractors, and local and state water surveys.

Before each site visit, the following near-region and site-specific reference materials were obtained:

- U.S. Geological Sur- (USGS) 1:24,000-scale topographic maps of the area surrounding site, to n 8-kilome- (5-mile radius. If these were not available, suitable topographic coverage at a smaller scale was obtained for the same radius of coverage.

- U.S. Geological Survey (USGS) 1:250,000-scale topographic maps of the area surrounding each site, to a 40-kilometer (25-mile) radius.

- U.S. or State Geological Survey geologic quadrangle maps of any available scale for the site and area, to a 32-kilometer (20-mile) radius.

- County soil survey reports of the Soil Conservation Service or its predecessors at the U.S. Department of Agriculture.

- Site-specific topographic maps or construction drawings, if available.

During site visits, utility representatives were interviewed by the hydrogeological/geotechnical representatives of the team to gain access to site-specific information sources. These included construction drawings and documents relating to the disposal site, site-specific topographic surveys and geologic maps, boring logs and logs of local water wells, site-specific groundwater surveys, site area environmental studies, and others. A preliminary reconnaissance surficial geologic map of the disposal site was made during the visit, and general and specific site geologic and hydrogeologic conditions were observed and noted. Color slides of the site area were obtained to document existing site conditions.

Local public and private agencies were also visited to gather information on near-region and site-specific geologic and hydrogeologic conditions.

Groundwater Quality Information. Background information on groundwater quality was available from several source. The availability of such information was checked routinely during visits with utility personnel and by telephone contact with government agencies. The data available from these sources included:

- well data from explorations during utility planning/construction and information from neighboring projects, such as data from individual water supply wells (e.g., Smith and Sherburne County sites); and

- groundwater monitoring data from studies conducted by the utility (e.g., Sherburne County, Allen, Powerton and Dave Johnston sites).

The U.S. Geologic Survey Water Resources Data for different states is a publicly available source of groundwater quality data. These data were requested for sites that were being considered for test plan development. The amount and level of detail that were available varied widely from state to state. For example, available data for the Smith site area included generalizations about the chemical nature of local aquifers (based on sampling data). Only physical hydrologic data were available for most of the other sites.

Climatology Information. Historical and current climatology information were obtained from the National Weather Service and National Climatic Center. Data on historical precipitation and evaporation were collected for the vicinities of each site. The historical precipitation data were updated monthly during the field portion of the effort to help schedule sampling visits for targeted (wet or dry) periods, and for subsequent use in interpreting measured information obtained during the visits.

4.7.2.1.2 Identification of Present Effects of Disposal -- The overall approach to groundwater assessment at each site relied on two major sources of information: (1) background information in at least two categories (climate and geohydrology) and (2) data collected during the project in three major categories:

- geology/geohydrology of the site;
- physical and chemical properties of the site waste(s) and solids; and
- groundwater quality associated with the site.

In the broadest sense, the groundwater assessment approach consisted of three steps. First, the measured geohydrologic and geotechnical information was used to describe a site water balance. Next, correlations between chemical concentrations in the waste and downgradient groundwater (but absent from background groundwater) were identified and described. The final step was to assess the significance of any disposal-related changes in groundwater quality by comparing them with appropriate standards and prevailing background conditions.

Development of Geological Profiles and Water Balance at Each Site. Development of a site-specific water balance involved three-steps: (1) analyzing hydraulic conductivity (permeability) test data for soil units at the site; (2) generating generalized hydrogeologic profiles of the site; and (3) using a mass balance or flow net approach to generate a water balance.

The hydraulic conductivities of subsurface soil units (including waste) were determined from data collected in-situ from boreholes and completed well installations, and from laboratory testing of undisturbed and remolded soil samples. In most cases, the hydraulic conductivity measurements made in the field were considered more representative of the in-situ soil conditions than the laboratory measurements. Laboratory hydraulic conductivity measurements were supplementary.

Representative hydrogeologic profiles were developed for the specific sites, based on the revised surficial geology plan, geologic cross sections, groundwater level contour map, and hydraulic conductivity data. The number of profiles developed depended on the site's geologic and hydrogeologic complexities. The hydrogeologic profiles were generalized to account for most of the geologic and hydrologic conditions. The hydrogeologic profiles indicated the hydraulic conductivities of soil units, the transmissivities of soil units, hydraulic head conditions in surface water bodies, the presence or absence of unsaturated zones beneath the waste repositories, hydraulic head conditions in confined and unconfined water-bearing soil units, and horizontal and vertical components of hydraulic gradient and groundwater flow.

The water balance for each site attempted to account for all major inputs and outputs of groundwater and surface water in the site area and in the immediate vicinity of waste repositories in such a way that the potential for and amount of leachate movement could be assessed. Site-specific water balances were generated based on groundwater level contour maps, hydraulic conductivity determinations for subsurface soil units, and hydrogeol[illegible]c profiles.

The water balance at a site could be determined either by a mass balance or a flow net approach. The particular method depended on the complexity of the site and on the amount of available geologic and hydrologic information. The mass balance approach to generating a water balance involves determining the fluxes of area- and point-source inputs of groundwater and surface water. The flux of one unknown variable can be determined if values for all other vari[illegible] are known. For example, if the value of all inputs to a pond are known, as well as the loss of water due to all mechanisms other than seepage through the pond bottom, the loss of water by seepage is equal to the total water input minus the loss of water due to all mechanisms other than seepage. If the amount of incident precipitation, runoff, and evapotranspiration are known for a landfill, the amount of groundwater recharge can be determined. The results of the mass balance approach to a water balance are fluxes of groundwater and surface water for the various components of the hydrologic system in the site area.

A flow net approach is preferable for generating a water balance at a site where more than one variable of the hydrologic system is unknown. With this approach, the unknown variables may be calculated directly or indirectly based on Darcy's Law and a knowledge of the hydrogeologic and hydraulic conditions at the site. For example, if some inputs to a pond are not known, the seepage through the pond bottom can be estimated if the hydraulic properties of the pond bottom and the hydraulic gradient across the pond bottom are available. Similarly, the amount of groundwater movement to a surface water body can be estimated by analyzing a flow net generated on the basis of hydrogeologic and hydraulic information obtained during site development. The results of the flow net approach to a water balance can be fluxes of groundwater and surface water for the various components of the hydrologic system in the site area, or average linear velocities of groundwater flow in subsurface soil units.

Assessment of Groundwater Quality Data. Data on the composition of groundwater at the site collected by the chemical sampling and analysis were a major source of information on the present-day effect of the disposal operation on the surrounding environment. The assessment of the interactions, effects, and implications of this data involved two major types of activities: (1) establishing the reliability range of the data sets; and (2) examining the data within the context of selected concentration limits for particular species and for overall trends across the site. The assessment process was repeated as each successive series of sampling and analysis data became available. The practice of evaluating successive data sets before collecting succeeding samples gave special flexibility in the testing/assessment parts of the program. It allowed potential mid-course redirection or refocusing of the subsequent chemical sampling and analysis efforts, if such changes appeared advantageous for the overall assessment task.

Establishing Data Reliability. The QA/QC effort for the chemical sampling and analysis activities gave estimates of the confidence limits associated with the various data sets generated in the test program (see Section 4.5.). The confidence limits were translated into a context that could be used in the environmental assessment. For example, the confidence range measurements might be appropriately expressed in terms of some factor times selected environmental standards, such as those for drinking water. Accordingly, after the confidence limits had been established, the data were examined, initially against some appropriately selected standards. This served to identify data points in which the concentrations reported were either high or low enough to constitute identifiable environmental effects. These data points were then subjected to a recheck of calculations and data transcription (but not necessarily reanalysis, see below) in order to confirm the levels identified and reported. This activity was related to but different from QA/QC activities in that a set point related to the environmental content was used to trigger reexamination of the data rather than the deviation from some analytical standard. In rare cases, it appeared that a questionable value was reported correctly, and that an actual reanalysis of the sample was called for. Such requests for reanalysis depended on the nature and magnitude of the reported analytical value and on whether the sample was unique or the location was likely to be resampled and analyzed during a subsequent sampling trip.

Such data examination began after the data for the first full sampling trip were available. At that point, trends between sampling points had been compared. The data available from samples collected during site development were evaluated to determine trends, such as those that would indicate stabilization of wells or continuing variations that could mean real changes in the water composition. This data evaluation effort was an ongoing process. As the data for each additional sampling visit became available, they were subjected to the same examination for reliability and trends so that a picture of the site water chemistry became clearer on a continuous basis throughout the project.

Comparison of Data With Concentration Limits, and for Trends Over the Site. Once the data had been analyzed for reliability of confidence intervals and for trends (which would indicate whether composition in sampling points had stabilized or was continually changing), the data for the individual sampling points within the site were compared in several ways, including:

- examining the degree of correspondence between the levels of potential naturally occurring tracers (chemical constituents) in the waste interstitial waters or water extracts and downgradient well water, versus background well water;

- determining the "chemical logic" associated with the observed presence or absence of correlations;

- characterizing the patterns of elevated concentrations in time and space across the site; and

- determining the degree to which concentrations of parameters were elevated relative to reference concentrations, such as drinking water standards, or standards for agricultural use, including whether such levated concentrations actually occured in the settings that the standards were intended to protect.

4.7.2.1.3 Techniques for Further Interpretation of Groundwater Data -- Interpretation/projection techniques were used to assess groundwater effects. In this approach, observable effects were accorded greater importance and credibility than projected effects. Simple techniques, based on practical hydrogeological experience and appropriate assumptions, were initially applied. More complicated techniques were considered only in cases where simple techniques were incapable of addressing important assessment issues.

Many techniques are available for interpreting groundwater data. These vary in their levels of mathematical complexity and in their abilities to address specific assessment issues. The general approach to using the interpretation/projection techniques began with identifying an assessment issue as a result of evaluating field observations. The issue could generally be framed as one or more questions. For example, "Groundwater directly beneath the waste is observed to contain concentrations of selenium and arsenic in excess of relevant standards. However, groundwater monitors around the perimeter of the disposal site do not exhibit elevated levels of selenium and arsenic. What is the likelihood that concentrations exceeding standards will eventually be observed off-site? If elevated levels are expected to migrate off-site, when would such contamination be observable?" Questions of this nature were formulated during the assessment of the measured groundwater quality data (described in Section 4.7.2.1.2).

In the assessment phase of this project, the simplest techniques for further interpreting groundwater results were generally characterized by the following assumptions:

- Either the head distribution or the flow velocities were known.

- Flow was primarily in one-dimension.

- Disperson and/or chemical processes did not need to be accounted for.

An initial list of potentially applicable projection techniques was prepared. This list was based on the state-of-the-art analysis of groundwater migration problems and familiarity with the assessment issues likely to be addressed in this project.

Some issues were generally not sufficiently resolved by the available interpretation/projection techniques to justify their use at several of the sites. These issues included:

- The considerable ranges of uncertainty associated with geotechnical and hydrogeologic measurements in field situations. While such data may be simple to represent mathematically, there is often order-of-magnitude uncertainty in key physical variables upon which projections must be based. Where such uncertainty prevailed, the quantitative projection techniques were deemphasized in favor of more qualitative discussion of the cause-effect phenomena and expected ranges of future effects at the various sites.

- Description of physical and chemical phenomena in wastes as well as soils. Many of the techniques have been validated for naturally occurring soils, but only a few (and sometimes at limited scale) for FGC wastes.

- Mathematical integration of dynamic surficial, unsaturated zone, and saturated zone physical phenomena in materials of differing physical and chemical properties. Many of the techniques reviewed address one or two of these parts of the picture, but few if any represent the type of interactive conditions that occur in the field and have been validated at field scale.

- Physical phenomena (e.g., water flow) tend to be better represented (mathematically) than chemical phenomena, such as the various factors contributing to chemical attenuation. This trend called for more independent evaluation and interpretation of physical and chemical factors at various sites, as in the case of As attenuation at the Allen site.

- Cost effective techniques for representing subsurface phenomena in three dimensions are not generally available. At some sites (depending on such factors as site surface area versus depth to the water table), such techniques would have been more appropriate than one- or two-dimensional representations. The available three-dimensional techniques tend to have excessive programming and storage requirements, and in some cases may only represent many iterative one- or two-dimensional solutions.

Concerns such as these were taken into account to ensure that the selection process was judicious and that a balance of mathematical and judgemental interpretive techniques were used for the project.

4.7.2.2 Assessment of Effects on Surface Water Quality

4.7.2.2.1 Development of Background Information -- Background information for physical hydrology and water quality was available from several sources. Among the more useful sources of water background data were:

- environmental assessments for the utility or neighboring projects (e.g., Smith site); and
- water quality/quantity studies by the utility (e.g., Allen site).

The availability of such sources was routinely checked during visits with utility personnel and by telephone contact with state and/or regional government agencies.

Another publicly available source of surface water data is the STORET system. This is a federally supported repository for surface water data, principally that collected pursuant to the Clear Water Act. At the least, the system contains surface water data that result from regular, repeated monitoring at fixed locations. For some sites, it also contains data from special studies that have been conducted, as well as effluent data and data on public water supply intake quality. Physical characteristics such as temperature and flow rate are also frequently available. The amount of data stored in the system varies from state to state, although the reporting of fixed station monitoring is required of all states.

For this project, the boundaries of one or more USGS quadrangles containing the site were used to recall all STORET water quality data for the last five years for all the sites considered for test plan development. The results of this retrieval varied greatly with site location -- from a large number of parameters measured in water bodies and sediments near the site in question, to essentially no information on surface waters near another given site.

The U.S. Geologic Survey water resources data for different states are publicly available sources of surface water data. These were routinely requested for all sites being considered for test plan development. While largely hydrologic in nature, such state surveys can also contain some water quality data. Data on the rate of stream discharge, including information on means and extremes, were of particular interest for sites like Powerton, where the disposal operation was adjacent to a small stream with variable flow.

Such information helped the investigators understand potential sources of contaminants (e.g., mine drainage at the Elrama site). Information on mixing volumes for non-point source additions was developed from stream flow data, together with with an understanding of approximate stream surface area (a USGS map could be a source).

In all cases, the timeframe, proximity to the site, and the sampling and analysis methods used to generate data were considered. Where surface water quality or hydrologic data were part of in the overall assessment, especially for trend assessment, an effort was made to contact the source of data reports (e.g., the utility), and identify sampling and analysis methodologies and detection limits. An overall evaluation of the usefulness of surface water background data included a careful look at those areas sampled frequently, for evidence of reproducibility.

4.7.2.2.2 Identification of Present Effects of Disposal -- The assessment of non-point source effects on surface water quality at the various sites drew on background information and data gathered during this project. Background information was considered in at least two categories (climate and surface water hydrology and quality). Information gathered during the project included:

- topography and surface water hydrology of site drainages;
- physical and chemical properties of the site waste(s) and soils; and
- surface water quality associated with the site.

Additionally, the mechanisms of non-point source effects on surface water quality at the sites included leachate discharge from groundwater to a receiving surface water body (as opposed to or in addition to runoff discharges). Thus, the above considerations were supplemented by the results of groundwater effects assessment (described in Section 4.7.2.1), which served as inputs to the surface water quality evaluations.

The main steps in assessing present surface water quality effects at the various sites were:

- review and comparison of the results of physical hydrologic measurements from this project and other studies to define admixing conditions;
- identification of correlations between waste-related adjacent and downgradient chemical species concentrations in the water body; and
- evaluation of the significance of any disposal-related changes in surface water quality by comparison with background values and appropriate standards.

These steps were relatively simple to implement for the small stream at the Powerton site. In the fast-moving or large mixing volume waters at most of the other sites (e.g., Elrama), non-point source constituents were not found or expected in high enough concentrations to be picked up by monitoring. The estuary at the Smith site represented a somewhat more complicated situation. For example, tidal action can cause both upstream and downstream movement of entering constituents, and specific "parcels" of water can visit the same areas many times before finally moving seaward. Under these circumstances, so called "upstream" correlations had to be made with different background locations (checked with sediment analyses) -- in this case, parallel tidal creeks not under the potential influences of non-point discharges from the ash disposal pond.

Three types of potentially applicable water quality standards promulgated by EPA were used to judge the significance of waste-related changes in surface water quality:

- Interim Primary and Secondary Drinking Water Standards;
- Water Quality Criteria for the protection of aquatic life; and
- Water Quality Criteria for protection of other water uses, such as the criterion for boron designed to protect certain sensitive crops from elevated levels in irrigation water.

In cases where one or more of the above standards was used, the assessment took into account the extent to which the uses designated for protection actually prevailed in the respective disposal site settings.

4.7.2.2.3 Further Interpretation of Effects on Surface Water Quality -- The evaluations of present-day effects on surface water quality at several sites largely pre-empted the need for further study of cause/effect hypotheses (beyond simple mixing phenomena) or of expected future concentrations of waste-related chemical species. This was in part because the magnitude of measured water quality effects appeared to be so small, even in a perceived steady-state where off-site concentrations equaled or exceeded those in the waste deposit (see Powerton results in Section 5), and also because the potential for relative contributions at the other "pre-steady-state" sites (e.g., Allen, Elrama, Dave Johnston, and Sherburne County) was too small to justify detailed analysis.

4.7.2.3 Assessment of Mitigative Practices

Overall Approach -- The overall approach to assessing the effects of mitigative design, management, and/or control practices at the study sites included:

- evaluating the observed effects of the mitigative measures employed;
- assessing the environmental effects of these mitigative techniques;
- considering the potential environmental effects in the absence of such mitigative measures; and
- evaluating the potential for future use of these mitigative techniques, in light of their costs.

The mix of sites selected for investigation gave an opportunity to evaluate and recommend many of the basic types of mitigative design, management and control practices generally used. Table 4.20 shows the particular mitigative practice(s) used at the six plants.

As illustrated in Table 4.20, the Allen and Smith plants collectively exemplify not only the unlined ponding of combined fly ash and bottom ash, but

TABLE 4.20

TYPE OF MITIGATIVE DESIGN, MANAGEMENT AND CONTROL PRACTICES EMPLOYED

Plant Name	Sluice Water Recycle	Dry Disposal	FGD Waste Processing				FGD Waste Fixation	Liners
			TH	VF	FO	CD		
Allen	--		NA				NA	
Dave Johnston	NA	✓	NA				NA	NA
Elrama	--	✓	✓	✓	--	✓	✓	--
Powerton	--	✓	NA				NA	✓
Sherburne County	✓	--	✓	--	✓	✓	--	✓
Smith	✓	--	NA				NA	--

TH - Thickening
VF - Vacuum Filtration
FO - Forced Oxidation
CD - Codisposal of Fly ash and FGD waste
NA - Not Applicable

Source: Arthur D. Little, Inc.,

also the potential environmental advantages of ash pond sluice water recycle. Ash pond overflow at the Smith plant is recycled back to the plant to be used as a source of water for ash sluicing. The Sherburne County plant also gives the opportunity to evaluate a ponding operation; however, this pond is lined with clay and receives both fly ash and FGD wastes. The lining is about 0.5 meter (1.5 feet) of clay and can be considered a potential mitigative design/-control measure. In addition, the FGD system at the Sherburne County plant uses forced oxidation. This can improve the dewatering characteristics of the FGC waste. The Elrama plant shows potential mitigation offered by FGD waste stabilization. The operation at the Elrama plant uses the Conversion Systems, Inc. (CSI) fixation process, in which both fly ash and lime are added to the FGD waste.

Finally, the Dave Johnston and Powerton plants illustrate dry disposal (landfilling) of fly ash in different unlined and lined settings, respectively. Part of the Powerton plant landfill is artificially lined with Poz-O-Pac®, an admixture of coal ash and lime which is produced by a proprietary process. In another adjacent part of the landfill, essentially no liner was found in the excavations made for this program. The disposal areas studied at the Johnston site are unlined, and the active landfill was developed in an excavation reportedly designed to reduce the potential for wind-borne loss of fugitive ash particles.

4.7.3 Summary of Approach to Generic Projection of Industry-Wide Implications of Coal Ash and FGD Waste Disposal

Six major steps were taken to translate the results from the individual sites into findings broadly applicable to the coal ash and FGD waste disposal practices of the utility industry:

1. Characterization of the major cause/effect mechanisms applicable to the non-point source water quality effects of coal ash and FGD waste disposal.

   This step involved identifying and characterizing four principal effects mechanisms that act in combination to determine water quality — leachate formation, leachate movement, admixing, and attenuation. These mechanisms are in turn governed by three main factors, namely, waste type, disposal method, and environmental setting. The roles played by these factors were also identified and characterized. Section 7 of this report details the results of this step.

2. Identification of the broader implications of the findings at each of the study sites.

   In this step, the results from each site were evaluated in the context of the above cause/effect relationships to assess the transferability of the findings to various combinations of wastes, disposal methods, and settings. Section 5.2 presents the results of these evaluations for each site.

3. <u>Evaluation of the findings of other studies.</u>

   Results of the various other full-scale and pilot-scale field studies, and laboratory studies of coal ash and FGD wastes from other programs were reviewed in the same context as the results from the six sites studied in this program. Section 7.5 discusses these findings.

4. <u>Matrix assessment of findings.</u>

   The results of steps 2 and 3 were superimposed on the matrix of sixty possible combinations of major waste types, disposal methods and environmental settings. This showed the range and likelihood of generic effects applicable to the individual and major categories of matrix combinations. Sections 7.5.5 and Appendix H detail these findings.

5. <u>Assessment of mitigative practices.</u>

   Based on the potential needs for mitigation made apparent by steps 1-4 and the engineering/cost evaluations (Section 6), potentially applicable mitigative measures were evaluated and are discussed in Section 7.6.

6. <u>Translation into a decision framework.</u>

   As Section 8 describes in detail, the assessment results were translated into a decision framework. This framework identifies the information needs and sequence of activities that could provide utility planners and/or regulatory agencies with comprehensive coverage of the major technical, environmental, and engineering/cost disposal issues in a manner to facilitate decision-making.

SECTION 5

RESULTS AND CONCLUSIONS FOR THE SIX STUDY SITES

5.1 OVERVIEW

This section summarizes the environmental assessment and engineering cost results for each of the six sites. Some of the significant, general, environmental assessment conclusions are that:

(1) Major dissolved species, especially sulfate, can be expected to migrate off-site, in exceedance of secondary drinking water standards, and remain unattenuated. However, in all cases except direct, upgradient hydrogeologic proximity to drinking water or a very small surface water body, such migration would have little environmental significance. This is because the elevated concentrations would prevail only in a fairly small area and are generally below damage thresholds. Thus, they would have few, if any, adverse ecological effects.

(2) Releases of most trace metals are generally within acceptable limits (e.g., drinking water and aquatic life standards), because of the combined effects of receiving water dilution and the chemical immobilization of most waste-related species. Arsenic is a significant exception that would require case-by-case evaluation for analogous wastes. In this study, elevated concentrations of arsenic in the in-situ liquid phase and/or off-site mobility of arsenic were observed at three of the six sites.

(3) In settings characterized by at least modest precipitation and fairly pervious soils where disposal occurs in direct hydrogeologic proximity to a subsurface drinking water supply or small, high-quality surface water body, an artificial disposal site liner may be needed to minimize contamination by (at least) the major species. A minimum liner thickness of about 0.5 m (1.5 ft) would suffice for proper engineering placement of soil-like liners.

(4) Isolated areas of high-quality surface or groundwater may be expected at disposal site settings where most of the ambient water is highly mineralized. This phenomenon was observed

in the highly mineralized western and acid-mine drainage settings studied in this program.

(5) In many cases, adverse environmental water quality impacts that may occur can be adequately mitigated by careful location of the disposal site. Areas with less permeable and more chemically attenuative soils are preferable, as are locations that are removed from drinking water supplies or key small surface water bodies.

The results and conclusions are discussed in more detail below for each individual site studied in this program.

5.2 PLANT ALLEN

5.2.1 Site Description

5.2.1.1 Background--

Plant Allen of Duke Power Company is located in Gaston County, North Carolina, four miles southeast of the town of Belmont. The plant site is adjacent to the west bank of Lake Wylie, one of eleven impoundments that comprise the 386 km (240 miles) Catawba River Development. The site location is shown on Figure 5.1.

The coal ash disposal site at Plant Allen consists of two separate, major units. The first unit is comprised of retired ash ponds, approximately 206,000 m^2 (127 acres) in total area, that were used and expanded from 1957 to 1973. The second unit is the active ash pond, approximately 239,000 m^2 (146 acres) in area, that was constructed in 1973. A combination of fly ash and bottom ash is presently sluiced directly into this pond located immediately south of and adjacent to the retired pond complex. The liquid overflow from the ash pond is discharged untreated into adjacent Lake Wylie. The ash ponds are retained by earth dikes constructed from residual soils excavated from within the ash pond limits.

The following factors were important in the selection of the combined fly ash/bottom ash disposal ponding operation at Plant Allen for study:

- The practice of pond disposal of combined fly ash and bottom ash is the most common FGC waste disposal practice in the United States and virtually the only disposal practice in the Piedmont Region.

- The amount of precipitation and the mix of residual and alluvial soils at the Plant Allen site represent environmental conditions typical of many other locations in the eastern half of the United States and are particularly representative of the Piedmont Region, which supports significant coal-fired generating capacity.

- Co-disposal of intermittent, contaminant-rich waste streams (i.e., boiler cleaning wastes and coal pile run-off) in ash ponds occurs at

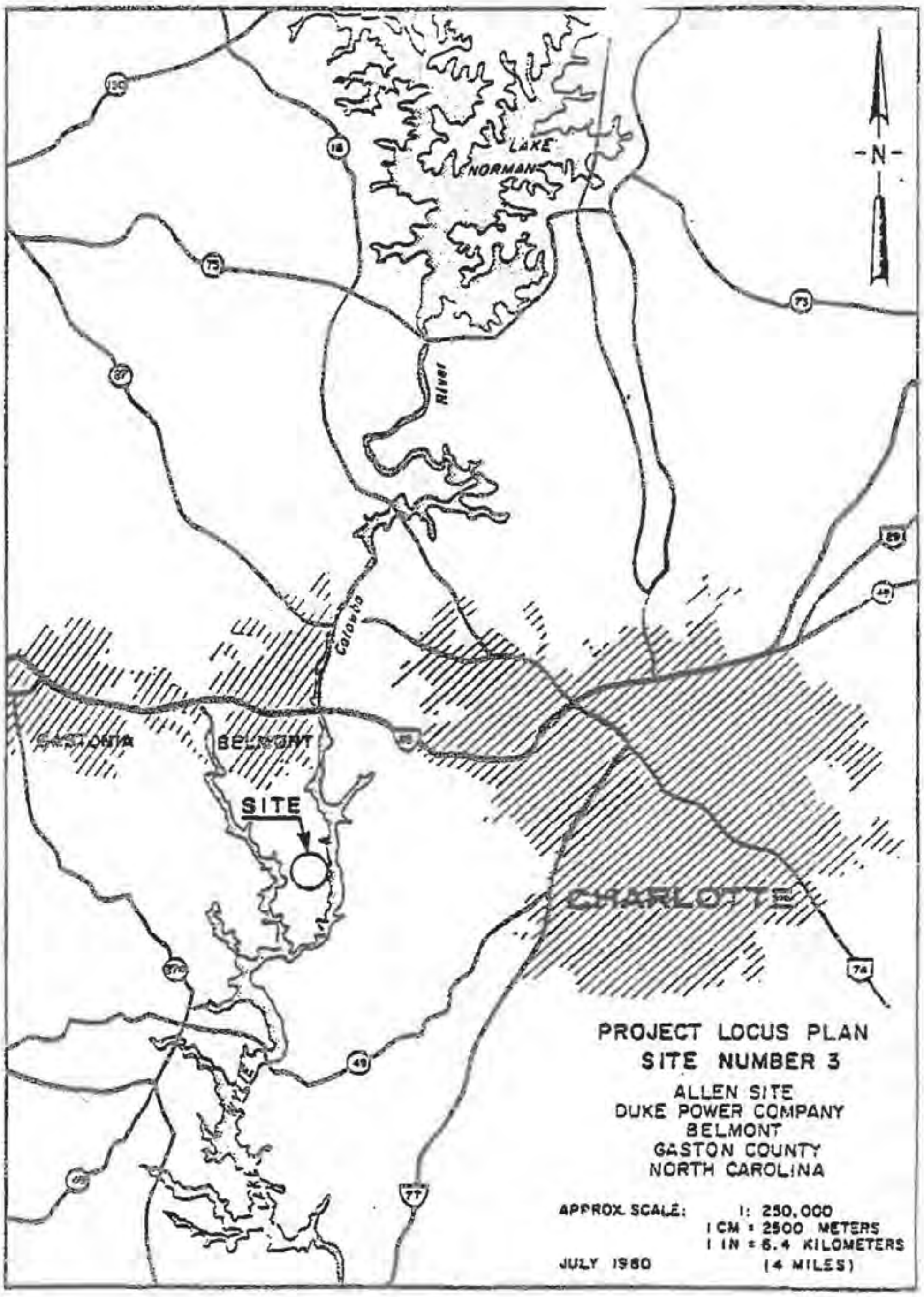

N
LAKE NORMAN
River
Catawba
GASTONIA
BELMONT
SITE
CHARLOTTE
PROJECT LOCUS PLAN
SITE NUMBER 3
ALLEN SITE
DUKE POWER COMPANY
BELMONT
GASTON COUNTY
NORTH CAROLINA
APPROX. SCALE: 1: 250,000
1 CM = 2500 METERS
1 IN = 6.4 KILOMETERS
(4 MILES)
JULY 1980

FIGURE 5.1

Plant Allen and is widely practiced, with potentially broad applicability in the future.

5.2.1.2 Geologic Conditions--

The site area lies within the upland section of the Piedmont Physiographic Province and is characterized by broad, rolling topography and isolated Monadnock-type hills and ridges. The majority of the overburden soils were formed from the chemical decomposition of the underlying micaceous diorite bedrock. These deposits are referred to as residual soils and consist primarily of slightly plastic silts and sands with varying amounts of clay and quartz pebbles. The weathering profile is moderately deep but highly irregular. The bedrock and overburden soils are also characterized by a variety of younger, more permeable igneous dikes and sills which have intruded the original bedrock unit.

Active and ephemeral surface drainage systems have created several major surface drainage valleys with gradients lying at right angles to the Catawba River. Several small, localized alluvial deposits, filled with relatively loose and permeable material, are now incorporated within the ash basin complex.

Figure 5.2 summarizes the site area surficial geologic conditions, and Figure 5.3 presents an idealized subsurface geologic profile sketch.

5.2.1.3 Hydrologic Conditions--

The Plant Allen site lies within the Piedmont Groundwater Province. All groundwater is derived from local precipitation which varies from 1.12 to 1.38 m (44 to 55 in) annually, resulting in approximately 0.26 to 0.38 m (10-15 in) of percolation to the watertable. The plant obtains all of its cooling and process waters from Lake Wylie; approximately 50,000 m^3/day (14.4 million gal/day) are used for sluicing ash into the disposal pond, and ultimately return to Lake Wylie.

The original groundwater table depth varied considerably with the site topography, from at or above ground surface in the low-lying alluvial areas, to an approximate depth of 10 m (33 ft) beneath the higher elevations of the site. The limited data available indicate that plant discharges into the disposal ponds have created groundwater mounding in their immediate vicinity, saturating the former vadose zone above the regional piezometric level. All local surface and groundwater flow is easterly towards Lake Wylie (see Figure 5.2).

5.2.2 <u>Site Evaluation Plan and Site Development</u>

Duke Power Company conducted several environmental studies at Plant Allen that supplied valuable hydrogeologic baseline information; in addition, subsurface exploration information obtained in 1972 for the active ash pond dike construction was made available to the study team. Twenty existing observation wells installed throughout the plant site by Duke Power provided supplemental groundwater level monitoring locations.

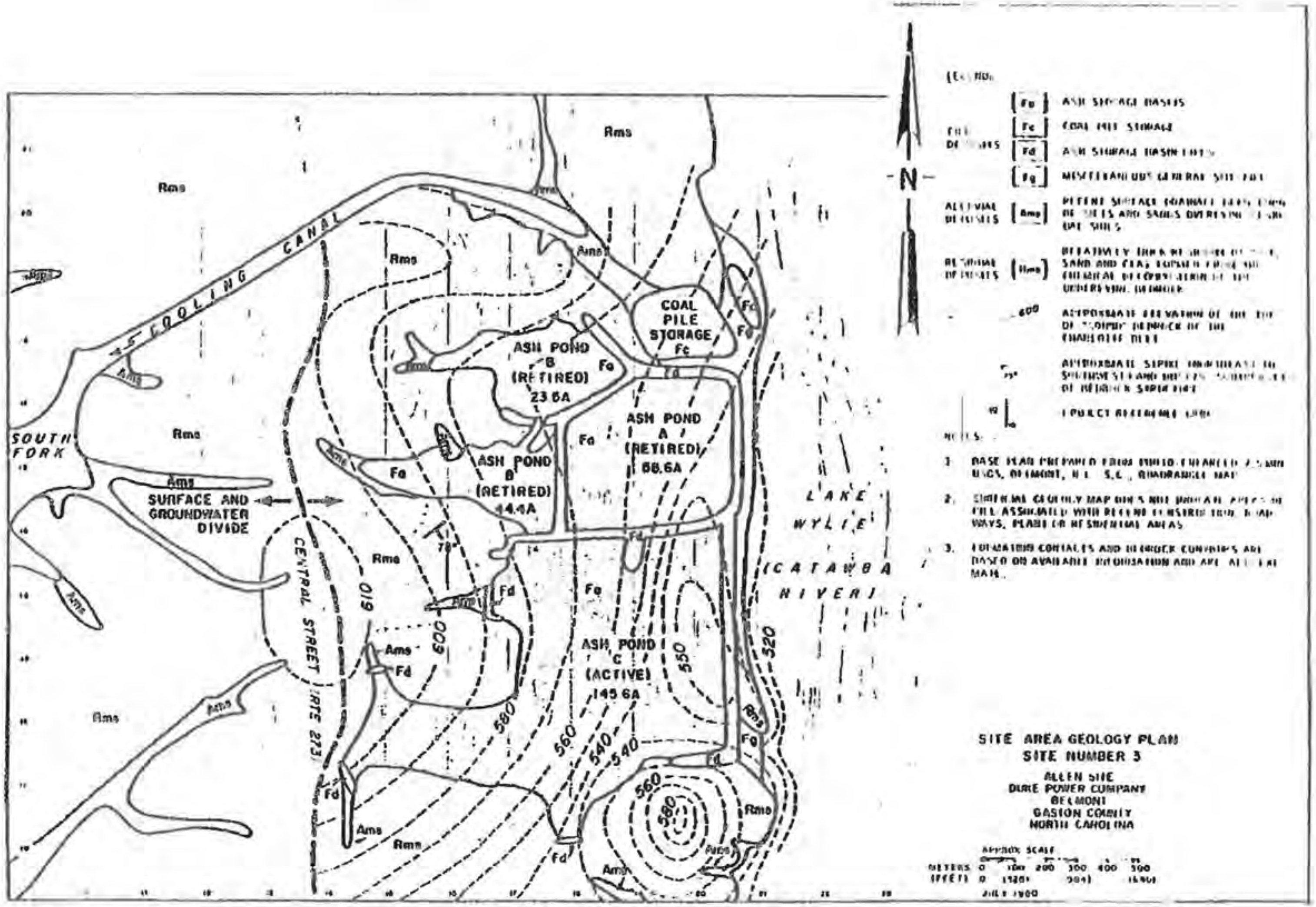

N
COOLING CANAL
SOUTH FORK
SURFACE AND GROUNDWATER DIVIDE
CENTRAL STREET
RTE 273
ASH POND B (RETIRED) 23.6A
ASH POND B (RETIRED) 44A
ASH POND A (RETIRED) 68.6A
ASH POND C (ACTIVE) 145.6A
COAL PILE STORAGE Fc
LAKE WYLIE
(CATAWBA RIVER)
Rms
Ams
Fa
Fd
Fc
610
600
580
560
550
540
520
SITE AREA GEOLOGY PLAN
SITE NUMBER 5
ALLEN SITE
DUKE POWER COMPANY
BELMONT
GASTON COUNTY
NORTH CAROLINA

FIGURE 5 2

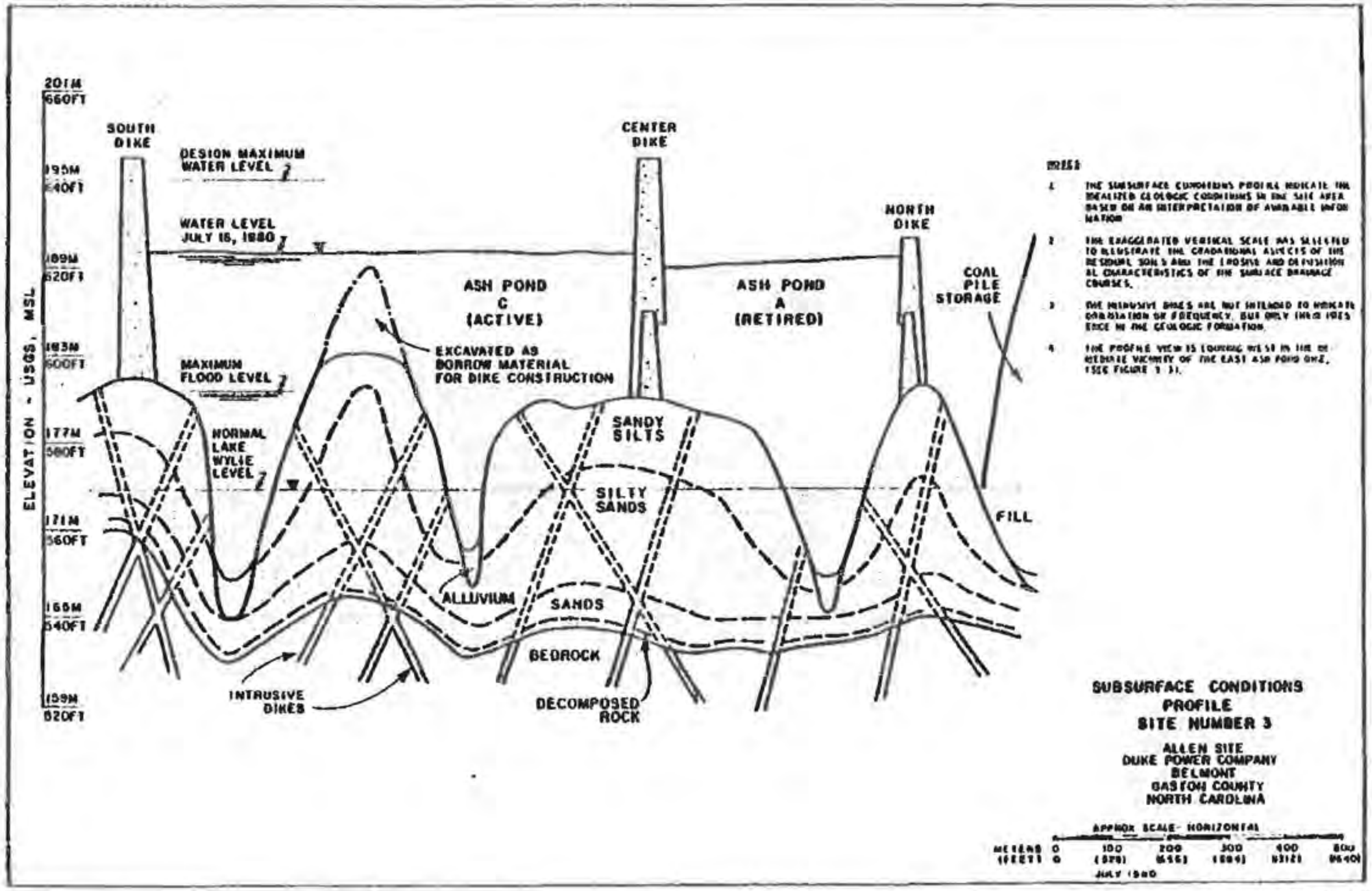

201M
660FT
195M
640FT
189M
620FT
183M
600FT
177M
580FT
171M
560FT
165M
540FT
159M
520FT
ELEVATION - USGS, MSL
SOUTH
DIKE
DESIGN MAXIMUM
WATER LEVEL
WATER LEVEL
JULY 16, 1980
MAXIMUM
FLOOD LEVEL
NORMAL
LAKE
WYLIE
LEVEL
EXCAVATED AS
BORROW MATERIAL
FOR DIKE CONSTRUCTION
CENTER
DIKE
ASH POND
C
(ACTIVE)
ASH POND
A
(RETIRED)
NORTH
DIKE
COAL
PILE
STORAGE
SANDY
SILTS
SILTY
SANDS
FILL
ALLUVIUM
SANDS
BEDROCK
INTRUSIVE
DIKES
DECOMPOSED
ROCK
SUBSURFACE CONDITIONS
PROFILE
SITE NUMBER 3
ALLEN SITE
DUKE POWER COMPANY
BELMONT
GASTON COUNTY
NORTH CAROLINA
APPROX SCALE- HORIZONTAL
100
200
300
400

FIGURE 5 3

The project site development plan for Plant Allen included the installation of multi-purpose wells and exploratory borings for hydrogeological and geotechnical evaluation purposes. Two upgradient observation wells were installed for background monitoring purposes, and seven downgradient wells were installed at various locations and elevations to determine the presence and vertical extent of any leachate movement. One well was installed in the retired ash disposal pond to determine the piezometric surface (which was in a state of hydrologic non-equilibrium), and two wells were installed within the active ash pond using floating equipment. A piezometer was also placed within the active ash disposal area for sampling purposes.

At the completion of installation of all monitoring apparatus in January 1981, the wells were flushed and bailed, and initial samples were obtained for chemical evaluation purposes.

The locations of all explorations and monitoring/sampling installations are indicated on Figure 5.4. A summary of all field tests and results, the types of samples collected, sampling locations, well types and well depths is presented in Table 5.1.

5.2.3 Physical Testing Results

Figure 5.5 shows the results of field and laboratory permeability tests performed on the fly ash and bottom ash wastes at the Allen site. In addition, results of standard penetration unified soil classification tests are presented.

One boring (3-1) was drilled in the abandoned ash pond that contains fly ash from mechanical collectors and from electrostatic precipitators and bottom ash. Apparently, ash has been discharged at various locations at the site resulting in the segregation of fly ash and bottom ash in Boring 3-1. It is estimated that the bottom ash, located near the center of the abandoned ash deposit, has a coefficient of permeability greater than or equal to 3×10^{-3} cm/sec. The fly ash located near the surface and near the bottom of the abandoned pond is much finer (87 percent of the particles passing a U.S. No. 200 sieve) with a coefficient of permeability ranging between 1×10^{-4} cm/sec and 1×10^{-5} cm/sec.

Two borings (3-2 and 3-3) were advanced through the active ash disposal pond that contains fly ash from both mechanical collectors and electrostatic precipitators as well as bottom ash, all of which have been disposed throughout the life of the active pond. Unlike the abandoned pond, the active pond had no distinct zones of fly ash and bottom ash. Instead, thin lenses of coarser ash were noticed throughout the ash deposit. Results of field permeability tests indicate a range in permeabilities of 2×10^{-4} to 4×10^{-3} cm/sec at those locations tested. Because of the horizontal layering of the ash in both ponds, it is estimated that the coefficient of permeability of the waste deposit in the vertical direction will be approximately the coefficient of permeability of the fly ash (approximately 1×10^{-4} cm/sec). The coefficient of permeability of the waste deposit in the horizontal direction

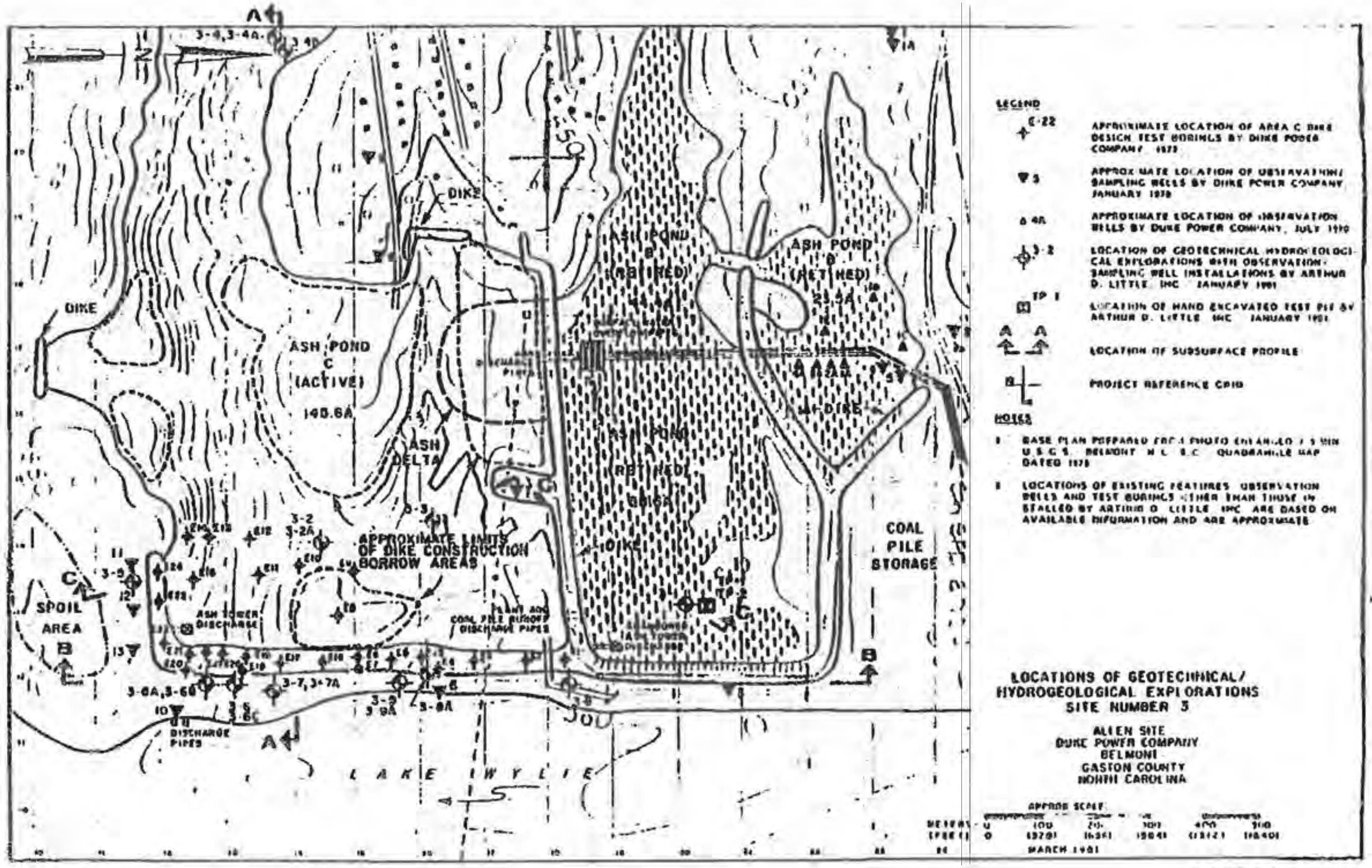

DIKE
ASH POND C (ACTIVE) 148.6A
ASH DELTA
ASH POND B (RETIRED)
ASH POND D (RETIRED)
ASH POND (RETIRED)
DIKE
APPROXIMATE LIMITS OF DIKE CONSTRUCTION BORROW AREAS
COAL PILE STORAGE
SPOIL AREA
ASH TOWER DISCHARGE
PLANT AND COAL PILE RUNOFF DISCHARGE PIPES
DISCHARGE PIPES
LAKE WYLIE
LEGEND
LOCATION OF SUBSURFACE PROFILE
PROJECT REFERENCE GRID
NOTES
LOCATIONS OF GEOTECHNICAL/ HYDROGEOLOGICAL EXPLORATIONS SITE NUMBER 5
DUKE POWER COMPANY
GASTON COUNTY
NORTH CAROLINA
APPROX SCALE
MARCH 1981

FIGURE 5 4

TABLE 5.1

SITE DEVELOPMENT SUMMARY

SITE: PLANT ALLEN SITE
GASTON COUNTY, NORTH CAROLINA

DATES: January 6, 1981 [illegible] January 28, 1981
FILE NO. 453503

TOTAL NO. EXPLORATIONS ON SITE: 9

Boring #	3-1	3-2	3-3	3-4
Soils Classification [depth (m); class]	0-17.4; Fly Ash 17.4-18.4; Alluvium 18.4-18.7; Weathered Rock	0-12.3; Fly Ash 12.3-13.6; Alluvium 13.6-14.3; Residual Soils	0-7.5; Fly Ash 7.5-8.5; Alluvium 8.5-11.4; Residual Soil	0-3.3; Fill 3.3-6.2; Alluvium 6.2-6.9; Weathered Rock
Number of Samples Obtained	20	21	16	12
Field Permeability Test [depth (m); Results (m/sec)]		13.3-14.5; 3×10^{-7} 3-2 7.6-8.8; 4×10^{-6} 3-2A	9.8-11.4; 2×10^{-7} 1.2-3.2; $3.3 \times 10^{[illegible]6}$ to 11.0' - 16.0'	3.4-5.8; $2.7 \times 10^{[illegible]7}$
Well Installation [wellpoint type; diameter (in); location (m)]	0.020" slot; 2.0 ID 17.1-18.3	Vyon fabric; 1.0 ID 3-2 13.3-14.5 7.6-8.8 3-2A	Vyon fabric; 1.0 ID 9.9-11.1	0.020" slot; 2.0 ID 3-4 3.4-4.9 0.020" slot; 2.0 ID 3-4A 1.4-2.9
Boring #	3-4B	3-5	3-6	3-6A,C
Soils Classification [depth (m); class]	0-1.7; Fill 1.7-3.0; Alluvium 3.0-6.2; Rock	0-0.9; Fill 0.9-14.3; Weathered Rock	0-9.8; Fill 9.8-10.8 Alluvium 10.8-18.1; Decomposed Rock	0-9.8; Fill 3-6A 9.8-11.0; Alluvium 0-12.3; Residuals 3-6C 12.3-13.0; Rock
Number of Samples Obtained	6	13	24	4
Field Permeability Tests [depth (m); results (M/sec)]	4.1-5.0; 6.0×10^{-6} m/s	10.1-13.2; 10×10^{-6} m/s	No Test In Piezometer	10.1-11.0; 1.5×10^{-6} m/s 3-6 1.1-6.1; 6.0×10^{-7} to $5.2 \times 10^{[illegible]}$ [illegible] 3-6B
Well Installation [Well point type; diameter (in); location (m)]	0.020" slot; 2.0 ID; 4.1-5.6	0.020" slot; 2.0 ID; 10.1-11.2	Vyon fabric; 1.0 ID; 11.1-13.0	0.020" slot; 2.0 ID 6A 10.1-10.7 0.020" slot; 2.0 ID 6B 3.8-5.3 Vyon fabric; ID 6C 10.8-12.9

(continued)

TABLE 5.1

Boring #	3-7, 7A	3-8, 8A	3-9	3-9A
Soils Classification [depth (m), class]	0-6.2; Residual Soil 6.2-8.0; Quartzite	0-4.0; Fill 4.0-10.7; Weathered Rock	0-3.4; Fill 3.4-5.2; Weathered Rock	0-1.4; Fill 1.4-4.3; Alluvium 4.3-9.9; Weathered Rock
Number of Samples Obtained	9	11	6	5
Field Permeability Tests [depth (m); Results (M/sec)]	6.1-7.6; 4.6 x 10^{-5} 3-8 2.6-4.1; 3.7 x 10^{-6} 3-8A	9.1-10.7; 4.7 x 10^{-6} 3-8 2.6-4.1; 3.7 x 10^{-6} 3-8A	3.7-4.4; 1.0 x 10^{-5}	7.5-9.0; 4.1 x 10^{-6} m/s
Well Installation [well point type; diameter (in)]	0.020" slot; 1D; 6.1-7.6 Vyon fabric; 1.0 in	0.020" slot; 2.0 1D; 9.1-10.7 0.020" slot; 2.0 in 3-8	0.020"; 2.0 ID; 3.7-4.4	0.020 slot; 2.0 ID; 7.5-9.0

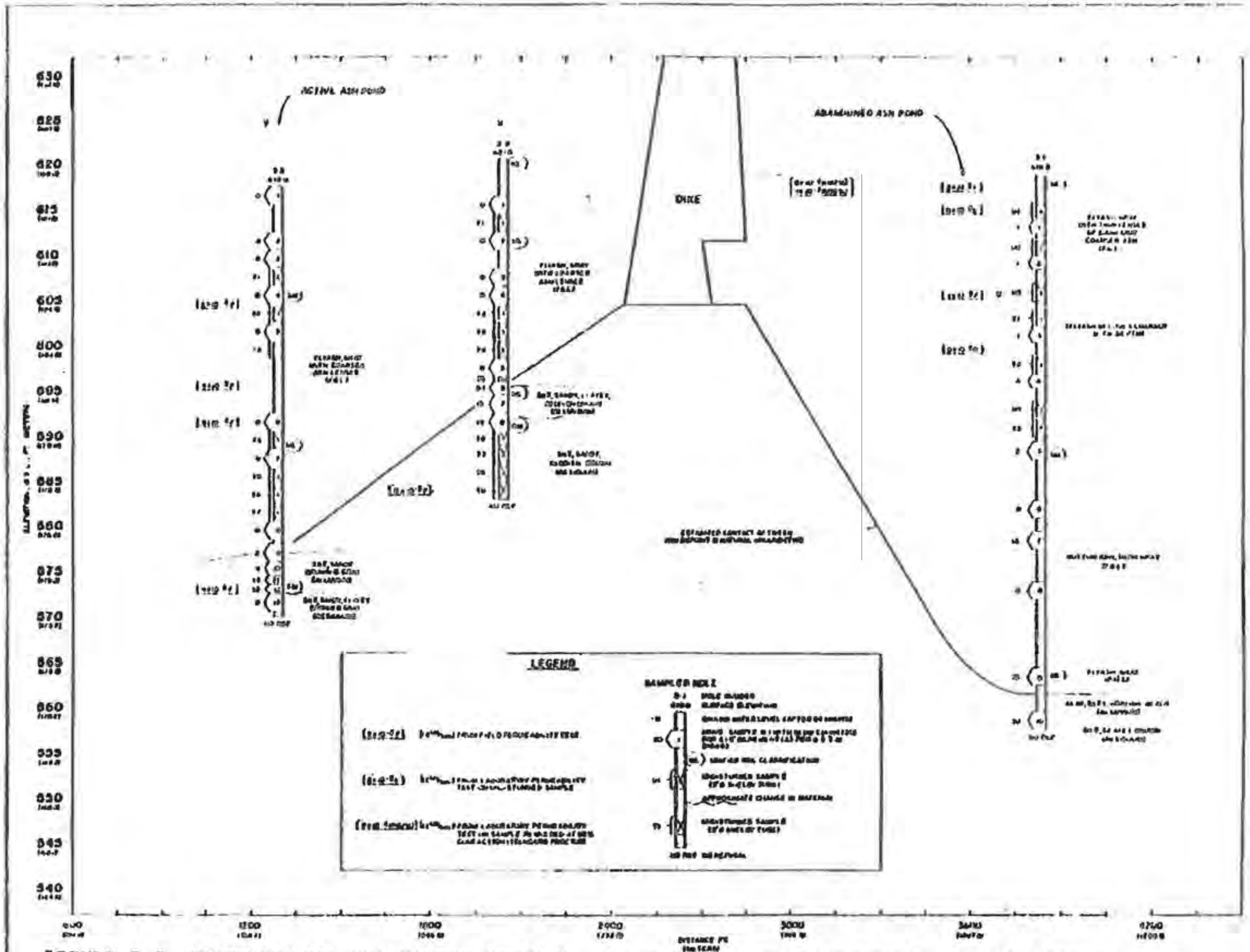


FIGURE 5.5 GEOTECHNICAL EVALUATION RESULTS, ALLEN PLANT, DUKE POWER CO., GASTON COUNTY, N.C.

is approximately equal to the coefficient of permeability of the coarser ash lenses (approximately 3 x 10^{-3} cm/sec).

A more detailed presentation of the physical testing results for Plant Allen wastes is provided in Appendix E. Table 5.2 provides a summary of selected physical testing results.

5.2.4 Chemical Testing Results

The site monitoring infrastructure was developed in January 1981, with emphasis on the active ash pond. At that time, samples of wastes and soils were collected for physical and chemical testing; surface water and groundwater samples were obtained for chemical testing. Subsequent water sampling occurred in late February through early March 1981 and in July 1982. Year-to-date precipitation was somewhat below normal prior to the 1981 visits, but it was in the high to normal range prior to the 1982 visit. Boiler cleaning wastes were collected for analysis in November and December 1981.

Selected results of chemical analyses of samples from the Allen site are presented in Table 5.3. A summary of chemical attenuation test results is presented in Table 5.4. A compilation of the chemical analysis results is presented in Appendix F.

5.2.5 Environmental Assessment

5.2.5.1 Approach for Plant Allen--

The environmental assessment of the Allen site results focused on the following three issues:

1) effects of the ash pond leachate on downgradient groundwater quality;

2) effects of the ash pond leachate on water quality in Lake Wylie, including comparison with the magnitude of ash pond point source (overflow) discharge; and

3) effects of co-disposal of intermittent, metal-rich waste streams (especially boiler cleaning wastes) on Items 1 and 2 above.

The steps employed in the environmental assessment at this site were as follows:

- A site subsurface geological profile and a site water balance were prepared.

- The values of and trends in chemical sampling and analysis results for the various areas of the site were compared with the results of previous sampling by Duke Power Company and with relevant EPA standards for groundwater protection.

TABLE 5.2

SELECTED PHYSICAL TESTING RESULTS

ALLEN PLANT[a]

Permeability (cm/sec)	$1 \times 10^{-7} - 2 \times 10^{-4}$
Specific Gravity	1.96 - 2.20
Grain Size Distribution (Weight Percent)	
• > 74 µm	13 - 69
• 2 - 74 µm	22 - 85
• < 2 µm	0 - 15
Moisture Content (Weight Percent)	10.9 - saturated
Effective Strength Parameters	
• Angle of Internal Friction	28.8°
• Effective Cohesion (PA;psi)	0.0; 0.0

[a]See Appendix E for more detailed data.

Source: Arthur D. Little, Inc., and Bowser-Morner Testing Laboratories, Inc.

TABLE 5.3

SELECTED DATA FOR REPRESENTATIVE SAMPLING LOCATIONS
AT ALLEN PLANT

CONCENTRATION (mg/ℓ or ppm except where noted)

LOCATIONS	SO_4	Ca	B	Sr	As (ug/ℓ)
Well 3-4B (Background)	2.1	9.95-10.9	<0.005-0.016	0.141-0.166	<0.2-7.0
Well 3-1 (Under Retired Pond)	89.9-100	59.4-64.1	1.71-1.87	3.60-4.71	56.3-57.2
Well 3-2A (In Active Ash Pond)	169.4-320	63.7-129	1.99-3.68	1.35-4.13	318-2425
Well 3-2 (Under Active Ash Pond)	1.4	15.8-17	0.057-0.76	0.241-0.274	<0.15-1.6
Wells 3-7A and 3-8 (Downgradient)	13-76.2	18.1-37.9	0.05-0.999	0.231-0.411	<0.10-0.78
Wells 3-6 and 3-9 (Downgradient)	4-5.4	11.2-18.0	<0.005-0.116	0.078-0.164	<0.2
Pond Overflow 3-13	56-62	19.6-21.4	0.205-0.238	0.297-0.342	58
Ash Solids 3-2 and 3-3	--	2251-4578	--	112-239	16.2-57.1
Background Soils 3-4	--	471-4056	--	8.85-33.1	0.6-1.41

EPA Interim Primary Drinking Water Standards for As - 50 ug/ℓ
EPA Proposed Secondary Drinking Water Standards are: Cu - 1 mg/ℓ
SO_4 - 250 mg/ℓ
Zn - 5 mg/ℓ
Fe - 0.3 mg/ℓ
Mn - 0.05 mg/ℓ
EPA Criterion for Protection of Sensitive Crops: B - 0.750 mg/ℓ

continued

TABLE 5.3

CONCENTRATION (mg/ℓ or ppm except where noted)

LOCATIONS	Cu	Ni	Zn	V	Fe	Mn
Well 3-4B (Background)	<0.008	<0.05	<0.05	<0.005-0.016	<0.01	<0.01-0.07
Well 3-1 (Under Retired Pond)	<0.008	<0.05	<0.05	0.018-0.034	<0.01	<0.01
Well 3-2A (In Active Ash Pond)	<0.008	<0.05	<0.05	0.035-0.043	<0.01-0.02	0.06-0.16
Well 3-2 (Under Active Ash Pond)	<0.008	<0.05	<0.05	<0.005	25.9	6.44-14
Wells 3-7A and 3-8 (Downgradient)	<0.005-0.013	<0.05	<0.05	<0.006	<0.01-0.02	<0.01-0.07
Wells 3-6 and 3-9 (Downgradient)	<0.008	<0.05	<0.05	<0.005-0.014	0.01-14.4	<0.01-2.72
Pond Overflow 3-13	<0.008	<0.05	<0.05	0.030-0.047	<0.01	<0.01-0.09
Ash Solids 3-2 and 3-3	20.8-45.1	15.3-26.0	18.5-45.7	22.2-41.5	11,700-29,491	83-171
Background Soils 3-4	9.52-17.6	4.48-10.8	22.8-36.2	28.1-49.1	11,164-16,558	155-303

EPA Interim Primary Drinking Water Standards for As - 50 ug/ℓ
EPA Proposed Secondary Drinking Water Standards are: Cu - 1 mg/ℓ
SO_4 - 250 mg/ℓ
Zn - 5 mg/ℓ
Fe - 0.3 mg/ℓ
Mn - 0.05 mg/ℓ
EPA Criterion for Protection of Sensitive Crops: B - 0.750 mg/ℓ

TABLE 5.4

SELECTED RESULTS OF SOIL ATTENUATION STUDIES
ALLEN SITE[a]

Element and Soil Sample[a]		Solution Concentration (ppb)	Soil Capacity (µg/gm)	Soil Capacity ÷ Solution Concentration
Arsenic	(A)	<0.2-413	1.0-215	>5500-261
	(B)	<0.2-225	0.3-47	>5500-128
	(C)	2.4-492	1.1-66.9	458-136
Selenium	(A)	0.2-113	0.25-127	90-9844
	(B)	<0.1-96	0.25-124	2500-92
	(C)	2.8-138	0.24-1.73	86-5.1
Calcium	(A)	42.3-73 mg/ℓ	68-590	1.6-8.1
	(B)	12.4-368 mg/ℓ	130-322	0.5-10
	(C)	52.5 mg/ℓ	44 ± 5	0.8
Cadmium	(A)	40-120	0.24-42	6-350
	(C)	70-150	0.17-12	2.4-8.0
Chromium	(A)	0.040-0.190	0.03-0.96	<0.35-11.8
	(B)	0.040-0.130	0.47-1.45	11.8
	(C)	0.030-0.250	0.06-0.49	<0.35-16.3
Copper	(A)	<0.008-0.072	>0.03-328	12-4500
	(B)	0.012-0.159	0.14-290	8.3-1800
	(C)	0.013-0.179	0.69-220	15-1200.
Nickel	(B)	0.210	4.5 ± 1.3	---
	(C)	0.220	0.31	1.4
Vanadium	(A)	0.009-0.030	0.05-6	5.5-200
	(B)	0.008-0.014	0.05-2.20	6-157
	(C)	0.021-0.031	0.03-0.05	1.4-1.6

[a] Soil types used were as follows: (A) boring 3-2, alluvial material, ~30% clay; (B) boring 3-3, residual soil, silty sand; and (C) boring 3-6, alluvial material, ~20% clay.

- Using the chemical analysis results and the gross and net water balance, mass balance estimates were made for selected contaminants entering the ash pond via the fly ash and bottom ash discharges and through the addition of boiling cleaning wastes, and for contaminants leaving the pond via overflow to Lake Wylie and leaching to groundwater.

- The water balance, geological profile, and chemical and physical testing results were considered together to structure and evaluate hypotheses concerning the nature of leachate generation and movement at the site. The importance of events such as the temporary cessation of the point source (pond overflow) discharge during boiler cleaning was considered in this step.

- To evaluate further hypotheses concerning chemical attenuation of leached trace metals by the soils surrounding the ash pond, a series of attenuation tests were executed using ash pond liquor and local soils.

- The results of the attenuation tests were evaluated along with the water balance, geological profile, mass balance and physical testing data to estimate the potential for long-term leaching of arsenic from the ash ponds to Lake Wylie.

- The broader implications of the Allen site results were considered in terms of their applicability to similar combinations of waste types, disposal methods and environmental settings. This step can be considered particularly important for the Allen site because the combination represented there is quite prevalent at other sites.

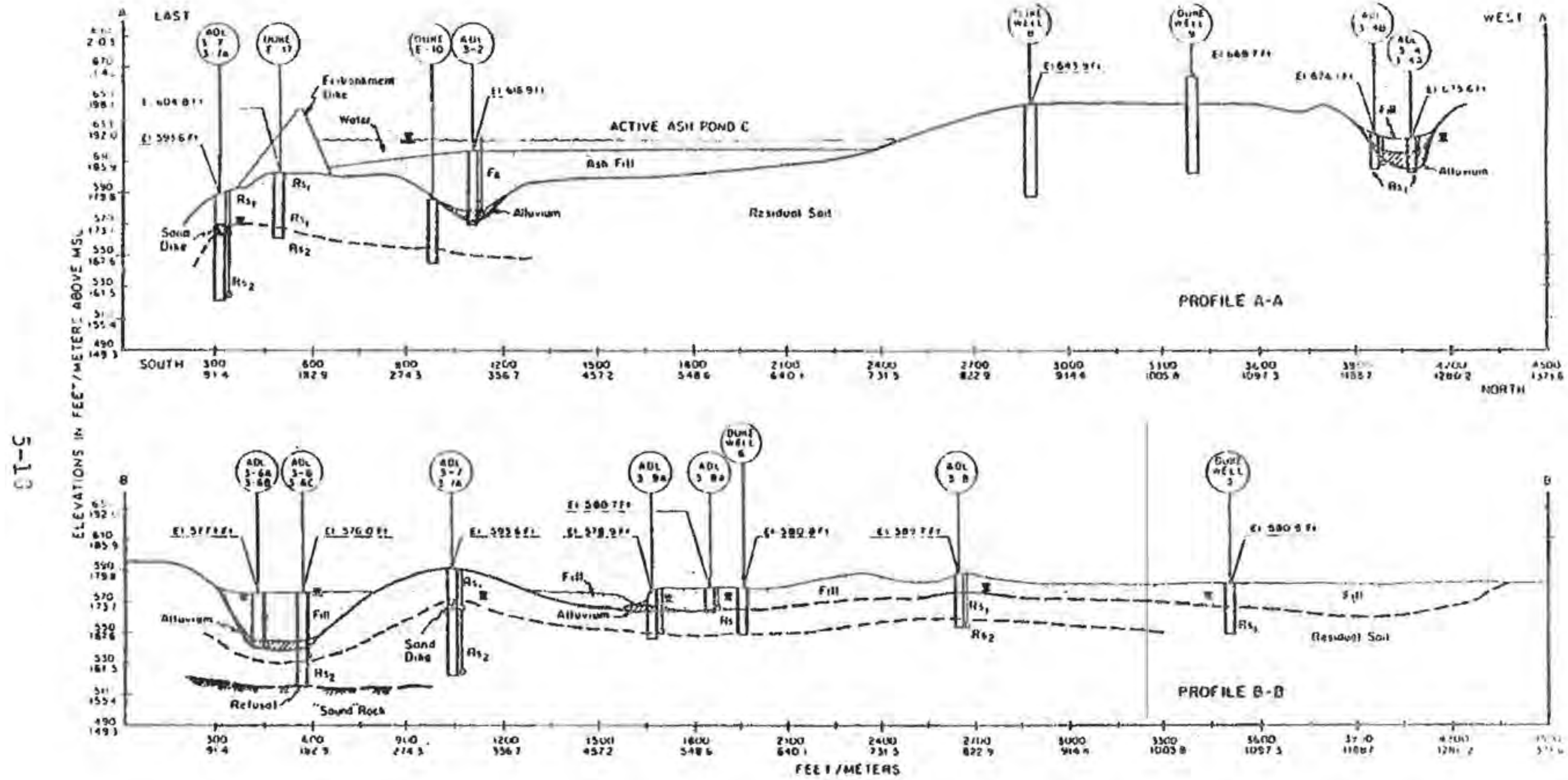
5.2.5.2 Geological Profile and Water Balance--

Figure 5.6 illustrates the subsurface geological profiles for three areas of the Allen waste disposal site as delineated above in Figure 5.4. These profiles were prepared on the basis of the site development results for this program along with the available site background information.

The annual water balance estimated for the Allen site is summarized briefly below and illustrated in Figure 5.7.

Definition of Terms

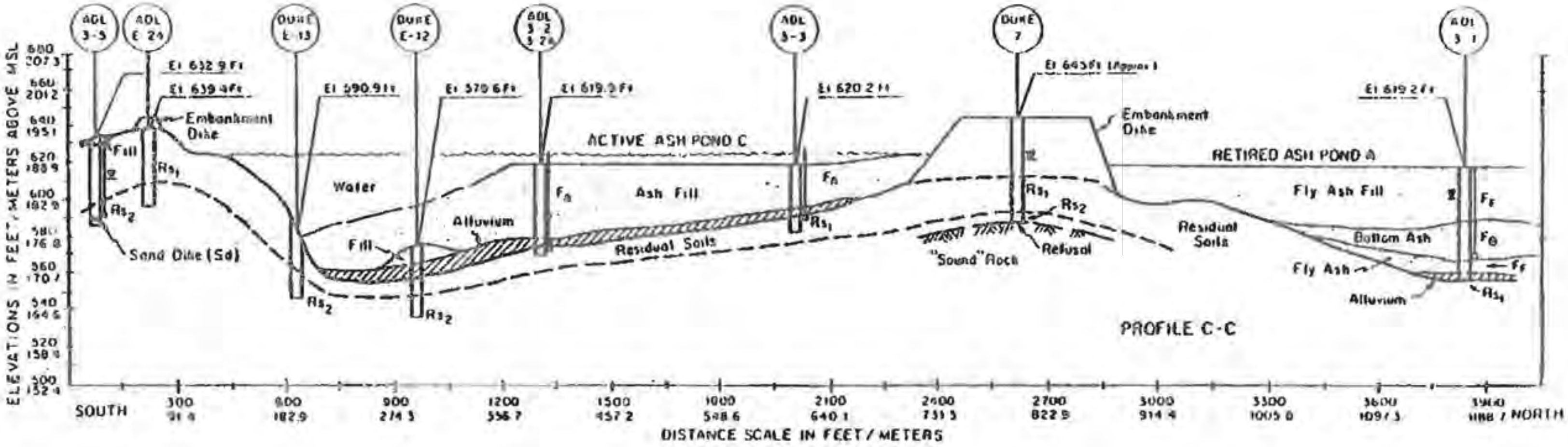
P = Precipitation
Ev = Evaporation
I_{PS} = Point Source Input to Pond
O_{PS} = Point Source Output from Pond
R_{SW} = Surface Water Runoff into Pond
R_{GW} = Groundwater Runoff beneath Pond
G_F = Groundwater Movement through Fill
G_A = Groundwater Movement through Alluvium
G_R = Groundwater Movement through Residual Soil



SUBSURFACE GEOLOGICAL PROFILES - ALLEN SITE
DUKE POWER COMPANY, GASTON COUNTY, N.Y.

FIGURE 6.6

(continued)



LEGEND

Alluvium A — Recent stream alluvial deposits varying from loose silty fine sands to soft, very slightly organic clayey silts with trace amounts of organic matter overlying residual soils.

Residual Soils Rs — Generally fine grained, cohesive soils formed from the chemical decomposition of the bedrock. General increase in grain size and density with increasing depth.

Rs_1 — Soft to stiff, reddish brown to gray white clayey silt to silt, little clay with trace sand, mica & occasional gravel.

Rs_2 — Medium compact to compact, yellow brown to greenish brown silt to fine sandy silt with trace amounts of clay, mica and gravel (gravel content increases with depth).

Sand Dikes (Sd) — Younger intruded igneous dikes varying in thickness from a few centimeters (inches) to several meters (feet) have intruded the overall older bedrock unit. Many of these dikes were observed in surface exposures and were encountered in several test borings. The dikes have decomposed to a coarse sand and gravel.

"Sound" Rock — In test borings, where abrupt auger penetration refusal was encountered at depth, it is assumed to be the top of the relatively unweathered, sound, competent bedrock.

Fills — Relatively recent overburden materials associated with construction of the ash pond disposal facility or disposed ash.

F — General excess site construction fill materials utilized in increasing available land area downgradient of the disposal facility. Occasional fill materials were encountered which predated the disposal construction. Reddish brown to dark brown clayey silts to fine sandy silts with varying amounts of mica, sand, gravel and organic matter.

F_A — Miscellaneous, very loose to very soft, dark gray to black, intermixed ash fill with occasional stiff lenses and layers, undifferentiated from Bottom Ash and Fly Ash.

F_B — Very loose to very soft, black, coarse grained bottom ash fill.

F_F — Very loose to very soft, gray, fine grained fly ash fill with occasional stiff layers and lenses.

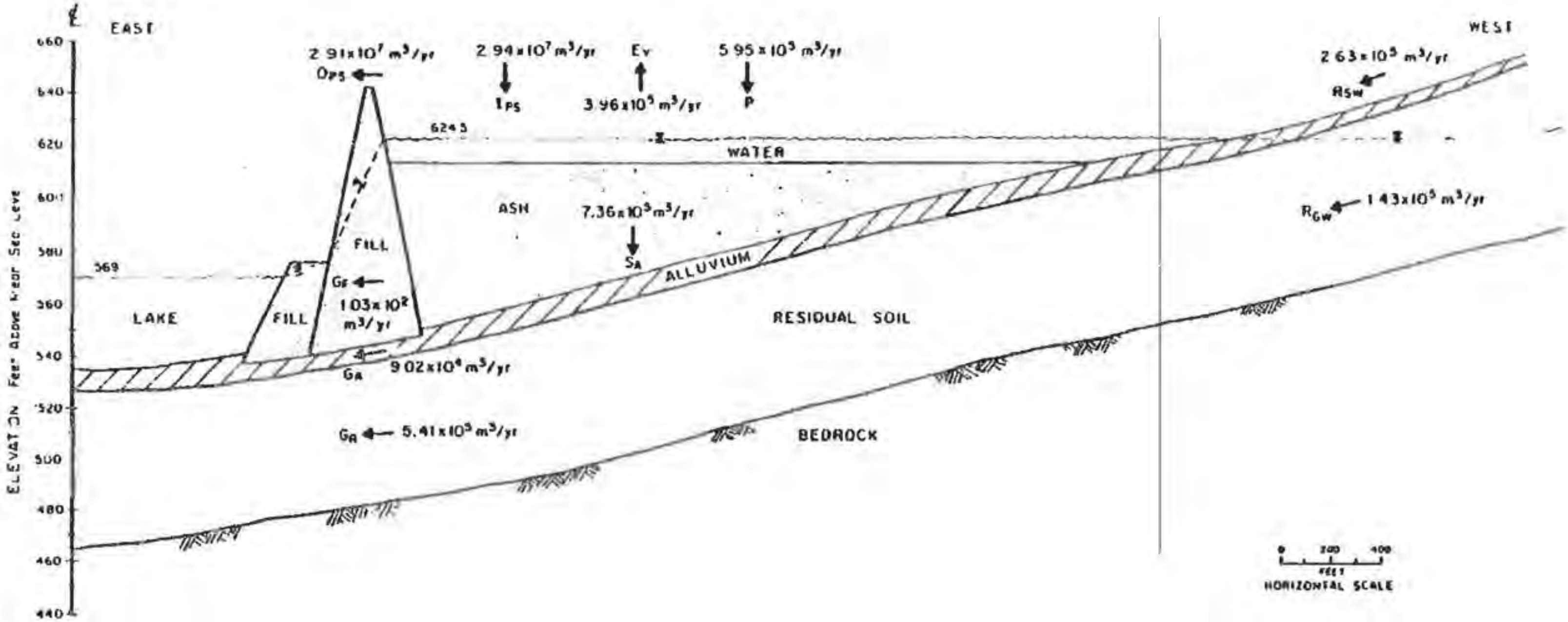
▽ — Symbol representing water depth in completed borehole or groundwater monitoring well at time of installation.

Symbol representing location of installed groundwater monitoring well or piezometer.

SUBSURFACE GEOLOGICAL PROFILE – ALLEN SITE

DUKE POWER COMPANY, GASTON COUNTY, N.C.

FIGURE 5.6



Refer to text for definition of terms

PLANT ALLEN WATER BALANCE (Annual Basis)

FIGURE 6.7

S_A = Water Seepage through Bottom of Pond

Calculation of O_{PS}

Inflow to Pond = Outflow from Pond

$$P + R_{SW} + I_{PS} = Ev + S_A + G_F + O_{PS}$$

$$O_{PS} = [5.95 \times 10^5 + 2.63 \times 10^5 + 2.94 \times 10^7 - 7.36 \times 10^5 - 1.03 \times 10^2]\ m^3/yr$$

$$O_{PS} = 2.91 \times 10^7\ m^3/yr$$

Balance of Groundwater Flow

Groundwater Inflow = Groundwater Outflow

$$R_{GW} + S_A = G_A + G_R$$

$$1.43 \times 10^5\ m^3/yr + 7.36 \times 10^5\ m^3/yr = 9.02 \times 10^4\ m^3/yr + 5.42 \times 10^5\ m^3/yr$$

$$8.79 \times 10^5\ m^3/yr \cong 6.31 \times 10^5\ m^3/yr$$

5.2.5.3 Evaluation of Testing Results--

The results of chemical analyses of samples, in conjunction with available background data, indicate the following:

- Absolute and relative concentration values measured on different dates at the same sampling locations were similar.

- Concentrations of likely ash-related "tracers" (boron, sulfate, calcium, strontium, vanadium and arsenic) were significantly higher in groundwater obtained from wells placed within the ash than in water from the other wells at the site; with the exception of vanadium, concentrations were significantly higher in the ash solids than in background soils (see Table 5.3).

- Concentrations of these same "tracers" exhibited a generally consistent pattern in downgradient wells, as follows:

  - Elevations of concentrations versus background concentrations were evident at some of the downgradient wells (wells 3-7A and 3-8, Figure 5.4);

  - Elevations of concentrations versus background concentrations were slight or lacking in samples from the other downgradient wells (e.g., wells 3-2, 3-6 and 3-9, Figure 5.4); and

  - High levels of iron and manganese in background soils (approximately 17,500 ppm and 400 ppm, respectively), groundwaters

(0.01 to 16 ppm and 0.014 to 11 ppm, respectively), and the River/Lake upgradient and upstream of the site (0.100 to 2.5 mg/l and up to 0.050 mg/l, respectively) were measured in this program and/or previous studies.

- Arsenic was measured at significantly elevated concentrations in groundwaters from lower strata within the ash (over 1000 µg/l at 12 to 14 m (38 to 40 ft); 50 to 100 µg/l in higher strata). The results of the EPA Extraction Procedure (EP) on samples from this site indicated arsenic levels about two orders of magnitude lower than the in situ field values (see Table 5.3). As noted above, arsenic was measured at near background levels in downgradient wells.

- Attenuation tests with ash pond liquor and site soils (see Table 5.4) indicated that the local soil attenuation capacity for arsenic was at least 10 µg/g soil; the attenuation capacity of the site soils was generally greater for the various trace metals than that measured for soils at any of the other five sites in the program.

- The amounts of copper, nickel, and zinc added to the pond during a boiler cleaning event represent 3 to 22 percent (280 kg, 71 kg and 80 kg, respectively) of the total amount of these same elements added in ash sluice water plus ash solids over a period of 18 months (time between boiler cleaning events). Other constituents added by boiler cleaning represented less than two percent of the total amount added over 18 months, and the contributions of most were less than 0.1 percent of the total amount added to the pond.

- The chemical analysis results of all sampling trips showed copper, nickel and zinc concentrations in well water, pond toe drains and pond overflow to be consistently low, approximately at or below the applicable detection limits. These were also generally at comparable levels in the ash and background soils, (Copper was somewhat elevated in the ash, as shown in Table 5.3).

- Natural soils under the site, treated with partial extraction, did not show much difference in concentrations of these three elements (Copper: 11-19 ppm; Nickel: 5-6 ppm; Zinc: 21-35 ppm) from similar background soils.

5.2.5.4 Cause and Effect Relationships--

The results from the investigations at Plant Allen are consistent with the following hypotheses:

- Leachate generated within the ash ponds contains elevated concentrations of several waste-related components. The surrounding soils in the immediate vicinity of the ponds have thus far been able to attenuate significant fractions of such leachate contaminants as arsenic and vanadium.

- Leachate water from the upgradient (western) portions of the ash ponds has not yet moved sufficiently to create steady-state concentrations of unattenuated parameters at the downgradient wells. This applies particularly to the active pond, but also appears to apply, to a lesser degree, to the most recently deactivated pond.

- Based on the results of the attenuation tests (Table 5.4) and analyses of site wastes and soils (Table 5.3), it appears likely that arsenic is chemically attenuated by iron and/or manganese in the soils under and around the ash ponds. Combining this information with the available information on arsenic inputs to the pond, the water balance and supporting hydrogeologic data, it also appears that the attenuative capacity of the surrounding soils would be sufficient to prevent passage of arsenic leachate with concentrations in exceedance of drinking water standards into Lake Wylie for longer than the estimated 15 year operating life of the active pond. This estimate would apply even if the pond remained active for almost 100 years, and for considerably longer (in excess of 500 years) if the pond is retired as scheduled.

- The chemical nature of various boiler cleaning wastes and the ash pond liquor (into which the former is periodically added) are such that chemical interactions likely alter the distribution of elements between the liquid and solid states. For example, while copper represents the most significant element added with boiler cleaning (by percent increment), precipitation of copper may occur upon decrease of the cleaning waste ammonia concentration by dilution in the pond. Copper and other elements, such as nickel or zinc, could be precipitated by additional interactions between boiler cleaning wastes and ash pond liquors. Such hypotheses are supported strongly by the lack of concentration elevation (availability) of these elements in pond liquor, the pond discharge well water and soil samples under the site (see Table 5.3).

Selected aspects of the above hypotheses are discussed further below.

Geohydrologic conditions at the site and the site water balance (Figures 5.6 and 5.7) reflect the fact that the spatial distribution of subsurface materials is relatively complex, leading to great uncertainties in defining leachate movement and admixing patterns. However, several pieces of information suggest that the downgradient wells have not yet reached steady state conditions with respect to the movement and admixing of leachate generated by the pond.

The water balance calculations suggest that downward leachate flow driven by the head of standing water in the pond is an important flow feature in the alluvial deposits under part of the pond. There is no analogous data to define vertical flow velocities in the residual soils that underlie most of the pond, which are estimated to carry the bulk of water flowing downgradient of the pond.

Given the variations and uncertainty in the length of flow paths, hydraulic gradient (especially accounting for variations over the life of the facility) and hydraulic conductivity at this site, it is only possible to conclude that leachate generated in eastern portions of the pond has begun to reach the downgradient well locations. It is not clear whether leachate from western portions of the pond has yet reached to downgradient locations, or what fraction of the total leachate emanating from the pond has actually migrated toward or reached the downgradient wells. Since steady state conditions would not be achieved until the whole pond (all potential flow paths carrying leachate) contributes leachate to downgradient locations, it is plausible that steady state conditions have not been achieved.

Another element of the water balance (see Section 5.2.5.2) also suggests that steady state conditions have not been achieved. Again, the magnitude of geohydrologic uncertainty compromises the conclusion. The water balance indicates that leachate seepage from the base of the pond exceeds groundwater underflow from upgradient areas by roughly an order of magnitude. The estimated seepage rate also exceeds the estimated groundwater flow rate away from the site by roughly a factor of two. This discrepancy probably roughly indicates the magnitude of error associated with the seepage rate estimate, but may be partly associated with the fact that water movement patterns at the site are still dynamically responding to pond seepage. (Seepage from all parts of the pond bottom has not yet reached downgradient locations.) At face value, the water balance estimates suggest that at steady state nearly all the downgradient flow would be leachate. Even if the seepage rate is one half of the estimated value, downgradient water at steady state would still be roughly 80 percent leachate plus 20 percent underflowing groundwater. Observed concentration levels for major constituents indicate that downgradient wells are sampling a mixture of roughly 20 percent leachate plus 80 percent underflowing groundwater. Thus, allowing for reasonable levels of uncertainty in the water balance, it appears that downgradient locations have not reached steady state, and increasing concentrations over the next several years would be expected.

Available data, however, cannot support a precise estimate of future groundwater quality at the site, although it is clear that steady state concentrations may range between existing concentrations and concentrations typical of ash leachate (e.g., as in well 3-2A at present).

5.2.5.5 Environmental Effects Implications--

Existing levels of most constituents in almost all groundwater sampling locations at the site do not exceed present water quality standards (see Table 5.3). The exceptions include:

- iron and manganese, which exceed secondary drinking water standards in background waters and over most of the site. (It has been noted that these elements may aid in attenuating constituents such as arsenic.); and
- sulfate, arsenic and boron in the "in-waste" well, with the concentrations of the latter two also high in groundwater under the waste, and in some cases, in the pond overflow.

As illustrated by the definition of water balance given in Section 5.2.5.2, the potential incremental leachate impacts at this site can be put in perspective by comparison with the point source discharge from the ash pond. Considering the mass transport rates of selected constituents from the Plant Allen pond, the following conclusions may be readily drawn:

- leachate generation rates are typically one to two orders of magnitude less than point source discharge rates;
- present downgradient transport of leachate into Lake Wylie appears to be about 8 times less than leachate generation rates; and
- the mass of ash-related contaminants entering Lake Wylie by non-point source transport appears to be about two orders of magnitude less than the mass entering by point source discharge.

The reasons why downgradient transport rates appear to be less than leachate generation rates have been discussed earlier, but are summarized as follows:

- downgradient locations may not be at steady state;
- some constituents have been attenuated; and
- leachate generation rates may be overestimated.

Exceptions to the above conclusions may be noted for iron and manganese, whose presence at greater concentrations in background water dominates the leachate contribution.

Considering the maximum observed concentrations of non-attenuated species (e.g., sulfate) in the leachate and the dominant influence of the point source discharge, the long-term impacts of leachate migration to Lake Wylie at this site are expected to be insignificant.

The results from the Allen site support conclusions 1,2,3, and 5 in Section 5.1 and have the following broader implications for similar disposal practices:

1. Concentrations of at least one trace metal (arsenic) in coal ash leachate can significantly exceed the applicable drinking water standards, and can be present at orders of magnitude higher in situ concentrations than would be indicated by the results of the EP test.
2. Chemical attenuation of leachate trace metals by surrounding soils can be a significant mitigative factor affecting the potential for downgradient water quality effects of coal ash disposal sites. This further implies that siting new disposal areas which are surrounded by such attenuative soils, or importing such soils for use as site liners may be important mitigative practices on a case-by-case basis.

3. In situations where pond disposal is practiced, the relative importance of a point source discharge can far exceed that of leachate contributions to changes in receiving water quality. However, because of the wide range of variation in disposal site water management practices, this is very much a case-by-case consideration.

4. The use of coal ash ponds as neutralization and admixing media for other intermittent, acidic, metal-rich waste streams (specifically boiler cleaning wastes and possibly coal pile runoff) appears to be an effective mitigative practice under conditions analagous to those at the Allen site. Boiler cleaning wastes were sampled and considered in some detail at this site; coal pile runoff, while not sampled in this program, was a known input to the ash ponds.

5.2.6 Engineering Cost Assessment

5.2.6.1 Engineering Assessment--

Plant Allen, a baseload facility, has a current total nameplate generating capacity of 1,155 MW, employing five units. Plant operation commenced in 1957, with the startup of Units 1 and 2, each unit having a 165 MW nameplate generating capacity. During the three-year period of 1959-1961, inclusive, three units with 275 MW nameplate generating capacities were installed at a frequency of one unit per year. Plant Allen boilers are pulverized coal, tangentially-fired units. Average annual boiler capacity factors during 1979 were 32 and 39 percent for Units 1 and 2, respectively. The newer boilers, Units 3, 4, and 5 had higher load factors during the same period, 57, 61, and 56 percent, respectively.

Air Pollution Control--Units 1 and 2 are equipped with conventional multiple-cyclone, reverse-flow particulate collectors. Units 3, 4, and 5 are equipped with cold-side electrostatic precipitators (ESPs). During the early 1970's, hot-side ESPs were added to each of the five units to effect more efficient fly ash removal. Experimental flue gas conditioning systems have recently been added to Units 1 and 2 in order to improve fly ash collection efficiency. Proprietary chemical additives injected directly into the boiler combustion zone are used for flue gas conditioning. The particulate control systems in use at Plant Allen were tested in October 1979, and were shown to be 97 to 98 percent efficient.

Coal Consumption--Bituminous coal used by this plant is obtained from a number of sources in Virginia, Kentucky, Tennessee and West Virginia. Annual coal consumption for the years 1977 through 1979, inclusive, ranged from 1.72 to 1.95 million metric tons (1.90 to 2.15 million tons). Annual average coal sulfur content remained constant over this period at 1.0 percent, by weight (dry basis). The average annual coal ash content during this period was 12 to 15 percent, by weight. Average heating value of the coal ranged from 28.1 to 28.4 million joules/kg (12,000 to 12,200 Btu/lb).

Waste and Water Management--Fly ash and bottom ash are the only high volume solid wastes produced by this plant. Annual ash production during the next decade is projected to remain constant at approximately 227,000 metric tons (250,000 tons).

Fly ash is conveyed by a vacuum pneumatic system to a hydro-ejector that is used to mix a fly ash/water slurry. The waste is sluiced to the disposal pond. Bottom ash collected in hoppers is directed to clinker grinders and is also sluiced to the disposal pond. Four pipelines are used to transport fly ash and bottom ash to the pond.

Coal pile runoff and plant drainage are intermittently pumped to the disposal pond by way of separate lines. There are two sumps at the Plant Allen site; one collects plant drainage, boiler blowdown, water treatment wastes, and pump sealing water, etc., and a second services surface water runoff from the coal storage area. The sump pumps automatically engage once a specified level of liquid is in the sump. Both sumps discharge into the northeast corner of the disposal pond.

Process flow diagram F-100, Figure 5.8, depicts the waste handling/transport scheme and provides a material balance for this operation.

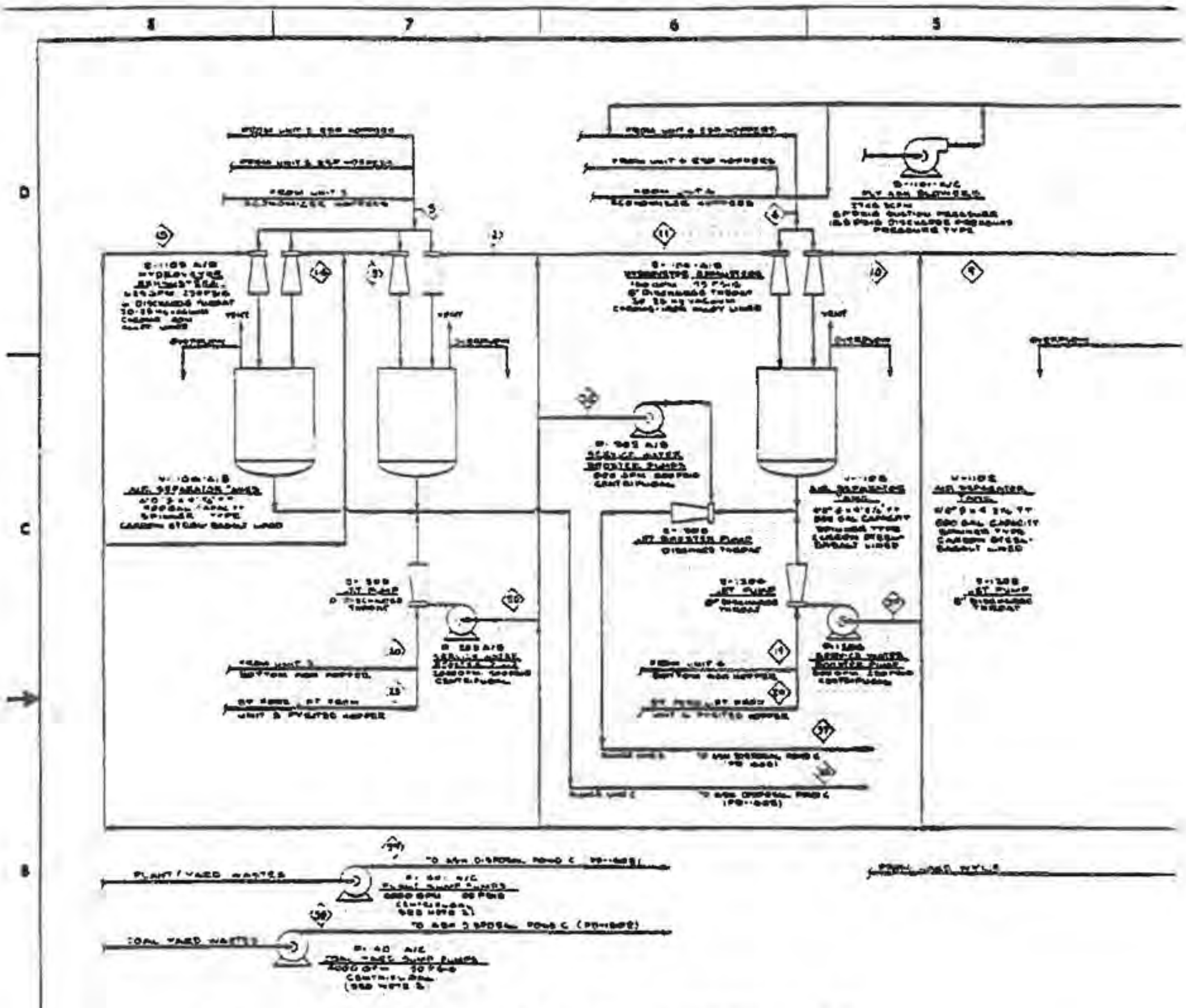
Disposal Operation--The current disposal pond, denoted Pond C, is 590,000 m^2 (146 acres) in size. Effluent from this pond is discharged to Lake Wylie. In prior years, two adjoining ponds, Ponds A and B, were used for coal ash disposal. These ponds were filled with ash and are now retired. Duke Power has undertaken a program of groundwater monitoring at the site and, hence, has installed monitoring wells at various locations around both the active and retired disposal ponds.

In addition to the process descriptions and process flow diagram developed for the Plant Allen coal ash handling and disposal operation, a list of Plant Allen area accounts and a detailed equipment list (divided among modular area accounts) were developed. These are provided as Tables G-1 and G-7, respectively, in Appendix G.

5.2.6.2 Cost Assessment--

Capital and first year annual cost estimates were developed for the coal ash handling and disposal operation at Plant Allen. These were based primarily on the engineering assessment results. However, to provide for consistency among the cost estimates developed for the six sites, it was necessary to specify certain engineering design premises that were consistent for all study sites (e.g., plant service life, load factor, heat rate, etc.). The engineering design premises that pertain to the Plant Allen cost estimates were listed in Table 5.5.

Detailed capital cost estimates for the Plant Allen coal ash handling and disposal system are presented in Appendix G, Table G-13. A summary of the modular capital cost estimates for the Plant Allen system is presented in Table 5.6. This table provides the modular capital costs broken down by waste type. As can be seen from this summary, the cost of the air pollution control system comprises a significant fraction (approximately 65 percent) of the total cost of the environmental control system for the plant. It is also



DESIGN CONDITIONS - TOTAL STREAM FLOW PER NORMAL 24 HOUR DAY (NOTE 5)

STREAM NO / DETAIL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
K TONS ASH/DAY	0.16	0.16	0.29	0.29	0.29	—	—	—	—	—	—	—	—	—	—	0.06
K TONS WATER/DAY	—	—	—	—	—	2.1	2.1	2.1	2.1	2.1	2.1	.9	.9	.9	.9	N/A
MGPD (WATER)	—	—	—	—	—	0.50	0.50	0.50	0.50	0.50	0.50	0.46	0.46	0.46	0.46	N/A
% SOLIDS	100.0	100.0	100.0	100.0	100.0	0	0	0	0	0	0	0	0	0	0	N/A
SPECIFIC GRAVITY	2.5	2.5	2.5	2.5	2.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	N/A

STREAM NO / DETAIL	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K TONS ASH/DAY	0.057	0.057	0.012	0.012	0.012	—	—	—	—	—	—	—	—	0.46	0.29	0.29
K TONS WATER/DAY	0	0	0	0	0	5.6	5.6	5.6	5.6	8.6	6.6	8.6	26.0	20.4	9.6	9.0
MGPD (WATER)	0	0	0	0	0	.5	.5	.5	.5	2.0	3.6	.5	2.4	4.9	3.6	3.6
% SOLIDS	100.0	100.0	100.0	100.0	100.0	0	0	0	0	0	0	0	0	2.2	2.5	2.4
SPECIFIC GRAVITY	2.5	2.5	2.5	2.5	2.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.02	1.02	1.02

N/A - INFORMATION NOT AVAILABLE

FIGURE [illegible]

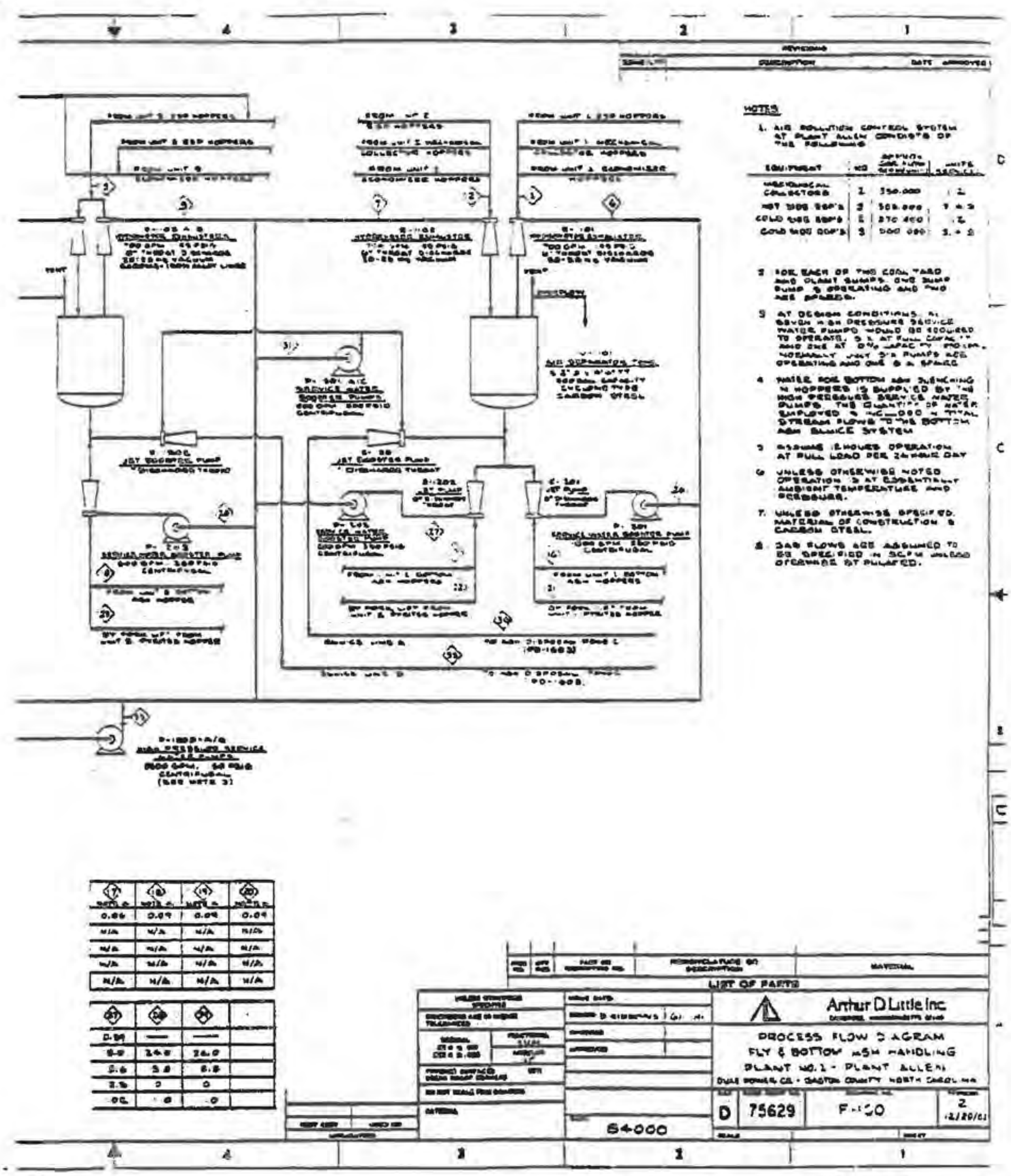

NOTES
LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
FLY & BOTTOM ASH HANDLING
PLANT NO. 1 - PLANT ALLEN
D
75629
64000

FIGURE 5.8

TABLE 5.5

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR
ALLEN PLANT
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES	
Power Plant	
Plant Size (MW)	1155
Boiler Type	Pulverized Coal
Heat Rate (M joules/kWh; Btu/kWh)	12; 11,400
Location	North Carolina
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Waste Generated (dry basis)	
Fly Ash/Bottom Ash Ratio	75/25
Fly Ash Generation (metric tons/yr; tons/yr)	275,900; 304,200
Bottom Ash Generation (metric tons/yr; tons/yr)	102,000: 112,[illegible]00
FGD Waste Generation (metric tons/yr; tons/yr)	--
Ash Utilization	None
Coal Properties	
Coal Type	Bituminous
Sulfur Content (Percent)	1.0
Ash Content (Percent)	12.0
Heating Value (M joules/kg; Btu/lb)	27.9: 12,000
Air Pollution Control	
Particulate Control	Mechanical Collectors (Units 1&2) Cold-Side ESP's (Units 3,4,5) Hot-Side ESP's (Units 1-5)
Particulate Removal (Percent)	>99
Sulfur Oxides Control	None
Disposal Site	
Type	Pond
Design Life (yr)	30
Land Area (m^2; acre)	1,104,800: 273
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner (type; m; ft)	None
Distance from Plant (km; mile)	1.6; 1.0

TABLE 5.6

CAPITAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Allen
Plant Location: Gaston County, North Carolina
Utility Name: Duke Power Company
Nameplate Generating Capacity (MW): 1155

	CAPITAL COSTS ($1000)			
WASTES	Fly Ash	Bottom Ash	Coal Pile Runoff/Plant Wastes	Total
MODULES				
• Waste Handling and Processing	$3,771	$1,433	$ –	$5,204
• Waste Transport	7,920	2,930		10,850
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	18,349	6,790	–	25,149
SUBTOTAL MODULAR COSTS	$30,050	$11,153	$ –	$41,203($36/KW)
RELATED ENVIRONMENTAL SYSTEMS				
• Miscellaneous Plant Wastes Handling, Transport, and Disposal	– *		1,940	1,940
• Air Pollution Control	84,373	–	–	84,373
TOTAL CAPITAL COSTS	$114,423	$11,153	$1,940	$127,516 ($110/KW)

[a] ENR Cost Index = 3931.11 (1913=100)
= 365.97 (1967=100)

Source: Arthur D. Little, Inc. estimates.

evident that the capital cost of solid waste placement and disposal is the largest cost element (approximately 60 percent) when the air pollution control system is not considered. This is commonly the case for ponding operations; in this study the waste placement and disposal module for ponding operations typically comprised 55 to 65 percent of the non-air pollution control environmental system costs. The Plant Allen capital cost estimate is consistent with this thesis.

Comparison of the Plant Allen waste handling and disposal system (excluding related environmental systems) capital costs ($36/kW) to those for other plants evaluated under this program that practice pond disposal (the Sherburne County Plant at $43/kW and the Smith Plant at $47/kW) indicates that this system has the lowest capital costs. This is primarily due to savings that result from economies of scale (i.e., Plant Allen has a nameplate generating capacity of 1155 MW, while that for the Smith Plant is only 340 MW) and from the fact that the pond construction did not require expensive materials (i.e., the Plant Allen pond is unlined, compared to that at the Sherburne County Plant that was lined with clay at an added expense). However, the difference among the Plant Allen capital cost estimate and those for the other plants that use pond disposal is not as pronounced as one might expect. This is because Plant Allen, with five boilers, has four distinct and separate coal ash handling and transport systems. The capital cost for this module is relatively high, since it is actually comprised of four small-scale systems and therefore exhibits very little economy of scale. In addition, the distance from the plant to the disposal site at Plant Allen is approximately four times as great as that at the Smith Plant.

A detailed annual cost estimate was prepared for the Plant Allen system (Table G-19, Appendix G). A modular summary of this estimate, Table 5.7, provides a less detailed account of these costs.

Annual costs for the three sites evaluated which practice ponding of FGC wastes were relatively similar in value. The unit annual cost for ponding at Plant Allen ($23.70/dry metric ton) is the lowest of the three; the unit cost for the Smith Plant is $25.10/dry metric ton while the Sherburne County Plant cost is $26.60/dry metric ton. The lower cost at Plant Allen (1155 MW) indicates some cost savings due to economies of scale (with respect to the Smith Plant 340 MW), however, one might expect this to be more dramatic. The fact that Plant Allen, with five boilers, has four distinct and separate coal ash handling and transport systems reduces economies of scale that one might expect. As with the capital costs, the major annualized cost element is due to the waste placement and disposal module, which typically contributes 45 to 55 percent of the total annual cost. This is primarily due to the large contribution of disposal ponds capital charges to the annualized cost. This, again, illustrates that pond disposal is highly capital intensive.

TABLE 5.7

ANNUAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Allen
Plant Location: Gaston County, North Carolina
Utility Name: Duke Power Company

Operating Load Factor (percent): 70
Name Plant Generating Capacity (MW): 1155
Waste Generation (dry metric tons/yr):
Fly ash - 275,900; Bottom ash - 102,000

WASTES	ANNUAL COSTS ($1000) Fly Ash	Bottom Ash	Coal Pile Runoff and Plant Wastes	Total
MODULES				
• Waste Handling and Processing	$1,216.1	$ 887.[illegible]	$ -	$2,103.7
• Waste Transport	1,903.6	703.[illegible]		2,607.1
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	3,092.9	1,143.8		4,236.7
SUBTOTAL - MODULAR COSTS	$6,212.6	$2,734.9	$	$8,947.5 ($23.70/dry metric ton)
RELATED ENVIRONMENTAL SYSTEMS				
• Miscellaneous Plant Waste Handling and Transport	$ -	$ -	$551.5	$ 551.[illegible]
• Air Pollution Control	NA[b]		-	NA[b]
TOTAL ANNUAL COSTS	$6,212.6 + NA[b]	$2,734.9	$551.5	$9,499.0 + NA[b]

[a] ENR Cost Index 3931.11 (1913=100)
365.97 (1967=100)

[b] NA = Information not available

Source: Arthur D. Little, Inc. estimates.

5-33

5.3 Elrama Plant

5.3.1 Plant Description

5.3.1.1 Background--

The Elrama Plant of Duquesne Light Company is located in Washington County, Pennsylvania, approximately 32 km (20 miles) south of Pittsburgh. The plant is adjacent to the Monongahela River. The FGC waste disposal facility is located approximately 19 km (12 miles) east of the plant in Elizabeth Township, Allegheny County. The plant and disposal site locations are shown on Figure 5.9.

The Elrama Plant began operations in 1952; the addition of flue gas desulfurization capabilities occurred in 1975. The waste disposal methods consist of wet sluicing of bottom ash and, occasionally, fly ash to an on-site interim pond. The dewatered contents of the pond are subsequently excavated and removed to a landfill disposal site. The FGD waste sludge is pumped from thickeners to a Conversion Systems, Inc. (CSI) processing plant where the waste is fixated with fly ash (which is collected and handled in dry form) and lime, and removed to the landfill site.

The selection of the fixated FGC waste landfill operation at the Elrama disposal site for study was based on a number of considerations in comparing this with other potential sites in the region. The two most important ones were the following:

- Fixated FGC waste landfilling was available for study at very few sites in 1980; however, this disposal option was a planned commitment at many other interior locations in the eastern United States. The type of fixation practiced at Elrama is based on controlled mixing of dewatered FGD waste with lime and fly ash to change the characteristics of the waste from a thick slurry to a highly alkaline, soil-like material. This process makes landfill disposal a practical alternative to pond disposal.

- Landfill disposal of FGC wastes in abandoned strip mines is also a growing practice. The Elrama landfill site occupies an abandoned coal mining area that exhibits acid mine drainage. While acknowledged as a potential complicating factor in the assessment, this situation represents an opportunity to fill a significant data gap on highly alkaline waste disposal in a typical acid mine drainage setting.

A number of other factors enhanced the attractiveness of Elrama as a study site and are included here because they had to be considered in both the design and interpretation of the monitoring program at this site:

- climatic conditions (average rainfall, temperature range and typical frost penetration) can be considered representative of the Appalachian Region;

- good groundwater flow in this setting was expected;

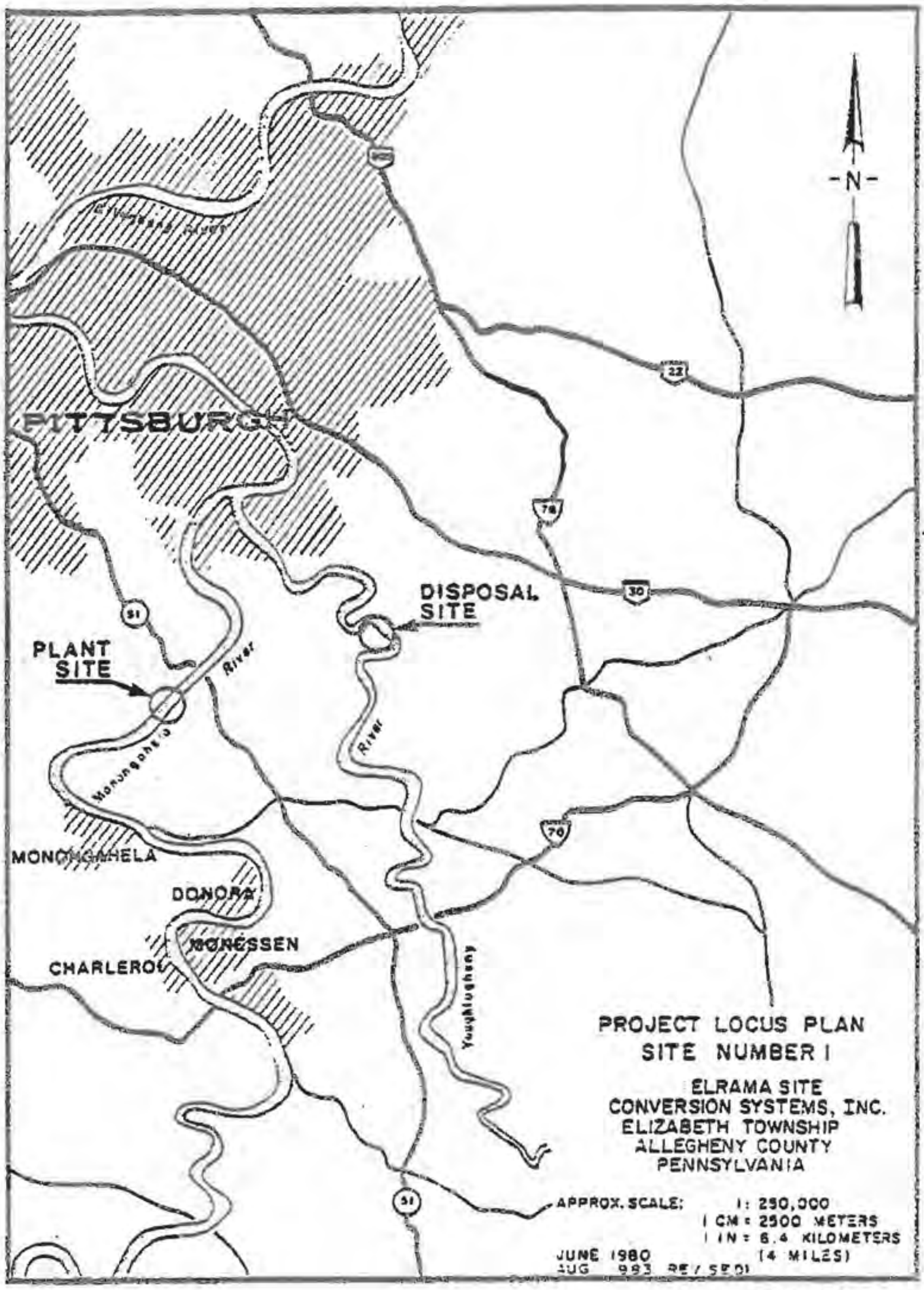

N
PITTSBURGH
DISPOSAL SITE
PLANT SITE
Monongahela River
River
Youghiogheny
MONONGAHELA
DONORA
MONESSEN
CHARLEROI
22
30
76
70
51
51
PROJECT LOCUS PLAN
SITE NUMBER I
ELRAMA SITE
CONVERSION SYSTEMS, INC.
ELIZABETH TOWNSHIP
ALLEGHENY COUNTY
PENNSYLVANIA
APPROX. SCALE: 1: 250,000
1 CM = 2500 METERS
1 IN = 6.4 KILOMETERS
(4 MILES)
JUNE 1980

FIGURE 5.9

- alluvium underlying the disposal area was anticipated to provide a good monitoring medium; and
- the landfill is in close proximity to surface water (Youghiogheny River), although it is separated from the river by runoff collection ponds. Additionally, the site is located on a hillside above the river.

While somewhat less important than other factors (e.g., the presence of acid mine drainage), these factors were considered in the selection process in the belief that data from a site such as Elrama would provide broadly generalizable information.

5.3.1.2 Geologic Conditions--

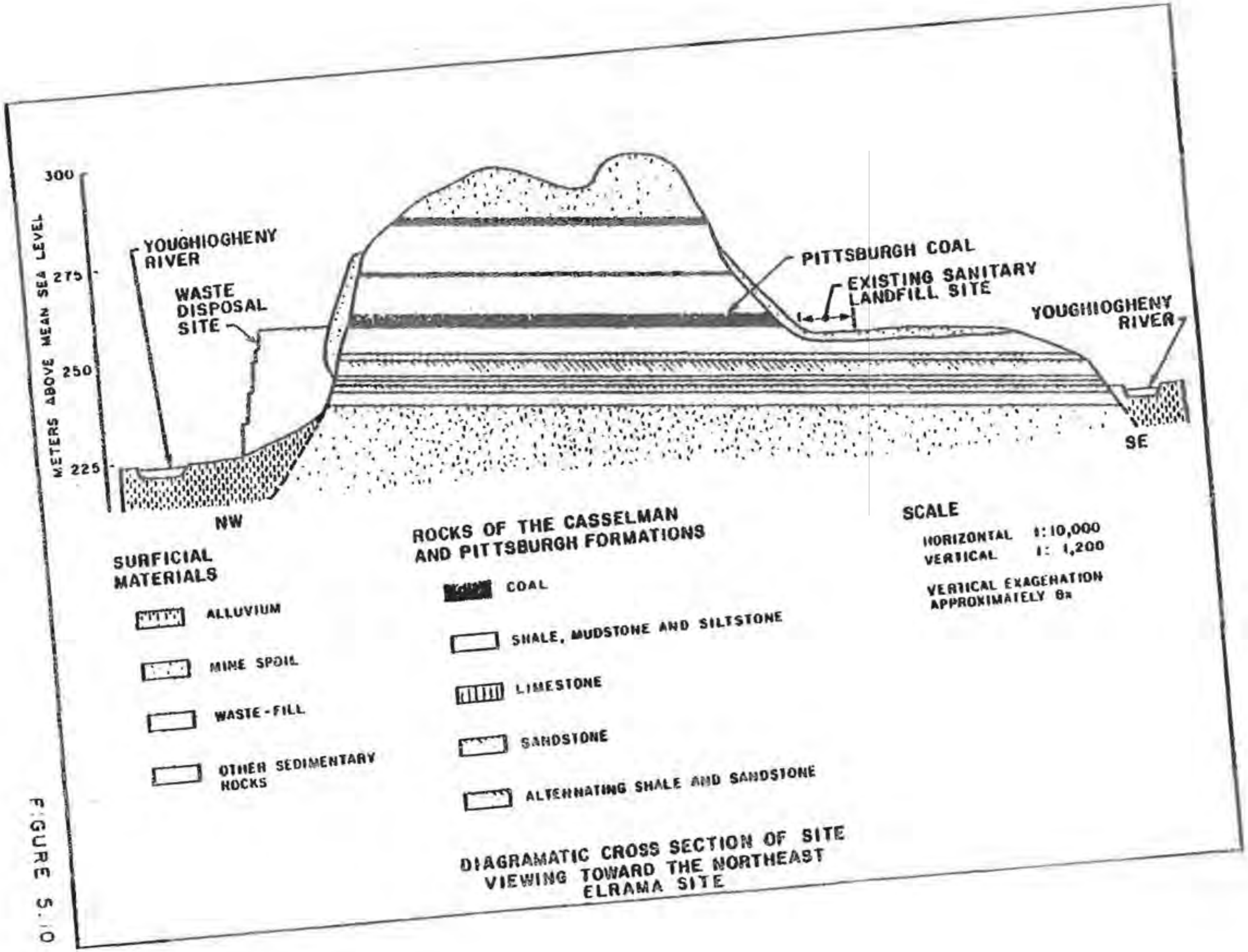
The project site area is located within the Allegheny Plateau of the Appalachian Plateau physiographic province. The Plateau is characterized by both major and minor erosional valleys and ravines, with broad meandering and mature streams displaying well developed flood plains and associated river terraces.

The majority of Allegheny County is underlain by very shallow, nearly flat-lying sedimentary rocks belonging to the Monongahela and Conemaugh groups of the Pennsylvania system. These geologic units are composed of complexly interbedded, repetitious sequences of a variety of rock types, in addition to the major and world-reknowned "Pittsburgh Coal" member. The Pittsburgh Coal seam has been extensively mined throughout Allegheny County, including the Elrama disposal site.

The majority of the overburden soils in the county are formed from the decomposition of the relatively shallow, underlying bedrock. These sediments are referred to as residual soils and consist primarily of silts and clays with trace amounts of partially decomposed rock fragments. Along the flanks and bases of the steeper slopes, sloughing and landslides have created intermixing of the rock debris and residual materials which are referred to as colluvial deposits. Previous surface contour strip coal mining operations have left behind major spoil piles which include a mixture of all soil and rock types in the site area.

The alluvial and river terrace deposits associated with the adjacent Youghiogheny River consist of silts and sands with minor amounts of clay and gravel. Figure 5.10 indicates the general subsurface geologic conditions in the project area.

During the project site development phase (March 1981), the Elrama waste disposal site occupied 89,000 m^2 (22 acres) of machine compacted, stabilized waste placed in four benches, each approximately 6 m (20 ft) thick. The disposal site will be eventually expanded to 258,000 m^2 (66 acres) with 13 additional benches. At the time of site development, the majority of the disposed waste was located within the low-lying alluvial terrace of the Youghiogheny River. Bedrock had been exposed during the previous coal mining operations above and slightly to the south of the existing waste disposal



DIAGRAMATIC CROSS SECTION OF SITE
VIEWING TOWARD THE NORTHEAST
ELRAMA SITE

FIGURE 5.10

limits. Major amounts of coal mining spoil debris underlie the upgradient portions of the disposal site. Continued expansion of the disposal site will eventually cover over all the mine spoil debris and exposed bedrock to the top of the adjacent hill. Figure 5.11 summarizes the site area surficial geologic conditions.

5.3.1.3 Hydrologic Conditions--

The Elrama waste disposal site is located within the Monongahela River Groundwater Province. The Youghiogheny River is the main tributary of the basin and drains an area of 4,569 km^2 (1,764 mi^2). The primary sources of groundwater recharge in Allegheny County are precipitation and infiltration of stream and river water. The average annual precipitation is 0.94 m (37 in) with historical fluctuations varying from 0.508 to 1.27 m (20 to 50 in). The majority of the precipitation is lost from the county by flow into the Ohio River or by evapotranspiration.

Groundwater levels vary considerably with the site topography, being relatively deep seated in the bedrock at the higher site elevations and varying from 60 to 90 m (20 to 30 ft) below ground surface in the low lying alluvial deposits. All surface and groundwater flow is westerly to the adjacent Youghiogheny River.

5.3.2 Site Evaluation Plan and Site Development

In 1975 the Elrama waste disposal site was first examined by the current owner as a possible sanitary landfill site. Additional studies of the site were conducted by CSI in 1977 for the existing disposal facility. Four large diameter observation wells were installed by CSI for long-term monitoring purposes. These previous studies provided valuable hydrogeologic baseline data which was utilized in developing the project site evaluation approach.

The project site development plan for Elrama included the installation of multipurpose wells, lysimeters, exploratory borings and test pits for hydrogeological and geotechnical evaluation purposes. A major site geochemical concern was to determine the amount of leachate derived from the adjacent, acidic mine spoil debris which abuts and underlies the disposal site on the upgradient side.

One observation well (Well 1-14) was installed in the alluvial floodplain for background monitoring purposes, and one upgradient well (Well 1-2) was installed within the mine spoil debris. Following site development and the April 1981 sampling visit, fixated FGC waste was disposed adjacent to and upgradient of well 1-2. Five downgradient observation wells were installed in the alluvial flood plain deposits of the Youghiogheny River. Three observation wells and three lysimeters were installed in the lower benches of the compacted waste fill. The lysimeters were installed in the unsaturated vadose zone beneath the waste fill deposit to provide leachate samples which had not been in contact with any mine spoil leachate. Machine excavated test pits were obtained to determine the presence and extent of underlying mine spoil debris and to obtain large block samples of aged, previously placed waste fill for laboratory testing. Down-hole nuclear density testing was also

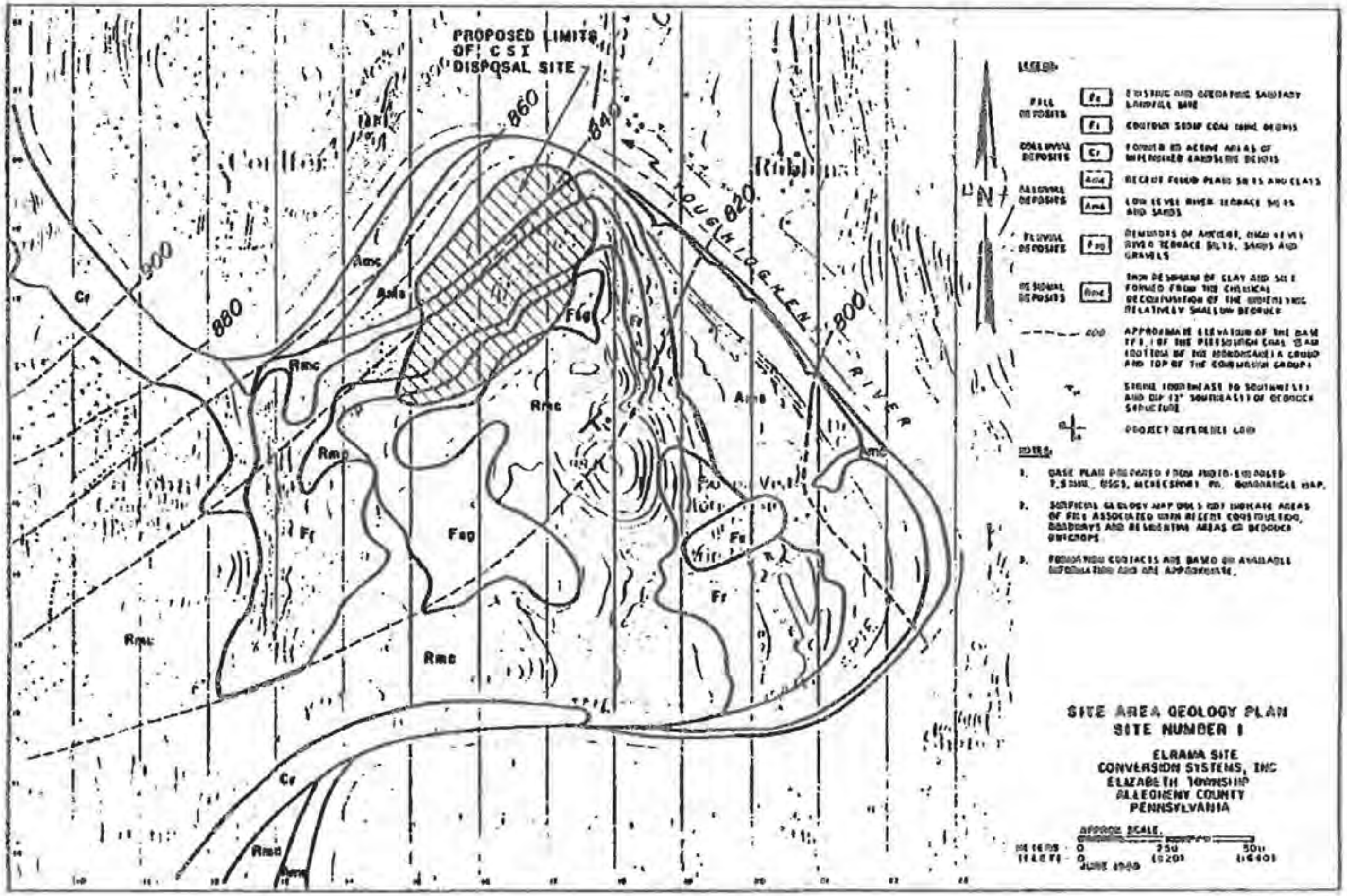

PROPOSED LIMITS OF CSI DISPOSAL SITE
860
840
820
800
880
900
RIVER
Cr
Rmc
Fag
Fr
Fs
N
SITE AREA GEOLOGY PLAN
SITE NUMBER I
ELRAMA SITE
CONVERSION SYSTEMS, INC
ELIZABETH TOWNSHIP
ALLEGHENY COUNTY
PENNSYLVANIA
APPROX. SCALE
0
250
500

FIGURE 5

conducted in the disposed waste and is discussed in more detail in Section 5.3.3.

At the completion of monitoring well installation, the wells were flushed, allowed to restabilize to the groundwater level and an initial sample obtained for chemical evaluation purposes. Upon completion of the field sampling phase in September 1982, all installations were sealed with cement grout at the request of CSI.

The location of all explorations and monitoring/sampling installations are indicated on Figure 5.12 and a summary of all field results, samples, well locations, well and sample depths, tests and well types are indicated on Table 5.8.

5.3.3 Physical Testing Results

Figure 5.13 presents results of permeability tests, standard penetration tests, down-hole nuclear density tests, and unified soil classification tests performed on fixated FGC waste from the Elrama disposal site are presented on Figure 5.13. Although bottom ash and fly ash excavated from the interim pond were reportedly randomly placed in the fill with the stabilized waste, layers of fly ash and bottom ash were encountered within each of the borings. Coefficients of permeability within the ash layers ranged from 7×10^{-6} cm/sec to 1×10^{-3} cm/sec; the higher coefficient of permeability was measured within a saturated ash zone in the fill by installing a temporary well and performing a recovery head field permeability test. During this test, approximately 50 gallons of water were evacuated without significantly affecting the stabilized water level in the well.

The stabilized waste, when compacted to approximately 95 percent of the standard Proctor maximum dry density and aged for 28 days, has a coefficient of permeability equal to approximately 1×10^{-6} cm/sec. At lower densities, however, the coefficient of permeability of the stabilized waste can be as high as 1×10^{-5} cm/sec after 28 days as measured in the field at the Elrama landfill and in the laboratory.

The effects of the pozzolanic reaction on the apparent dry density of the stabilized waste are important when analyzing the permeability data. A sample of stabilized waste remolded to a dry density of 1040 kg/m^3 (65 lb/ft^3) (Elrama project specifications) has an apparent dry density of 1170 kg/m^3 (73 lb/ft^3) after 28 days. This increase in apparent dry density is due to the free water in the sample, which is present during placement, being incorporated in the pozzolanic (cementing) reaction. Samples tested in this program to measure moisture content were dried at 60°C so as to remove only free water and not the moisture of hydration (refer to Appendix E). Therefore, the actual dry density of the stabilized waste during placement was approximately 10 percent less than the analyzed value (after aging). Accordingly, it appears that the waste was not compacted to the desired index throughout, thus explaining the measured range in the coefficient of permeability of the stabilized waste.

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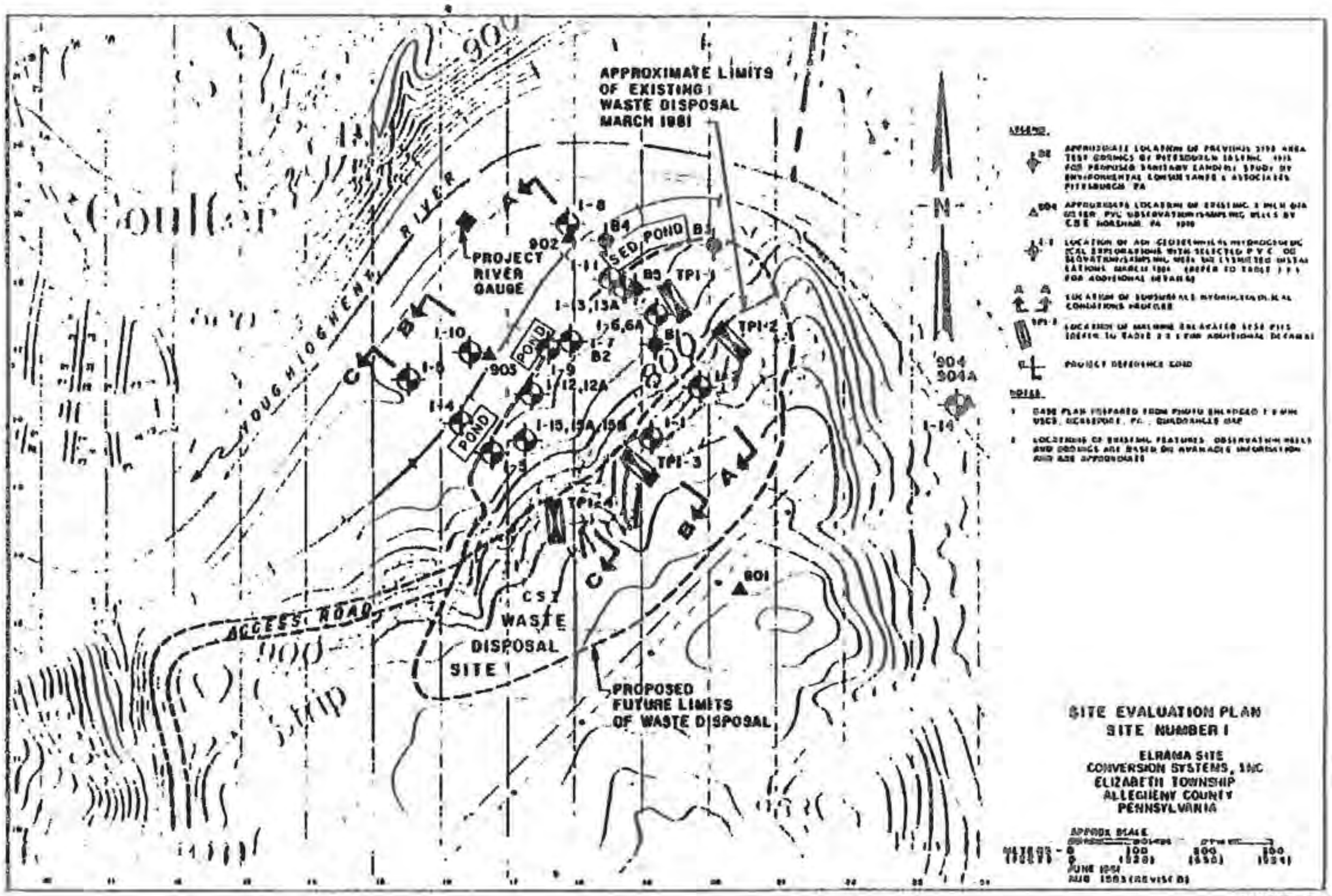


FIGURE 5 12

TABLE 5.0

SITE: ELRAMA PLANT
ALLEGHENY COUNTY, PENNSYLVANIA
NO. BORINGS ON SITE: 15

SITE DEVELOPMENT SUMMARY

DATES: February 22, 1981
March 31, 1981
FILE NO. 453501

Boring #	1-1	1-2	1-3	1-4	1-5
Soils Classification [depth (m): class]	0-0.9: Fill 0.9-2.3: Poz-o-Tec Fill 2.3-4.9: Strip Spoil Fill 4.9-5.5: Residual Soil 5.5-5.8: Rock	0-0.8: Strip Spoil Fill 0.8-2.6: Poz-o-Tec Fill 2.6-6.9: Fill 6.9-7.3: Decomposed Rock	0-0.5: Fill 0.5-1.4: Poz-o-Tec 1.4-4.5: Strip Spoil 4.5-7.3: Alluvial Soils	0-0.2: Topsoil 0.2: Fill 6.0-47.0: Alluvium 47.0-55.0: Decomposed Rock	0-14.2: Alluvium 14.2-14.4: Decomposed Rock
Number of Samples Obtained	6	6	9	12	11
Field Permeability Test [depth (m); results (m/sec)]	No Test	(FHT-1) 5.4-7.0; 4.86×10^{-6}	Well Bailed with immediate recharge	(RHT-1) 9.3-12.4; 3.32×10^{-5}	(RHT-1) 7.3-10.4; 9.398×10^{-6}
Well Installation	No Well	0.020" slot; 2.0 ID; 5.4'-7.0'	0.020" slot; 2.0 ID; 2.8'-4.4'	0.020" slot; 2.0 ID; 9.3'-12.4'	0.020" slot; 2.0 ID; 7.3'-10.4'
Boring #	1-6	1-6A	1-7	1-8	1-9
Soils Classification [depth (m): class]	0-24.7: Poz-o-Tec Fill 24.7-35.1: Alluvium 35.1-35.2: Weathered Rock	0-16.8: Poz-o-Tec Fill	0-5.3: Poz-o-Tec Fill 5.3-6.2: Alluvium	0-11.3: Alluvium 11.3-13.4: Residual Soils 13.4-14.2: Rock	0-0.8: Fill 0.8-13.3: Alluvium 13.3-15.1: Rock
Number of Samples Obtained	18	8	4	10	19
Field Permeability Tests [depth (m); results (m/sec)]	No Test	No Test	Lysimeter Hole	(RHT-1) 9.5-12.6; 5.12×10^{-7}	(RHT-1) 6.9-10.0; 1.25×10^{-6} (m/sec)
Well Installation	No Well	0.020" slot; 2.0 ID; 14.3-16.8	Pourous Cup; 1 15/16 ID; 4.7-5.3	0.020" slot; 2.0 ID; 9.4-12.6	0.020" slot; 2.0 ID; 6.9-10.0

* Chem sample; RHT - Rising Head Test; FHT - Falling Head Test

(Continued)

TABLE 5.8

SITE: ELRAMA PLANT

SITE DEVELOPMENT SUMMARY

NO. BORINGS THIS SITE: 15

Boring #	1-10	1-11	1-12, 12A	1-13, 13A	1-14
	*	*	*	*	*
Soils Classification [depth (m): class]	0-10.1: Alluvium 10.1-13.9: Residual Soil 13.9-14.5: Rock	0-1.2: Fill 1.2-11.7: Alluvium 11.7-12.8: Residual Soils 12.8-14.8: Rock	0-0.5: Fill 0.5-6.1: Poz-o-Tec 6.1-18.6: Alluvial	0-0.5: Fill 0.5-6.1: Poz-o-Tec 6.1-15.2: Alluvium 15.2-16.6: Residual Soils	0-9.8: Alluvium 9.8-10.7: Decomposed Rock
Number of Samples Obtained	10	10	14	11	8
Field Permeability Tests [depth (m); results (m/sec)]	RHT-1 8.3-11.1 K= 1.87×10^{-7} m/sec	Test Not In Saturated Zone	RHT-1 15.0-18.1 K= 7.19×10^{-7} m/sec	RHT-1 2.4-5.5 K= 8.79×10^{-8} m/sec	RHT-1 7.4-10.5 K= 3.43×10^{-6} m/sec
Well Installation [wellpoint type; diameter (in); location (m)]	0.020" slot; 2.0 ID; 8.3-11.3	0.020" slot; 2.0 ID; 7.8-10.9	0.020" slot; 2.0 ID; 5.9-18.1 (1-12A Lysimeter)	0.020" slot; 2.0" ID; 13.3-16.4 (1-13A Lysimeter)	0.020" slot; 2.0 ID; 7.4-10.5

Boring#	1-15, 15A, 15B
Soils Classification [depth (m): class]	0-14.2: Poz-o-Tec Fill 14.2-24.1: Strip Spoil Fill 24.1-27.7: Alluvium 27.7-30.3: Weathered Rock
Number of Samples Obtained	21
Field Permeability Tests [depth (m); results (m/sec)]	Tests Not In Saturated Zone
Well Installation [wellpoint type; diameter (in); location (m)]	1-15: 1.0 ID; 2.80-29.4 1-15A: 0.020" slot; 2.0 ID; 18.0-19.5 1-15B: 0.020" slot; 2.0 ID; 9.9-11.4

* Chem sample; RHT = Rising Head Test

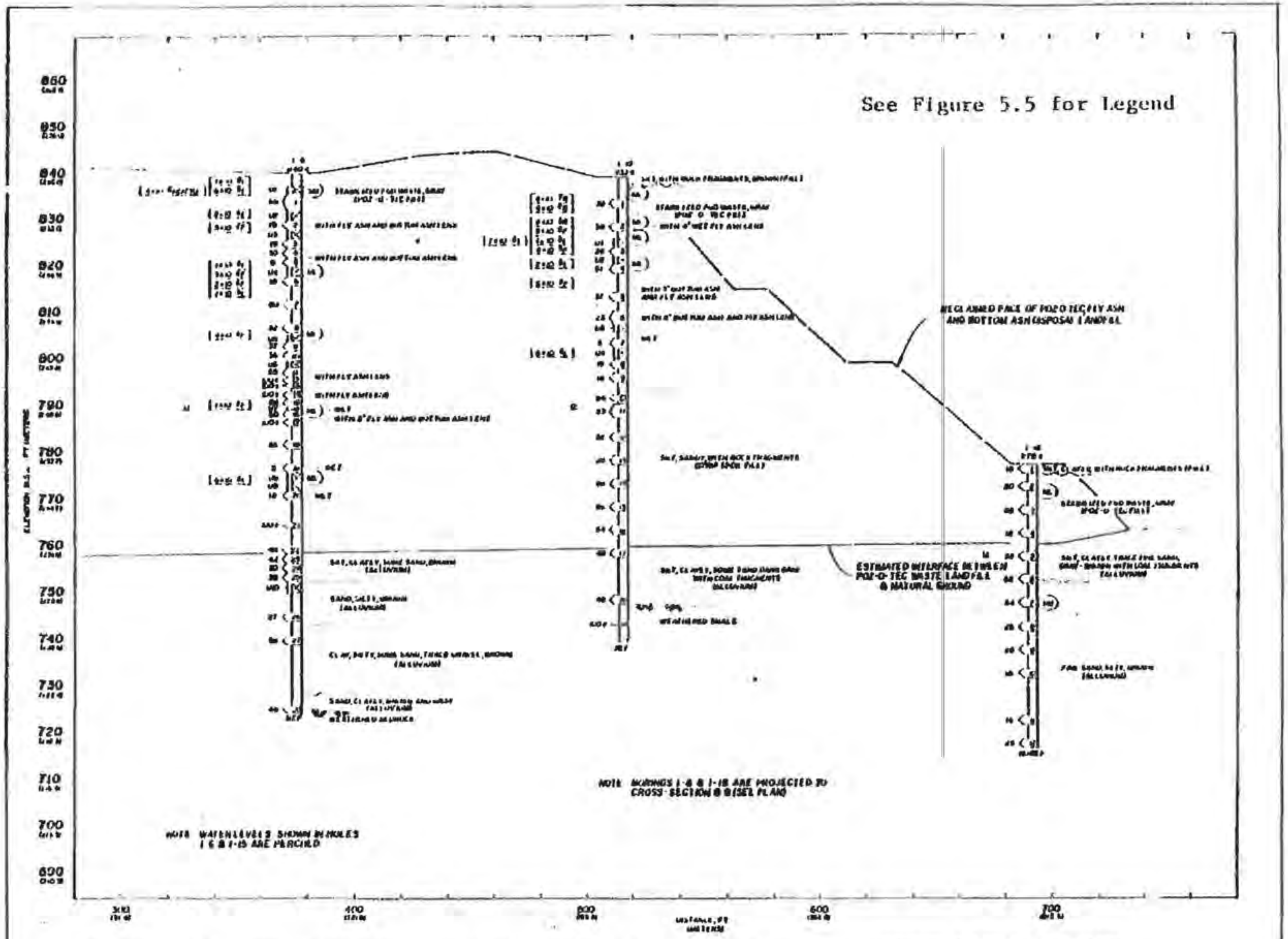


FIGURE 5.13 GEOTECHNICAL EVALUATION RESULTS, ELRAMA PLANT, DUQUESNE LIGHT COMPANY ALLEGHENY COUNTY, PENNSYLVANIA

A detailed compilation of physical testing results is provided in Appendix E. Table 5.9 provides a summary of selected physical testing results for the Elrama Plant.

5.3.4 Chemical Testing Results

The site monitoring infrastructure was developed in April 1981. At that time, samples of wastes and soils were obtained for physical and chemical testing; surface waters and groundwaters were sampled for chemical testing. Subsequent water sampling occurred in April, May, and November 1981. Precipitation and water levels were extremely high at the times of site development and sampling in the spring, but were typical of the dry season for the November visit.

Selected chemical sampling and analysis results from the Elrama Plant are summarized in Table 5.10. A comparison of analytical results to EPA drinking water standards is also provided in the table. The results of soil attenuation testing are presented in Table 5.11. A more detailed presentation of chemical testing results is provided in Appendix F.

5.3.5 Environmental Assessment

5.3.5.1 Approach for the Elrama Plant--
The environmental assessment of the Elrama site results focused on the following two issues:

1) effects of stabilized FGC waste landfill leachate and runoff on downgradient groundwater quality (Particular effort was made to attempt to distinguish the effects of interactions between the alkaline waste leachate and the background acidic mine drainage.); and

2) effects of landfill/runnoff pond leachate on water quality in the Youghiogheny River.

The steps employed in the environmental assessment at this site were as follows:

- A site subsurface geological profile and water balance were prepared. The latter was updated (annualized) as additional field data became available.

- The values and trends in the chemical sampling and analysis results for the various areas of the site considered ir this program were compared with the results of previous sampling by CSI and with the relevant EPA criteria for groundwater protection. In some cases, regression analyses were used to attempt to discriminate the apparent relative influence of mine drainage versus the waste landfill on groundwater quality at the several well locations.

- The water balance, geological profile and chemical and physical testing results were considered together to structure and evaluate

TABLE 5.9

SELECTED PHYSICAL TESTING RESULTS

ELRAMA PLANT

Maximum Dry Density (kg/m^3; lb/ft^3)	1170; 72.7
Optimum Moisture Content at 60°C (Weight Percent)	32.1
Permeability (cm/sec)	6×10^{-7} - 2×10^{-4}
Specific Gravity	2.30 - 2.48
Grain Size Distribution (Weight Percent)	
• > 74 µm	8 - 73
• 2 - 74 µm	15 - 66
• < 2 µm	0 - 34
Moisture Content (Weight Percent)	4.5 to Saturated

Source: Arthur D. Little, Inc., and Bowser-Morner Testing Laboratories, Inc.

TABLE 5.10

SELECTED DATA FOR REPRESENTATIVE SAMPLING LOCATIONS AT THE
FLRAMA PLANT

Locations	SO_4[a]	Ca	Cl[a]	pH[a] (Units)	F[a]	B[a]	Fe[a]	Na	Mn[a]	Zn[a]	As(µg/ℓ)[a]
	CONCENTRATION (mg/ℓ except where noted)										
Well 1-2 (Mine Spoil with overlying FGD waste)	1130-2330	319-659	62-27	5.1-6.6	<0.1 0.7	0.09-0.83	16.3 171	17-19	26.8-14	0.05 17	1.1 16.2
Well 1-14 (Upgradient, river edge)	339-202	87.3-109	4-2.5	4.5-5.0	<0.1 0.55	0.015-0.027	<0.01-0.55	6	2.1-2.7	0.18-0.1	0.4 8.6
Lysimeter 1-12A (one of several immediately under FGD waste)	1239-1945	892-1060	403-511	–	<0.1-3.1	1.23-2.68	0.04-0.07	94-113	0.69 2.19	<0.05 0.07	162-266
Seep 1-22 (One of several off FGD landfill)	1400-1026	538-434	180-154	5.7-7.5	<0.1-0.52	0.312 0.454	4.26 29	52-55	17.9-20.7	<0.05 .12	1.6
Downgradient Well 1-13 (One of several above landfill runoff)	346-463	132-178	22-84	6.3 7.9	<0.1-3	0.021-0.261	<0.01 0.02	7 8	2.00-4.38	<0.05	0.54
Downgradient Well 1-8 (Below ponds and one of several)	65-120	62.5-106	17-36	6-5.3	<0.1-0.3	0.016-0.035	0.01-0.11	5-9	0.1-1.09	<0.05 0.06	
Pond #1 Surface Water 1-20	740-998	310-611	33-14	8.6-9.1	<0.1-1.7	0.216-0.312	0.01-0.15	8-11	<.01	<0.05	2.7
Downgradient Well 1-10	83-147	80-107	4.1-5	6.8-6.9	<0.3	0.005	<0.01-0.01	2-5	1.4-1.8	<0.05	<.15
River water upstream of fill, 1-16	56-69	20.2-3	10-8	6-6.2	<0.3	0.011-0.021	0.02-0.05	12-17	0.12-0.21	<0.05	0.21
River water downstream of fill, 1-17	56-88	19.6-30	8.7-35	8.4-6.2	<0.3	0.009 0.027	<0.01-0.05	10-17	0.15-0.37	<0.05	0.3
EP Extract	–	–	–	–		–	–	–	–	–	6-65

[a]EPA Proposed Secondary Drinking Water Standards are:

SO_4 = 250 mg/ℓ, Cl = 250 mg/ℓ, pH = 6.0-9.0, Fe = .3 mg/ℓ, Mn = .05 mg/ℓ, Zn = 5 mg/ℓ, F = 1.4-2.4 mg/ℓ (depending on temperature)

EPA Interim Primary Drinking Water Standard for arsenic = .05 mg/ℓ;

Agricultural use criterion for boron = .75 mg/ℓ.

TABLE 5.11

SELECTED RESULTS OF SOIL ATTENUATION STUDIES
ELRAMA SITE[a]

Element	Solution Concentration (ppb)	Soil Capacity (μg/gm)	Soil Capacity ÷ Solution Concentration
Arsenic	0.7-275	1.1-252	1571-916
	0.4-483	1-44	2500-91
Selenium	0.35-95	0.25-3	714-32
	2.5-131	0.27-7.7	108-58
Cadmium	60-150	0.19-12.0	3-80
Chromium	170	0.06	< 0.35
	70-220	0.40-0.54	5.7-2.4
Copper	14-100	0.77-300	55-3000
	10-11	1.58-0.15	158-13

[a]Soil sample came from boring 1-14, background in alluvial flood plain.

hypotheses concerning the nature of leachate and runoff generation and movement at the site. The importance of leachate generation from the runoff holding ponds was given separate additional emphasis in this step.

- The results of soil attenuation tests were evaluated along with the water balance, geological profiles, and chemical and physical testing data to assess potential long-term downgradient concentrations of various chemicals at the site.

- The broader implications of the Elrama site results were considered in terms of their applicability to similar combinations of waste types, disposal methods, and environmental settings. This step can be considered particularly important because the number of sites practicing landfill disposal of fixated FGC wastes is increasing rapidly, and the number of disposal sites in Appalachian acid rain drainage settings is sizeable.

5.3.5.2 Geological Profiles and Water Balance--

Figure 5.14 illustrates the subsurface geological profiles for several areas of the Elrama waste disposal site as delineated above in Figure 5.12. These profiles were prepared on the basis of the site development results for this program along with the available site background information.

Water Balance--The estimated, seasonally adjusted water balance for the Elrama site is summarized in Table 5.12 and illustrated (from preliminary calculations) in Figure 5.15.

5.3.5.3 Evaluation of Testing Results--

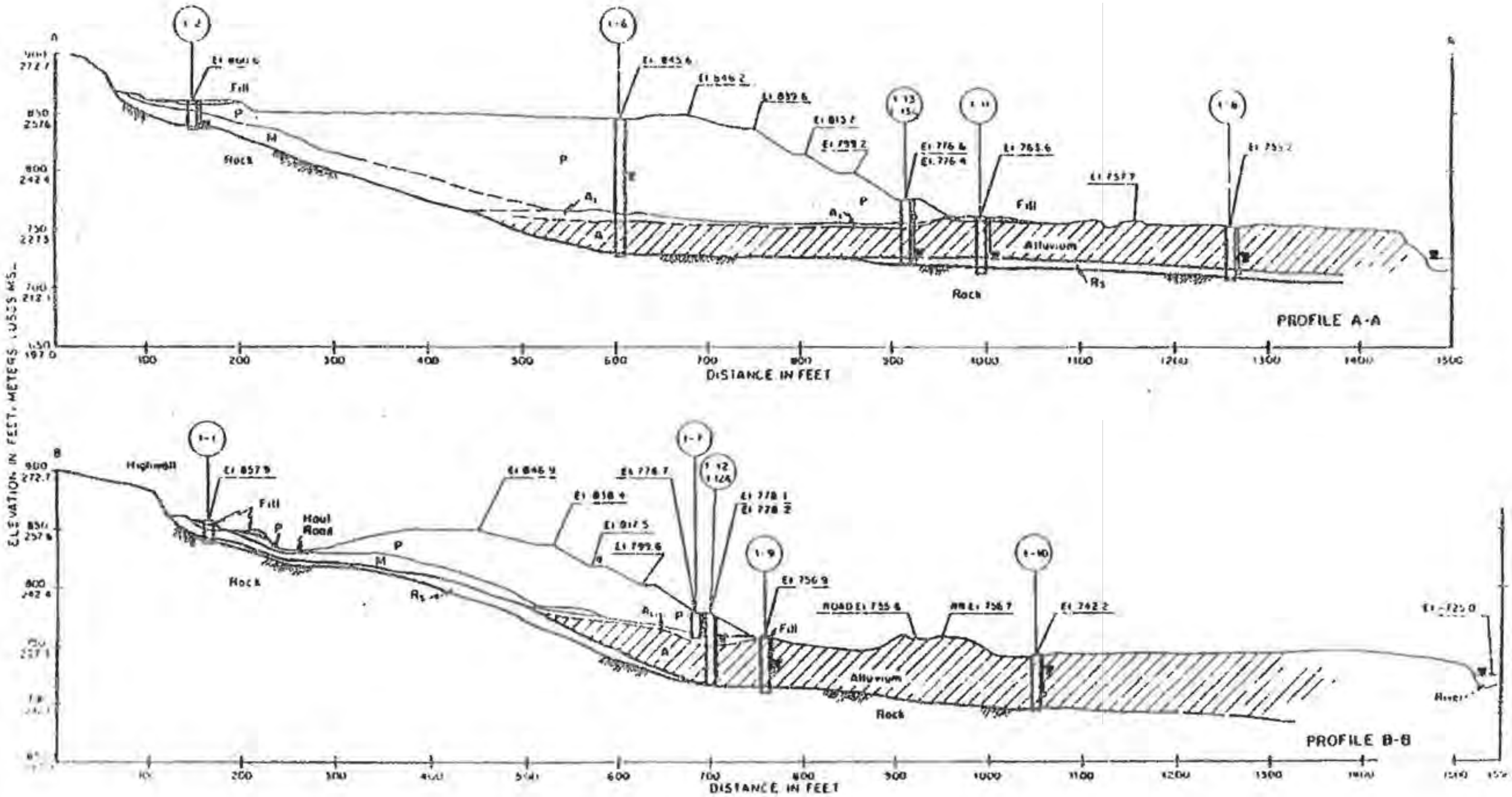
A summary of the chemical testing results evaluation for the solid wastes located at the Elrama landfill site follows:

- All three wastes occuring at this site, fixated (with lime and fly ash) FGD waste, bottom ash, and mine spoil, were chemically analyzed following acid digestion procedures. The results of these analyses indicated that calcium represented a good discriminator between the fixated waste and the other two wastes. The amount of calcium in each waste was: 9.45 to 17.8 percent in the fixated waste, 1.31 percent in bottom ash, and 0.28 percent in the mine spoil.

- Sulfate and aluminum concentrations are high in the mine spoil, as well as in the landfilled fixated FGD waste. However, the former is noticeably higher in the fixated waste.

- Calcium and arsenic were detected at significantly higher levels in the fixated FGD waste than in the other materials. Solids analysis also illustrated the high alkalinity of this waste as compared with acid mine spoil.

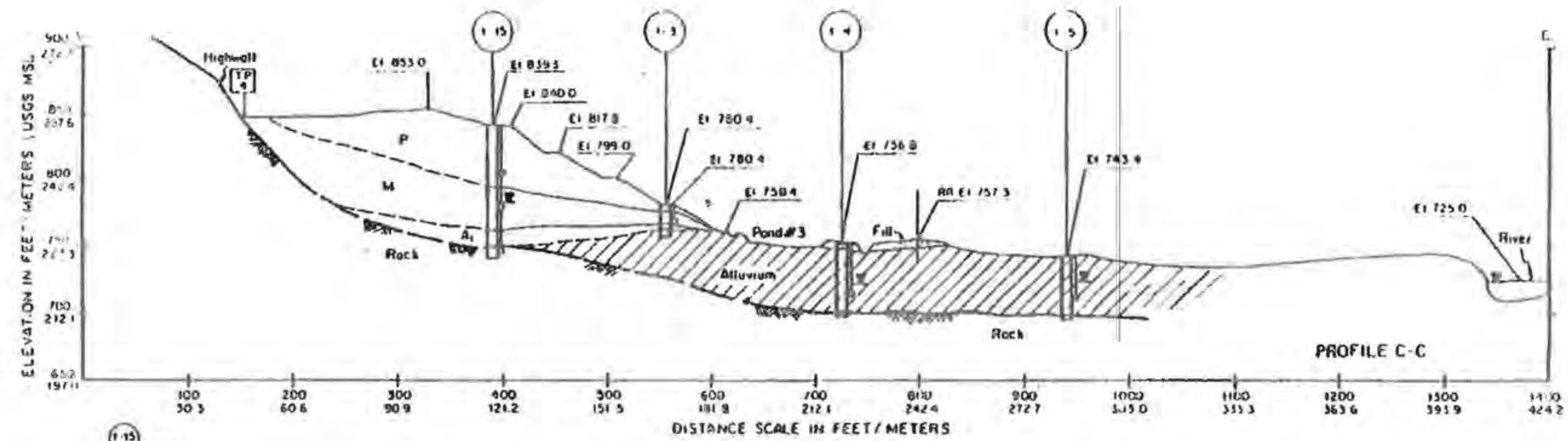
- Chloride levels were found to be only slightly higher in the fixated FGD waste than in the mine spoil.

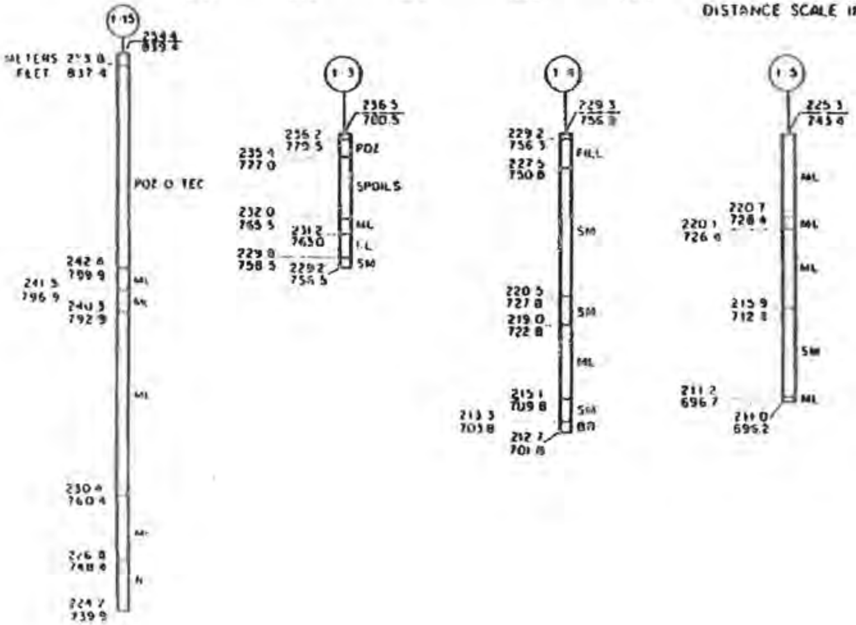


SUBSURFACE GEOLOGICAL PROFILES – ELRAMA SITE
DUQUESNE LIGHT COMPANY, ALLEGHENY COUNTY, PA.

FIGURE 5.14

(continued)





Fill Loose to very compact gray and brown coarse to fine sand and gravel with varying amounts of silt, clay and rock fragments

POZ O TEC Loose to very compact gray silt to fine sandy silt with trace amounts of medium sand

Mine Spoils Medium compact to very compact yellow brown silty coarse to fine sand with varying amounts of clay, gravel, and rock fragments.

Residual Soils Compact to very compact brown silty and clayey sands with trace amounts of gravel

Alluvial Soils Loose (soft) to compact (stiff) to very stiff brown and yellow silty fine sands with varying amounts of clay and medium to coarse sand with trace amounts fine gravel.

Rock Compact to very compact gray and brown sandstone and shale varying from fresh to moderately weathered

SUBSURFACE GEOLOGICAL PROFILES - ELRAMA SITE
DUQUESNE LIGHT COMPANY, ALLEGHENY COUNTY, PA.

FIGURE 5.14

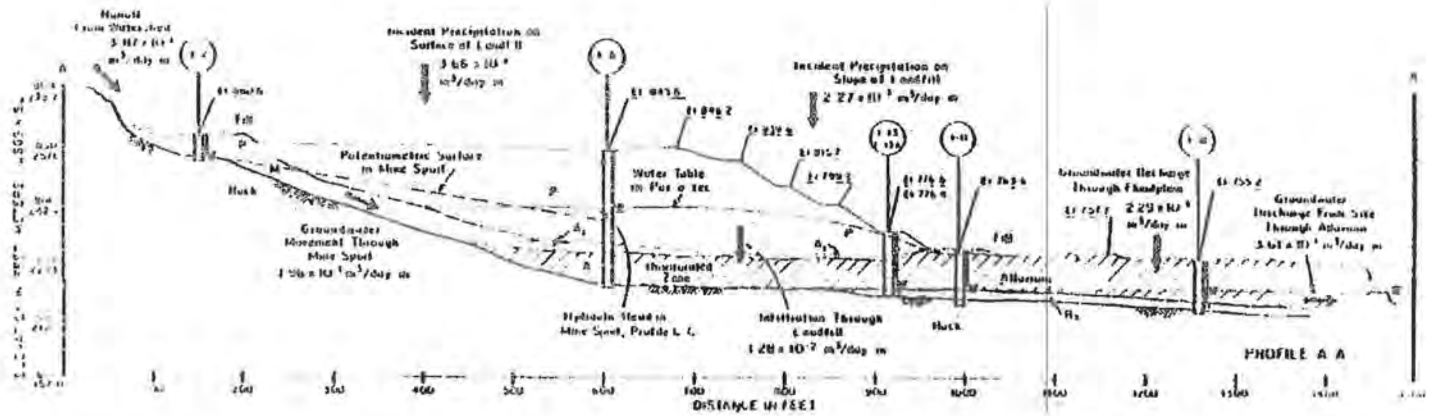
TABLE 5.12

ESTIMATED SEASONALLY ADJUSTED WATER BALANCE

ELRAMA SITE

	WATER FLOW (m^3/day - m width)	
	November-April	May-October
Groundwater discharge through alluvium	0.364	0.326
Infiltration through landfill	0.000	0.020
Groundwater movement through mine spoil	0.144	0.196
Groundwater recharge in flood plain	0.220	0.110
Incident precipitation on landfill slope	0.204	0.238
Incident precipitation on landfill surface	0.329	0.384
Runoff from watershed	0.560	0.182
Percent runoff to groundwater	16	38

Source: Arthur D. Little, Inc. Estimates



Notes

1 Flows indicated on profile are based on available information and are approximate.

2 Groundwater elevations used to calculate hydraulic gradients are based on most recent available groundwater depth measurements.

3 Key provided on Figure 5.14

CHAMA PLANT WATER BALANCE

FIGURE 5.16

An evaluation of groundwater and surface water testing results led to the following observations:

- As summarized in Table 5.10, elevated concentrations of many constituents were observed in groundwater sampled at various locations.

- High pH (7.9 to 9.9) characterized groundwater samples directly associated with the alkaline fixated waste. Low pH (4.5 to 6), very likely the result of acid mine drainage in the area, characterized background and some downgradient groundwater samples. Near-neutral pH (6.9 to 7.5) was characteristic of a few downgradient samples (in which concentrations of all constituents were relatively low).

- Strong correlations between the concentrations of some consitutents and extremes in pH were observed. For example, some constituents (e.g., zinc, 0.18 to 0.80 mg/l) were significantly elevated only at sampling locations exhibiting low pH; some components (chloride, 200 to 570 mg/l, and sodium, 100 to 300 mg/l) were detected at high concentrations in groundwaters with high pH; other constituents (e.g., sulfate, 300 to 2300 mg/l) were measured at elevated levels in groundwaters with both low and high pH.

Comparison of the analytical results with EPA drinking water standards (see Table 5.10) indicated the following:

- Iron and manganese concentrations appear to be elevated at many locations. The iron concentration is especially high in groundwater samples affected by FGD-related wastes, while manganese levels seem highest in samples more affected by mine drainage. Nonetheless, even the least contaminated groundwater samples show levels of these constituents in exceedence of EPA drinking water standards. One may conclude that the concentrations of these constituents are characteristically high in groundwater in the area, and both mining and FGC wastes are likely contributing to incremental elevations.

- Elevations in levels of chloride ions, even in the waste source samples, remain sufficiently low to be of relatively little concern. Drinking water standards are exceeded only in the waste itself.

- Fluoride and arsenic concentration elevations appear restricted to isolated runoff diversion pond samples and groundwater samples closely related to the waste.

- Sulfate levels in groundwater exceed drinking water standards in many mine spoil and FGD waste-related locations.

Attenuation tests using various waste liquors and soils obtained from the Elrama site indicated that these soils generally had high-intermediate capacities to attenuate trace metals in comparison to the soils at the other five study sites (See Table 5.11 and Appendix F).

5.3.5.4 Cause and Effect Relationships--

Based on the hydrogeologic information collected and interpreted for the Elrama site, contaminants leached from the stabilized FGD waste may move in a number of directions:

1. laterally through the waste to seeps along the wall of the landfill, subsequently running off to surface collection ponds placed between the fill and the river;

2. downward through underlying mine spoil or natural alluvial deposits to the alluvial aquifer of the flood plain, thus mixing with mine spoil leachate; or

3. as surface runoff to the collection ponds, interacting with surficial mine spoil at peripheral locations on the edge of the landfill.

It has been estimated that the ponds represent an important source of water to the alluvial flood plain aquifer, although the actual recharge rate is uncertain. Hence, water-mobile waste constituents collected in the ponds would also be expected to eventually migrate into the alluvial aquifer.

There also appear to be isolated pockets of relatively cleaner groundwater that have thus far been free of the acid mine drainage influence. Groundwater samples obtained from wells 1-10 and 1-11 are examples. It appears that mine drainage has missed these areas, and it is too early for the leachate plume from the three year old landfill to have traveled to these wells.

River water will eventually contribute to leachate dilution, and it is important to note that river background concentrations of some key parameters are quite low. (The reader is referred to data from sampling points 1-16 and 1-17, Table 5.10). At the very least, operating as what is presumably a final sink for site waste constituents, the river would appear to be a significant diluting source.

Concentrations of some major FGD waste constituents (e.g., sulfates) appear generally elevated at this site prior to its use for utility waste disposal, as a result of acid mine drainage. This is illustrated by the concentration similarity evident in lysimeters and wells downgradient of the landfill and within groundwater downgradient of mine drainage.

Results also seem to indicate that the landfill and runoff collection ponds will eventually generate a secondary plume of constituents, many of them common in identity and concentration range to the mine drainage.

For some parameters (calcium and sulfates, especially), concentration increases were observed in many wells during the sampling period. Earlier samples represented the wet season, later samples were taken at a time of year experiencing relatively little rain. Concentration increases could be attributed to leachate plume migration or could result from less dilution of the leachate. The pattern of increase suggests that both are contributing factors since the effect observed is not uniform for all constituents in all wells. Leachate migration from the stabilized FGD waste appears to contribute to later wet and dry season concentration increases at well 1-2, above which waste was placed early in the study period. Reduced dilution in the dry season appears a reasonable explanation for concentration changes at most of the wells.

Because of runoff transport, contaminants are expected to migrate to the downgradient alluvium and eventually to the river relatively quickly by the runoff and seepage directed to the ponds and subsequent recharge to the alluvium. The samples taken from the ponds appear to have been more strongly influenced by fixated waste-related contaminants than any downgradient well samples. Chloride, boron, calcium and pH appear to be relatively good tracers of stabilized FGD waste-related contamination.

The trends in contaminant concentrations over the sampling period indicate that groundwaters at several downgradient locations are only beginning to be affected by the landfill. The effects are expected to increase over time. As a result of significant complexity and uncertainty in the geohydrologic setting, travel times from the landfill to downgradient well locations are quite uncertain, but appear to range from one to five years for near downgradient locations and from five to ten years for far downgradient locations. Travel time from the runoff collection ponds to far downgradient locations are in the one to five year range. Thus, it is not surprising that three years after the development of the landfill, concentrations of landfill-related constituents began to exhibit a rising trend.

Table 5.13 shows estimates of the ranges of steady-state concentrations that may prevail in future at the Elrama site. Even in the future, there is expected to be little basis for qualitative distinction between the groundwater affected by the fixated FGD waste and mine drainage at the site.

5.3.5.5 Environmental Effects Implications--

In this case, the landfill is not the likely cause of continuing groundwater exceedence of the sulfate drinking water standard. However, the landfill is, and will continue to be, a contamination source of secondary importance to the prevalent acid mine drainage at the site, which has caused exceedance of potentially applicable water use standards. Additionally, analyses indicate that some constituents in landfill leachate (e.g., calcium) could represent a traceable, but not environmentally significant, influence in projected steady state downgradient groundwater concentrations. In the case of some major species (i.e., calcium and sodium) such influence will be incrementally small in magnitude in an already contaminated situation and would be expected to have no measurable adverse environmental effects in this setting. Major dissolved species appear not to be attenuated by physical or chemical factors at the site.

The findings at the Elrama site support all the conclusions presented in Section 5.1 and have the following broad implications for similar disposal operations:

TABLE 5.13

EXPECTED RANGE OF STEADY STATE GROUNDWATER CHEMICAL CONCENTRATIONS – ELRAMA PLANT

	CONCENTRATION RANGES (ppm)		
	Between Landfill and Ponds	In Pond	Between Ponds and River
Cl	8-84	14-114	8-114
SO_4	460-1900	500-1170	460-1900
Al	<0.01-0.7	0.06-0.35	<0.01-0.7
B	0.02-0.41	0.21-0.31	0.02-0.411
Ba	<0.005-0.045	<0.005-0.026	<0.005-0.045
Ca	180-530	200-410	180-530
Cd	<0.01-0.04	<0.01-0.02	<0.01-0.04
K	6-8	1-50	1-50
Mg	35-60	12-96	12-96
Mn	0.5-3.5	<0.01-1.4	<0.01-3.5
Na	7-18	7-40	7-40
Ni	<0.05-0.19	<0.05-0.09	<0.05-0.19
Pb	<0.05	<0.05	<0.05
V	<0.005	<0.005	<0.005
Zn	0.05-0.12	<0.05-0.1	<0.05-0.12
As	0.0004-0.0015	0.0027	0.0004-0.0027
Se	<0.00026-0.00046	0.006	<0.00026-0.006
pH(units)	6.1-7.9	7.3-9.1	6.1-9.1
Conductivity (umhos/cm)	900-2100	975-2600	900-2600

1. Disposal of processed (and other) FGC wastes in acid-mine drainage settings is facilitated by the opportunity for waste leachates to admix with groundwater already contaminated by many of the same major and minor species that characterize the FGC waste leachate. In such circumstances, the presence of FGC waste leachate may be detectable using tracers such as calcium, but it would be expected to have little, if any, incremental impact potential for water quality.

2. Concentration elevations of waste-related versus more typical background species are present in the Elrama waste. This suggests that disposal of similarly processed FGC wastes in areas of modest and high precipitation (i.e., both coasts and the Eastern half of the United States) and in proximity to drinking water supplies can be best accomplished where surface water admixing is significant or where surrounding soil can physically retard leachate and chemically attenuate some leachate constituents. Notably, leachate concentrations of sulfates and chlorides, which are among the major species not likely subject to significant chemical attenuation, would be expected to be two to ten times the secondary drinking water standards. Among the trace metal species, arsenic in water collected from the waste deposit was repeatedly recorded at levels three to five times the EPA Interim Primary Drinking Water Standards at one isolated location under the waste, reinforcing the possibility that similar wastes at other sites can leach arsenic at levels that would be of concern if arsenic was not attenuated by surrounding soils or diluted before reaching drinking water.

5.3.6 Engineering Cost Assessment

5.3.6.1 Engineering Assessment--

The Elrama Plant is a baseload facility with four pulverized coal-fired units providing a total nameplate generating capacity of 510 MW. Two 100 MW boilers, Units 1 and 2, were commissioned in 1952 and 1953, respectively. Unit 3, a 125 MW nameplate generating capacity boiler, was added during the following year. Unit 4, a 185 MW nameplate generating capacity boiler, was started up in 1960. In 1978, the average annual load factor for these units was 49.7 percent.

Air Pollution Control--Mechanical collectors and cold-side electrostatic precipitators service each of the four units. In October 1975 this plant was retrofitted with a flue gas desulfurization (FGD) system consisting of five venturi-type scrubbers. The scrubbers simultaneously remove excess particulates and sulfur oxide. A scrubber effluent, which is five percent solids (of which approximately 25 percent by volume of the solid material is fly ash), results. The high fly ash content is due to the inefficiency of the particulate removal system.

Coal Consumption--Bituminous coal used by the Elrama Plant has been obtained from Pennsylvania and West Virginia. Annual coal consumption during 1977 and 1978 were 1.26 and 1.00 million metric tons/yr (1.39 and 1.11 million tons yr), respectively. The annual average sulfur contents (dry basis) for these years ranged from 2.1 to 2.2 weight percent. Heat contents were reported in the range of 27.5 to 28.4 million joules/kg (11,815 to 12,015 Btu/lb).

Waste and Water Management--Fly ash and lime are employed at the Elrama Plant to fixate the FGD waste using the CSI fixation process. Based on the reported coal consumption in 1978, the Elrama Power Plant would have generated approximately 52,000 metric tons (57,300) of bottom ash (dry basis) and 378,000 metric tons (417,000 tons) of fixated FGD wastes.

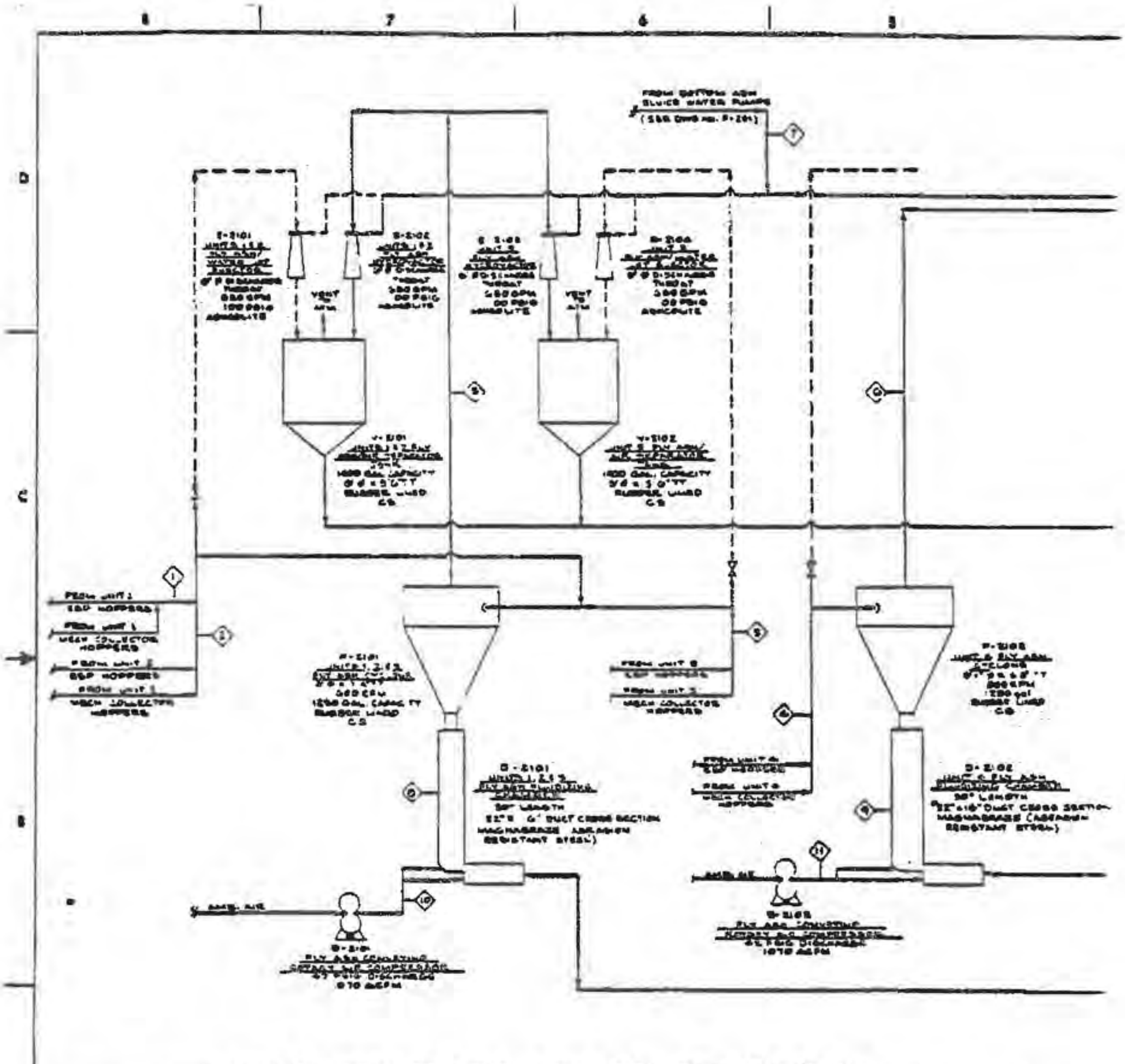
Fly ash is conveyed by a vacuum pneumatic system to a silo for storage. The fly ash can be alternatively conveyed to a hydro-ejector where it is slurried in water and subsequently sluiced to an interim disposal pond. Process flow diagram F-200, Figure 5.16, provides more detailed process information regarding the fly ash handling and storage system.

Bottom ash is collected in the boiler hoppers and transported in trenches to a collection sump; it is then sluiced 0.2 km (0.1 mile) to interim dewatering ponds. Two ponds are used alternately, with one receiving wastes during the period while the second is being dredged. This dredging cycle occurs quarterly. The dredged waste is removed to a landfill for ultimate disposal. Each pond has a 8,100 m^2 (2 acre) surface area and is about 7.2 m (23.5 ft) deep. Both ponds are lined with 0.9 m (3 ft) of clay. Process flow diagram F-201, Figure 5.17, depicts the bottom ash handling system.

Fly ash and FGD waste collected in the scrubber are directed to either of two thickeners. A surge tank is provided to hold the thickener effluent, which is 15 to 45 percent solids, prior to CSI fixation. CSI uses a proprietary process for FGD waste fixation. Thickened FGD waste is vacuum filtered to produce a cake which is approximately 55 percent solids. Fly ash and lime are combined with the filter cake in a pug mill. A material with a solids content in the 60 to 70 percent range is conveyed from the pug mill to a concrete stacker pad (for curing) from which it is then loaded into trucks and transported to a landfill for disposal. Process flow diagram F-202, Figure 5.18, illustrates the CSI FGD waste fixation process.

Trucks owned by subcontractors are employed to haul stabilized FGC wastes and coal ash dredged from the interim ponds to the landfill.

Disposal Operation--Fixated FGC wastes and dredged bottom ash are disposed in a landfill located in Allegheny County, 19 km (12 miles) east of the plant site. This landfill is owned by the Municipal Industrial Company, a subcontractor to CSI. The landfill has a design life of eight years. The active landfill has an 89,000 m^2 (22 acre) surface area and a maximum depth of 37 m (120 ft). Approximately 258,000 m^2 (66 acres) of the entire 2.4 million m^2 (600 acre) site are presently under permit for the utility plant disposal operation. Part of the site was surface mined in the past; deep mining has also occurred in the surrounding area.



DESIGN CONDITIONS - TOTAL STREAM FLOW PER NORMAL 24 HOUR DAY

DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
K TONS FLY ASH/DAY	0.12	0.12	0.16	0.22	—	—	—	0.84	0.22	—	—	0.84	0.22	—	—	0.01	—	—	0.01	—
K TONS WATER/DAY	—	—	—	—	—	—	12.9	—	—	—	—	—	—	6.0	7.9	—	0.09	—	0.09	N/A
K TONS AIR/DAY	—	—	—	—	N/A	N/A	—	0.05	0.05	0.20	0.20	0.23	0.23	—	—	0.30	—	0.30	—	—
MGD	—	—	—	—	—	—	3.1	—	—	—	—	—	—	1.2	1.9	—	0.02	—	0.02	N/A
KSCFM	—	—	—	—	N/A	N/A	—	0.5	0.5	4.1	4.1	4.6	4.6	—	—	4.2	—	4.2	—	—

N/A = INFORMATION NOT AVAILABLE

FIGURE 5.16

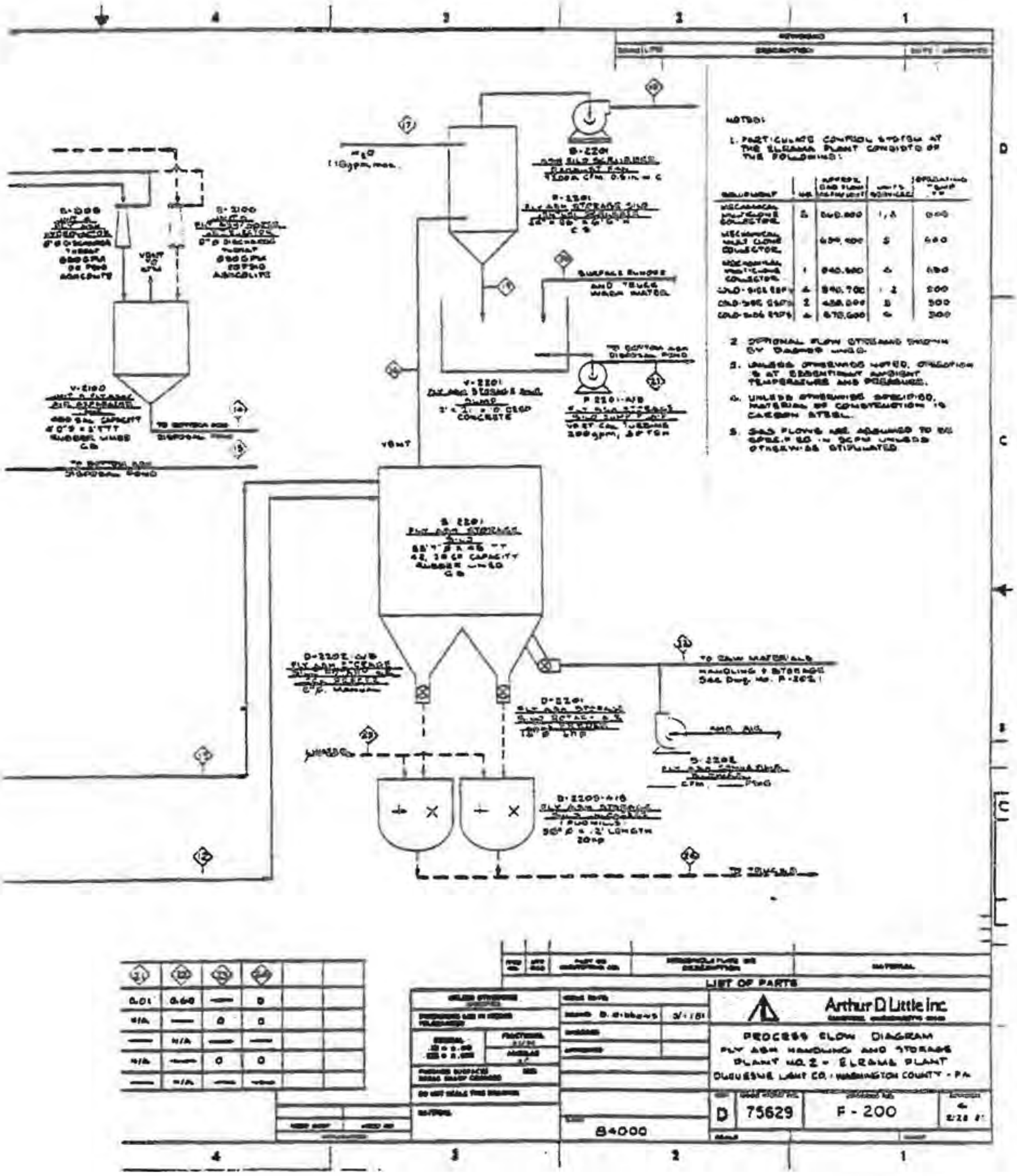
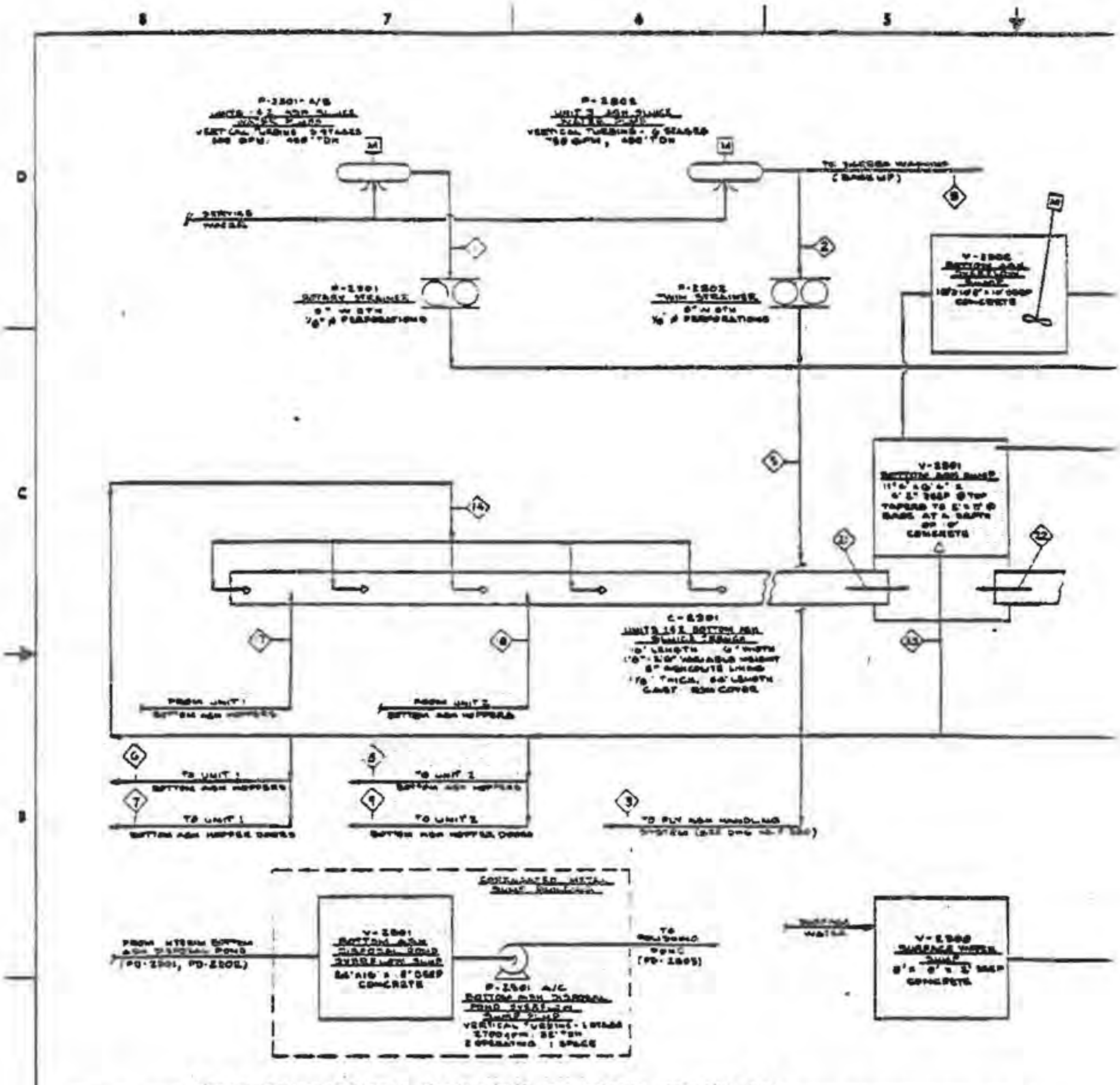

NOTES:
Arthur D Little inc
PROCESS FLOW DIAGRAM
FLY ASH HANDLING AND STORAGE
PLANT NO. 2 - ELRAMA PLANT
DUQUESNE LIGHT CO. - WASHINGTON COUNTY - PA.
75629
F - 200
84000

FIGURE 5.1c

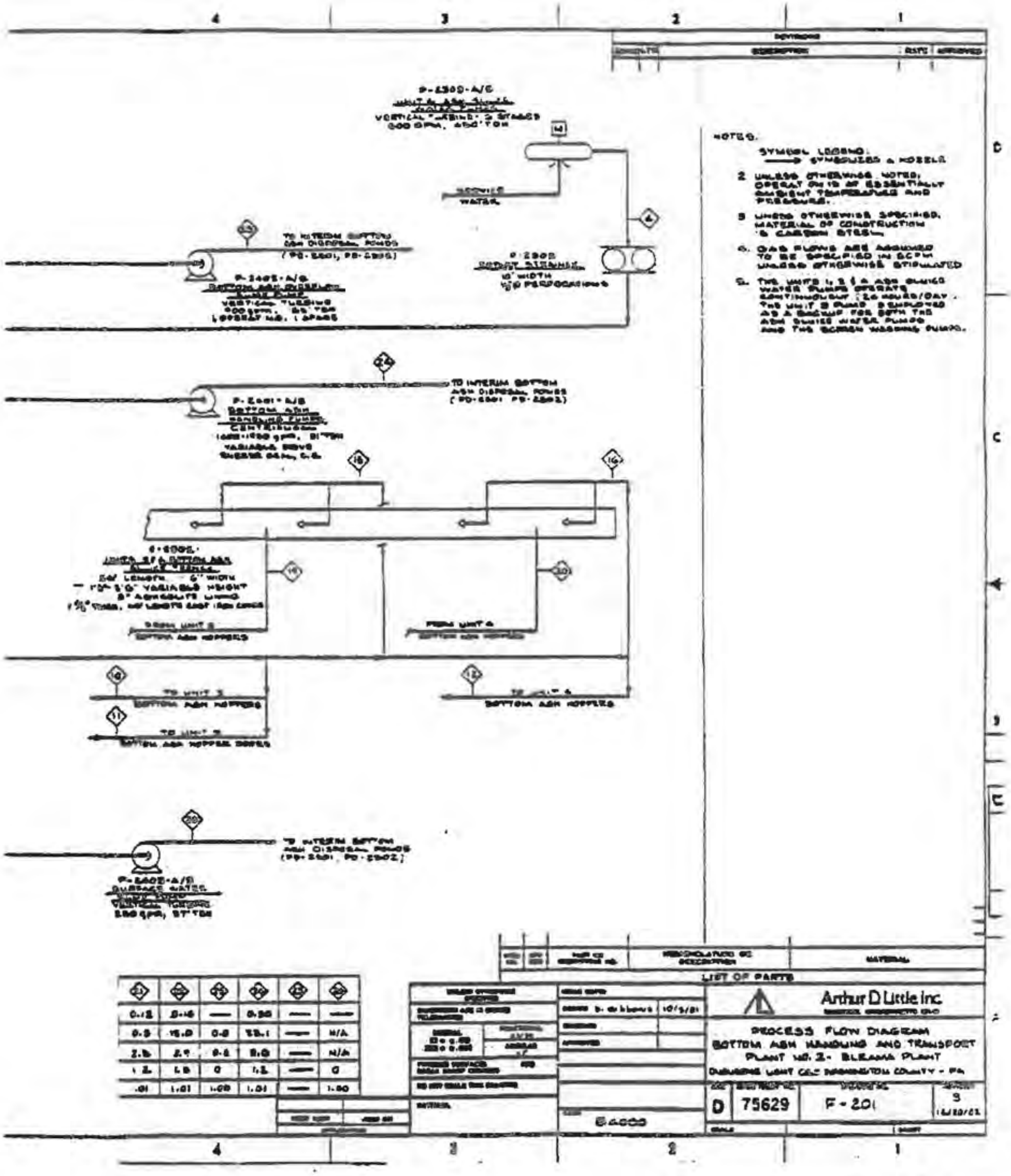


DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR OPERATING DAY

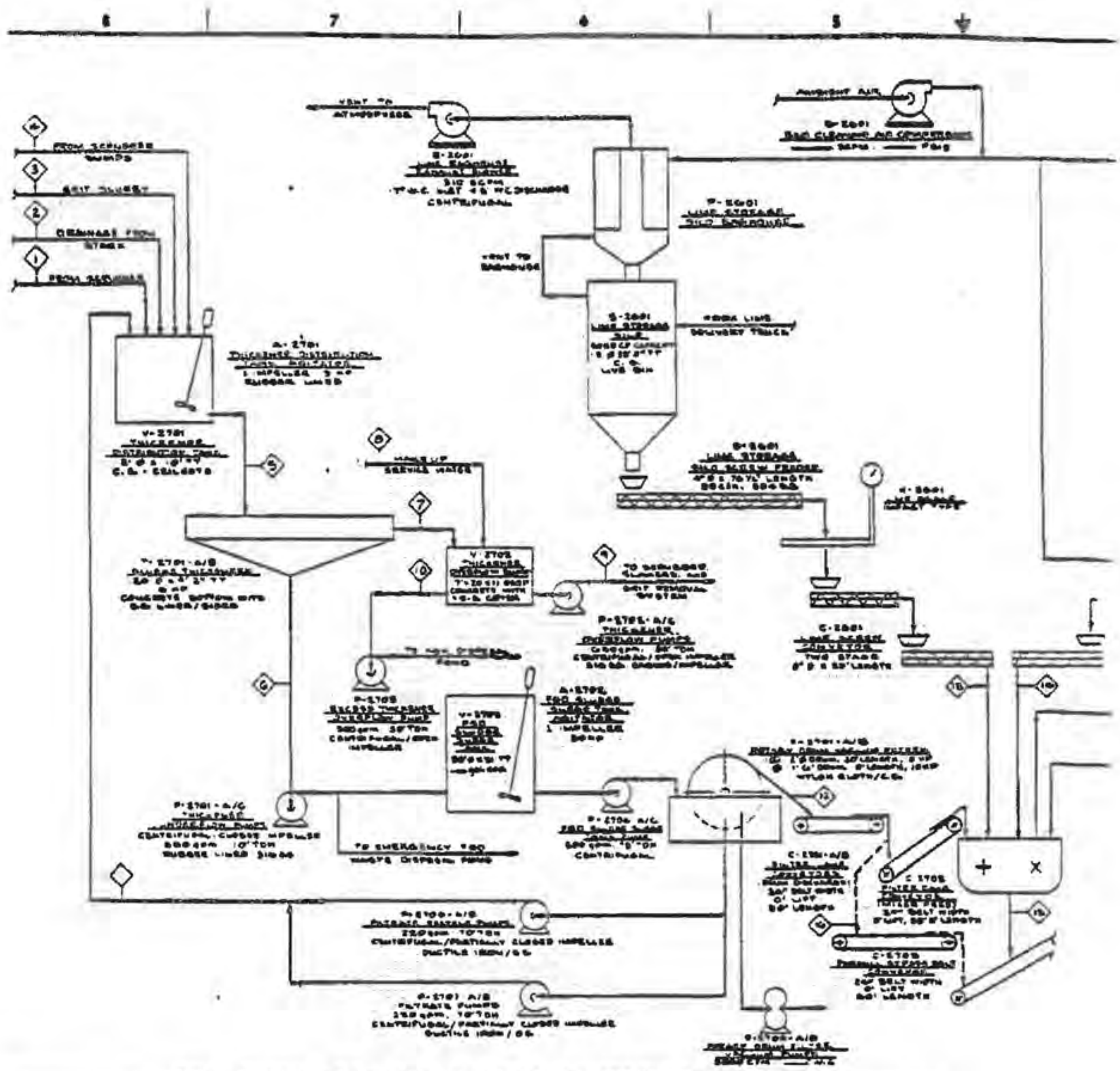
DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
K TONS ASH/DAY	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.06	0.08	0.07	0.1
K TONS WATER/DAY	18.0	0	0	6.6	56.0	3.0	1.3	2.0	1.6	3.0	.9	3.6	2.1	1.8	1.7	3.0	4.5	4.5	4.6	3.6
MGPD	4.5	0	3	4.5	8.6	0.7	0.4	0.7	0.4	0.7	0.4	0.9	1.1	0.5	0.4	0.8	1.1	[illegible]	1.1	0.9
% SOLIDS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	1.5	5	1.0
SPECIFIC GRAVITY	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.05

N/A = INFORMATION NOT AVAILABLE

FIGURE 5.17


PROCESS FLOW DIAGRAM
BOTTOM ASH HANDLING AND TRANSPORT
Arthur D Little inc.
75629
F-201

FI[illegible]RE 5.1[illegible]



DESIGN CONDITIONS - TOTAL STREAM FLOW FOR 24-HOUR OPERATING DAY

DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
K TONS/DAY	2.3	0.2	0.1	[illegible]	7?	17?	5.2	47?	9.9	0	2	.5?	0.07	0.06	2.2	0
MGPD	3.33	0.02	0.02	0.26	4.6	0.50	3.65?	1.2	4.73	0	0.90	—	—	—	—	—
% SOLIDS	5.0	0	1.6	0	4.3	30.0	0	5	0	0	0	55.0	100.0	100.0	60.0	—
SPECIFIC GRAVITY	1.05	1.00	1.09	1.00	1.02	1.24	1.00	1.05	1.00	1.00	1.00	—	—	—	—	—

FIGURE 5.18

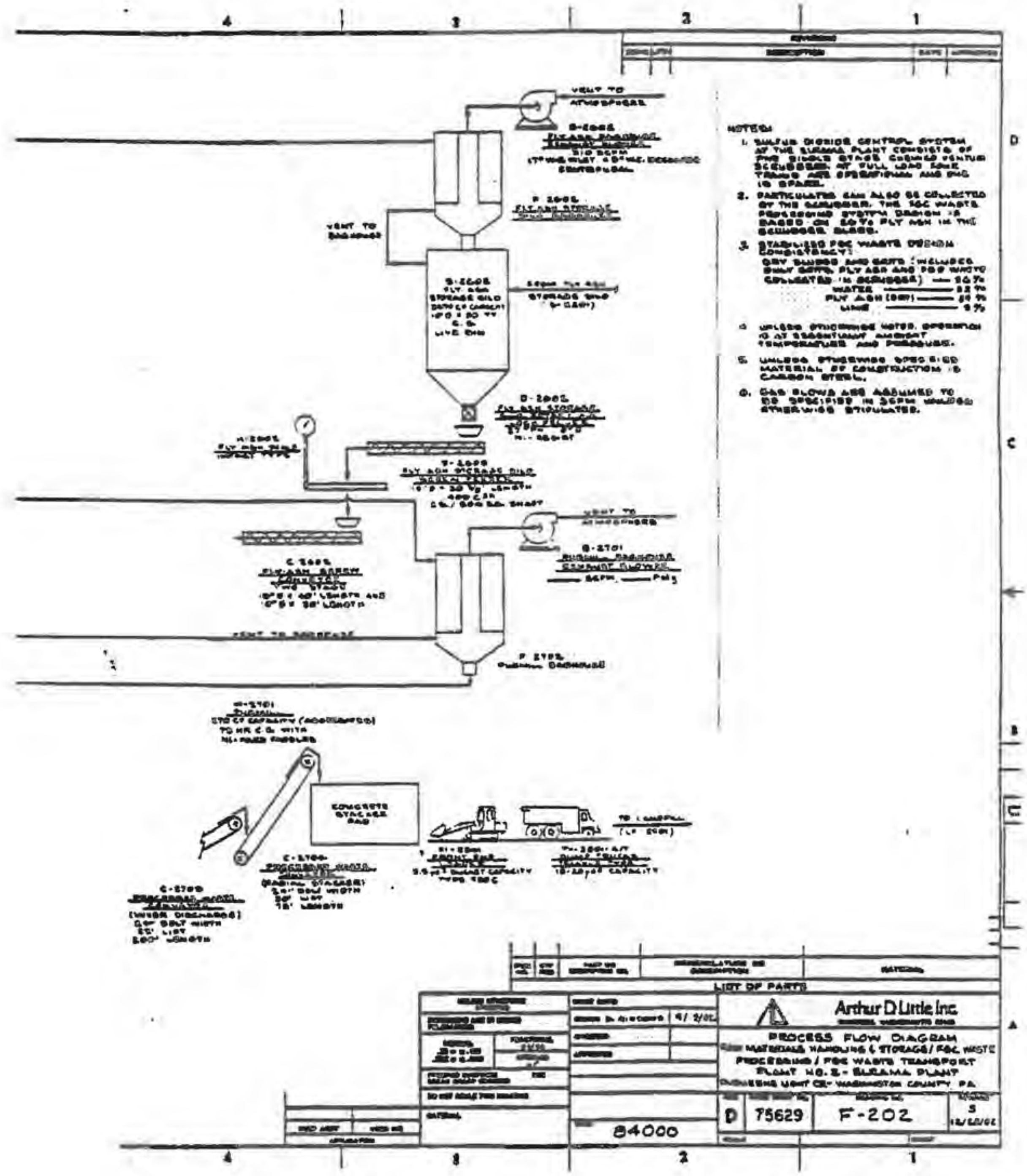

NOTES:
CONCRETE STACKER PAD
Arthur D Little Inc.
PROCESS FLOW DIAGRAM
LIST OF PARTS
D
75629
F-202
84000

FIGURE 5.18

The wastes are spread on the landfill and are allowed to settle for several days as the fixation reaction occurs. The material is subsequently respread and compacted.

In addition to the process description and process flow diagrams presented herein, a list of area accounts and a detailed equipment list were prepared for the Elrama waste handling and disposal operation. These are provided in Appendix G as Tables G-2 and G-8, respectively.

5.3.6.2 Cost Assessment--

Capital and first year annual cost estimates were developed for the coal ash and FGD waste handling and disposal operation at Elrama. These were based primarily on the engineering assessment results. However, to provide for consistency among the cost estimates developed for the six sites, it was necessary to specify certain engineering design premises which were consistent for all study sites (e.g., plant service life, load factor, heat rate, etc.). The engineering design premises which pertain to the Elrama plant cost estimates are listed in Table 5.14.

Detailed capital cost estimates for the Elrama plant coal ash and FGD waste handling and disposal system are presented in Appendix G, Table G-14. A summary of the modular capital cost estimates for the Elrama plant system is presented in Table 5.15. This table provides the modular capital costs broken down by waste type. As can be seen from this summary, the cost of the air pollution control system ($242/kW) comprises a significant fraction (nearly 80 percent) of the total cost ($310/kW) of the environmental management system for the plant. It is also evident that the cost ($37/kW) of waste handling and processing is the largest element (approximately 55 percent) of the total waste handling and disposal capital cost ($68/kW) when the air pollution control system is not considered. Waste handling and processing capital costs for the other two plants practicing landfill disposal range from $6/kW (Powerton Plant) to $16/kW (Dave Johnston Plant). The reason for the considerably higher cost at the Elrama Plant is due to the fact that FGD waste handling and processing at Elrama includes the use of thickeners, vacuum filters, and a pug mill for the fixation of FGD waste. The capital cost of the waste placement and disposal module for Elrama ($14/kW) constitutes 20 percent of the total capital cost (excluding air pollution control costs); this case is similar to that of the Dave Johnston Plant where the capital cost of the waste placement and disposal module ($11/kW) accounts for about 30 percent of the non-air pollution control-related capital cost. In contrast, the capital cost of the waste placement and disposal module at the Powerton Plant ($45/kW) constitutes over 80 percent of the total waste handling and disposal system capital cost (excluding air pollution control costs). This discrepancy is due primarily to the fact that all required Powerton landfill area anticipated for the remaining life of the plant was assumed to be lined with Poz-o-Pac [3 m (10 ft) thick on the sides and 1.5 m (5 ft) thick on the bottom]. The high unit cost for the liner, in addition to its considerable thickness, results in very significantly higher capital costs for the waste handling and disposal module at the Powerton Plant.

TABLE 3.14

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR
ELRAMA PLANT
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES

Power Plant	
Plant Size (MW)	510
Boiler Type	Pulverized Coal
Heat Rate (M joules/kWh; Btu/kWh)	12; 11,400
Location	Pennsylvania
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Waste Generated (dry basis)	
Fly Ash/Bottom Ash Ratio	75/25
Fly Ash Generation (metric tons/yr; tons/yr)	195,300; 215,300
Bottom Ash Generation (metric tons/yr; tons/yr)	69,600; 76,800
FGD Waste Generation (metric tons/yr; tons/yr)	135,300; 149,200
Ash Utilization	None
Coal Properties	
Coal Type	Bituminous
Sulfur Content (Percent)	2.2
Ash Content (Percent)	19.0
Heating Value (M joules/kg; Btu/lb)	27.9; 12,000
Air Pollution Control	
Particulate Control	Mechanical Collectors and Cold-Side ESP's
Particulate Removal (Percent)	>99
Sulfur Oxides Control	Conventional Lime Scrubber
Alkali Stoichiometry	1.1
SO_2 Removal (Percent)	83
Disposal Site	
Type	Landfill (abandoned strip mine)
Design Life (yr)	30
Land Area (m^2; acre)	837,700; 207
Groundwater Monitoring Wells (Number)	10
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner (type: m; ft)	None
Distance from Plant (km; mile)	19; 12

TABLE 5.15

CAPITAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Elrama
Plant Location: Washington County, Pennsylvania
Utility Name: Duquesne Light Company
Nameplate Generating Capacity (MW): 510

WASTES	CAPITAL COSTS ($1000) Fly Ash	Bottom Ash	FGD Waste	Total
MODULES				
• Raw Materials Handling and Storage	$ --	$ --	$ 697	$ 697
• Waste Handling and Processing				
– Dry Wastes	1,230	–	–	1,230
Wet Wastes	3,801	4,484	9,305	17,590
• Waste Storage	2,982			2,982
• Waste Transport				
Dry Wastes	1,221	423	847	2,491
– Wet Wastes	–	2,322	–	2,322
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	4,197	1,211	1,714	7,122
SUBTOTAL – MODULAR COSTS	$13,431	$8,440	$12,563	$34,434($68/KW)
RELATED ENVIRONMENTAL SYSTEMS				
• Air Pollution Control	–	–	–	123,533
TOTAL CAPITAL COSTS	$13,431	$8,440	$12,563	$157,956($310/KW)

[a] ENR Cost Index = 3931.11 (1913=100)
365.97 (1967=100)

Source: Arthur D. Little, Inc. estimates.

A detailed annual cost estimate was also prepared for the Elrama Plant coal ash and FGD waste handling and disposal system. This estimate is provided in Table G-20, Appendix G. A simplified summary of these estimates is provided in Table 5.16. On a unit cost basis, the annual cost for the overall Elrama waste handling and disposal system ($32.60/dry metric ton) is higher than those for the other two sites [Dave Johnston ($24.90/dry metric ton) and Powerton ($27.30/dry metric ton)] practicing landfilling, because the more complex CSI fixation process is used at Elrama. One might imagine that the operating cost at Elrama could be even more expensive in comparison to the other two plants than is indicated. The reason for this is that both the Dave Johnston and Powerton plants have some unusual and very costly site-specific conditions. For example, the pressure pneumatic fly ash handling system at Dave Johnston is considerably more expensive to both purchase and operate than the pressure/vacuum or vacuum pneumatic dry fly ash handling systems used at Elrama and Powerton, respectively. In addition, the Dave Johnston plant employs off-the-road ash hauling trucks which are more expensive to purchase than on-the-road trucks and which also provide significant over-capacity for waste transport. The Powerton Plant on the other hand, has a significantly higher operating cost than one would anticipate mainly due to the capital charges associated with the Poz-O-Pac® liner at the landfill.

5.4 DAVE JOHNSTON PLANT

5.4.1 Plant Description

5.4.1.1 Background--

The Dave Johnston Power Plant of Pacific Power and Light Company is located in Converse County, Wyoming, approximately 9.6 km (6 miles) northeast of the town of East Glenrock and 48 km (30 miles) east of Casper, Wyoming. The plant and ash disposal facility are located on the north bank of the North Platte River as shown on Figure 5.19.

The Dave Johnston Plant consists of four generating units with various flue gas cleaning capabilities. Units 1, 2 and 3 are equipped with cold-side electrostatic precipitators; Unit 3 is additionally equipped with a mechanical collector. Units 3 and 4 use an economizer ash removal system. Unit 4 is equipped with a wet scrubber to remove fly ash.

Fly ash from Units 1, 2 and 3 and economizer ash from Units 3 and 4 are handled in dry form and disposed in a landfill site east of the plant. Bottom ash is slurried to one of two settling ponds which are used alternately for interim dewatering. Periodically, the bottom ash is dredged and used for road construction or is codisposed in a landfill site with ash from Unit 4. Fly ash and bottom ash from Unit 4 are directed to an interim settling pond where they are dewatered and subsequently periodically excavated and disposed in a major disposal area north of the plant site. The various disposal areas and their constituents are indicated on Figure 5.19.

The Dave Johnston Plant was selected for study primarily because it provided the opportunity to evaluate landfill disposal of dry fly ash. As such, the remainder of this section will focus on the landfill disposal of dry

TABLE 5.16

ANNUAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Elrama
Plant Location: Washington County, Pennsylvania
Utility Name: Duquesne Light Company

Operating Load Factor (percent): 70
Nameplate Generating Capacity (MW): 520
Waste Generation (dry metric tons/yr):
Fly Ash 195,300
Bottom Ash - 69,600
FGD Waste 135,300

WASTES	ANNUAL COSTS ($1000) Fly Ash	Bottom Ash	FGD Waste	Total
MODULE				
• Raw Materials Handling and Storage	$ -	$	$1,647.2	$1,647.2
• Waste Handling and Processing				
Dry System	572.9	-	-	572.9
Wet System Exclusive of Interm Pond (Where Applicable)	1,065.2	601.9	2,608.7	4,275.8
Interim Pond	-	941.5	-	941.5
• Waste Storage	689.7	-	-	689.7
• Waste Transport				
- Dry Transport	1,334.6	461.1	925.9	2,721.6
- Wet Transport	-	536.1	-	536.1
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	816.7	281.4	566.5	1,666.6
SUBTOTAL - MODULAR COSTS	$4,479.1	$2,826.0	$5,748.3	$13,053.4 ($32.60/dry metric ton)
RELATED ENVIRONMENTAL SYSTEMS				
• Air Pollution Control	NA[b]	-	NA[b]	NA[b]
TOTAL ANNUAL COSTS	$4,479.1+NA[b]	$2,826.0	$5,748.3 + NA[b]	$13,053.4 + NA[b]

[a] ENR Cost Index 3931.11 (1913=100)
365.97 (1967=100)

[b] NA=Information not available

Source: Arthur D. Little, Inc. estimates.

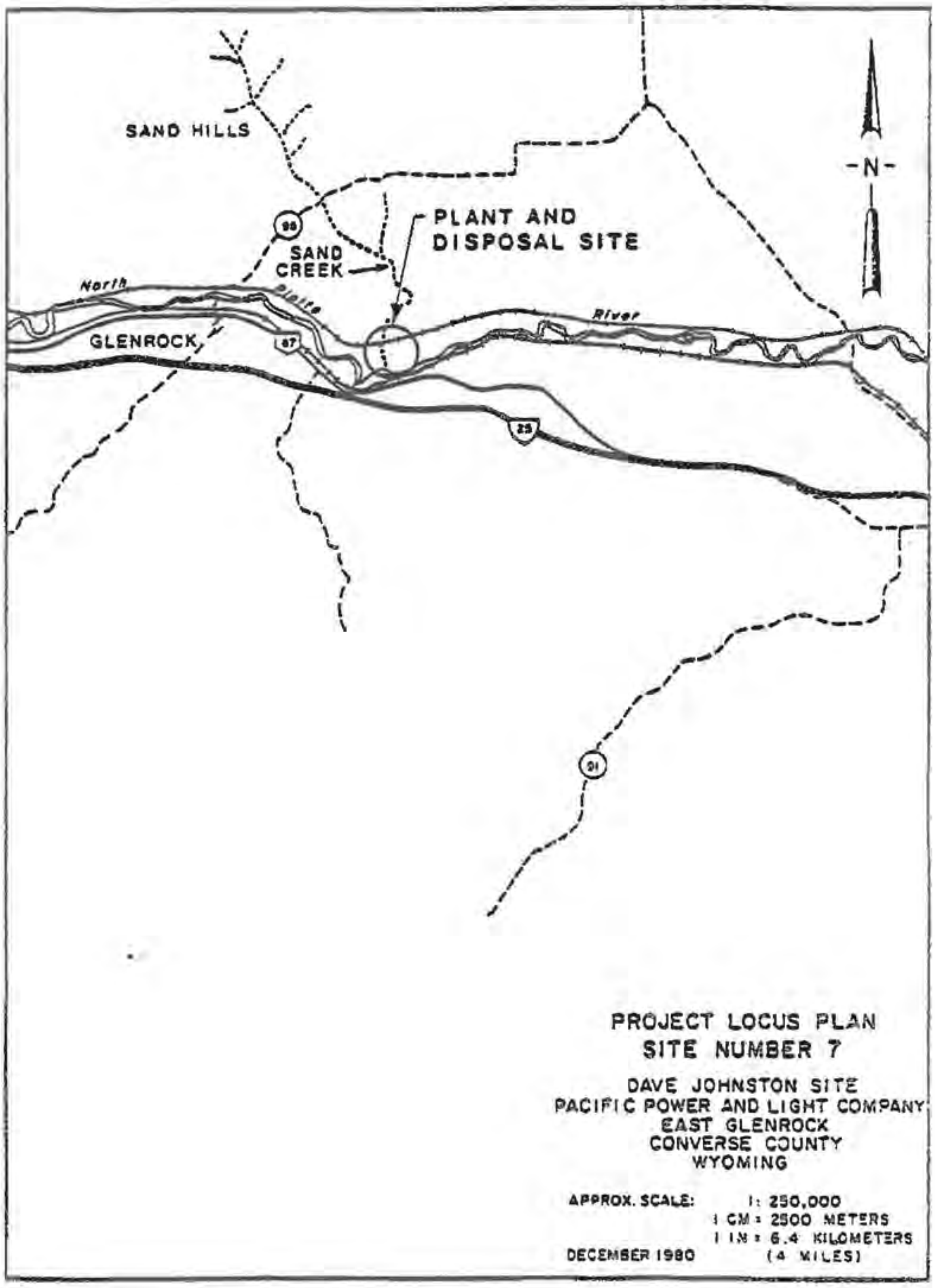

SAND HILLS
PLANT AND
DISPOSAL SITE
SAND
CREEK
North Platte River
GLENROCK
-N-
PROJECT LOCUS PLAN
SITE NUMBER 7
DAVE JOHNSTON SITE
PACIFIC POWER AND LIGHT COMPANY
EAST GLENROCK
CONVERSE COUNTY
WYOMING
APPROX. SCALE: 1: 250,000
1 CM = 2500 METERS
1 IN = 6.4 KILOMETERS
(4 MILES)
DECEMBER 1980

FIGURE 5.9

fly ash from Units 1, 2 and 3 and dry economizer ash from Units 3 and 4. Other factors of importance in the selection for study of the fly ash landfilling operation at the Dave Johnston Plant include the following:

- The site is located in the western United States, and the rate of growth of new coal-fired utility capacity in the west is expected to be significant.

- The environmental setting combines significant net evaporation with a flood-plain location that would be expected to illustrate contaminant migration in an identifiable pattern, while exemplifying arid western conditions.

- The disposal operation is representative of existing and future operations at many western locations. At the portion of the Dave Johnston site selected for study, fly ash, which is collected and handled in dry form, is disposed along with small amounts of miscellaneous plant trash; other utility solid wastes may also occasionally be disposed in this landfill. This is a modern practice that is characteristic of western plants, and was not expected to be a significant complication in the assessment.

- Both active and inactive landfills were available for study in the selected portion of the site. These landfills have been developed over about a 20-year period and are believed to be isolated from any other potential sources of waste contamination.

5.4.1.2 Geologic Conditions--

The Dave Johnston Plant is located within the Missouri Plateau Section of the Great Plains Physiographic Province in east-central Wyoming. The Plateau is characterized by badlands, broad valleys, deeply eroded gullies and low ridges and escarpments capped by resistant sandstone beds. Extensive sand dune deposits are common throughout the area.

The project site area is underlain by bedrock of the Lance Formation, which consists of carbonaceous shales with interbedded sandstones and thin coal units. Subsequent decomposition of the bedrock surface created a thin residuum of silt and clay, which contains numerous fragments of the more resistant sandstone. During the Quarternary time period, the ancestral North Platte River deposited fluvial sands and gravels directly over the underlying residual soils. Subsequent erosion removed much of these sediments beneath the main course of the river channel and left behind higher-level river terraces adjacent to the modern North Platte River. Intermittent flooding of the river caused the deposition of alluvial flood plain sands and silts with trace amounts of organic matter directly over the underlying fluvial deposits. Due to the arid conditions and lack of substantial vegetation, fine sand and silt aeolian deposits are common throughout the site area in the form of sand dunes.

The operational fly ash disposal area was excavated approximately 3 m (10 ft) into the natural sand deposits in order to increase the disposal area and provide cover material. No liner was placed in the excavation which is in close proximity to the groundwater table. Figure 5.20 summarizes the site area surficial geologic conditions and Figure 5.21 indicates the general subsurface geologic profile in the site area.

5.4.1.3 Hydrologic Conditions--

The Dave Johnston fly ash disposal facility lies within the Great Plains Groundwater Province. The North Platte River, which is adjacent to the plant site, is one of the three principal drainage basins of the Missouri River. Wyoming has serious water supply limitations in terms of both quality and quantity, with a mean annual precipitation of 0.305 m (12 in) in the site vicinity. The majority of the precipitation is lost through evaporation, with an annual runoff of only 0.013 m (0.4 in). Nearly all recharge to the groundwater system occurs during spring runoff and, occasionally, during periods of heavy precipitation. The landscape is constantly subjected to alternating wet and dry periods.

Groundwater occurs within the site area in two different and separate hydrogeological environments. The hydraulic communication between the deeper bedrock "aquifer" and the near-surface unconsolidated fluvial deposits is very minimal. The North Platte River and its associated alluvial deposits are the major source of water supply throughout the entire basin. The Dave Johnston Plant obtains the majority of its operational and domestic water supply from the North Platte River, which has been dammed to create a small water supply lake. The plant also supplements its water supply from both vertical and horizontal wells located in the river alluvial deposits. Various large diameter production wells in the bedrock were abandoned due to low flow rates and mineralization. All project site surface and groundwater flow is southerly towards the adjacent North Platte River.

5.4.2 Site Evaluation Plan and Site Development

The operational Dave Johnston fly ash disposal area, located east of the plant complex, was first evaluated in 1971 for a proposed ash disposal area. Prior to that time, isolated and local areas had been used for ash disposal purposes within the general 1.6 million m^2 (400 acres) available site area. All pre-1971 disposal areas had been retired, regraded and reclaimed. In 1976 additional studies were conducted that led to the state-licensed solid waste disposal facility. Several geotechnical reports for the various plant constructions, as well as test boring and well logs from a variety of studies, were supplied for this program by the utility; these provided invaluable hydrogeological information.

The project site development plan provided for a comparative assessment of two major ash disposal areas which reflect different times and methods of placement. The two separate but related disposal operations allowed evaluation of both the short- and long-term effects of ash disposal in an arid environment.

The project site evaluation included the installation of multi-purpose wells, piezometers, exploratory test borings and test pits for hydrogeological

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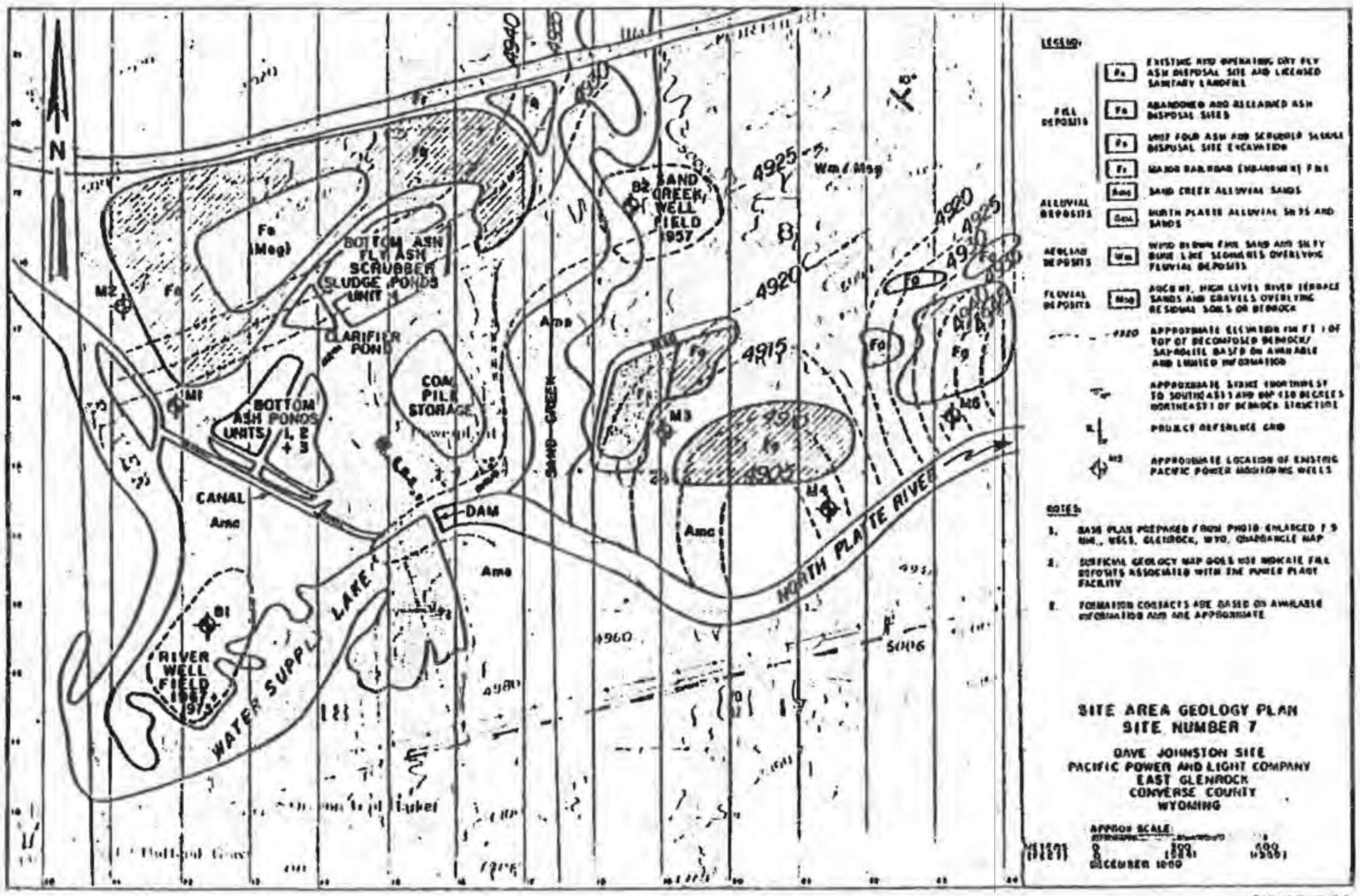
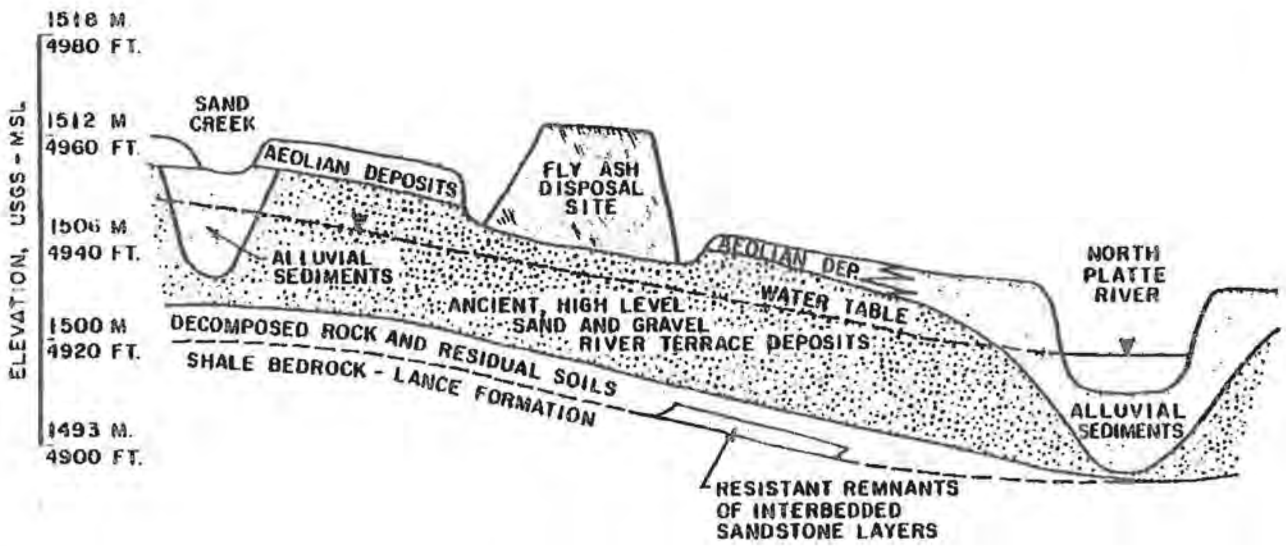


FIGURE 5.20



IDEALIZED SUBSURFACE GEOLOGIC CONDITIONS
IN THE VICINITY OF THE FLY ASH DISPOSAL SITE
VIEW LOOKING EAST

FIGURE 5.21

and geotechnical evaluation purposes. One upgradient observation well was installed for overall site background monitoring purposes, and an upgradient well was installed in the alluvial deposits of ephemeral Sand Creek. Monitoring/sampling wells were installed within the disposed fly ash in both the active and retired disposal areas. Seven downgradient observation wells, at various locations and elevations, were installed to evaluate the active and retired disposal areas and their combined effects on the environment. Ten machine excavated test pits were obtained throughout the site area to determine the vertical and lateral extent of the various natural and artificial surficial deposits.

At the completion of all monitoring installations, the wells were flushed, bailed and an initial sample obtained for chemical evaluation purposes.

The location of all explorations and monitoring/sampling installations are indicated on Figure 5.22 and a summary of all field results, sample locations, types, depths, tests and wells are indicated on Table 5.17.

5.4.3 Physical Testing Results

Results of permeability tests, standard penetration tests, and unified soil classification tests performed on wastes from the Dave Johnston landfill site are presented as Figure 5.23.

Physical testing showed that bottom ash had been disposed within the fly ash landfill resulting in layers of ash that vary in particle size. Specifically, in boring 7-2, fly ash was encountered near the surface (coefficient of permeability equal to5 x 10^{-5} cm/sec) while coarser ash was encountered at a depth of approximately 5.5 m (18 ft) (coefficient of permeability equal to2 x 10^{-3} cm/sec). At a depth of 7.5 m (24.5 ft) the fly ash was encountered again (coefficient of permeability equal to 3 x 10^{-4} cm/sec), and the fly ash extended to the bottom of the boring. As can be seen from the test results, grain size has a substantial effect on the coefficient of permeability of the Dave Johnston ash samples. The extended permeability test and tests performed on loose and dense (remolded) samples of the same ash indicate that density does not have a significant effect on the coefficient of permeability of the Dave Johnston ash samples.

Selected physical testing results for this site are provided in Table 5.18. A more detailed presentation of these results can be found in Appendix E.

5.4.4 Chemical Testing Results

The site monitoring infrastructure was developed in May 1981. Samples of wastes and soils were taken at that time for physical and chemical testing, and groundwaters were sampled for chemical testing. Subsequent groundwater sampling took place in July and October 1981 and May 1982, along with limited sampling of standing surface water at the base of the landfill. Year-to-date precipitation was typical at the time of each sampling visit.

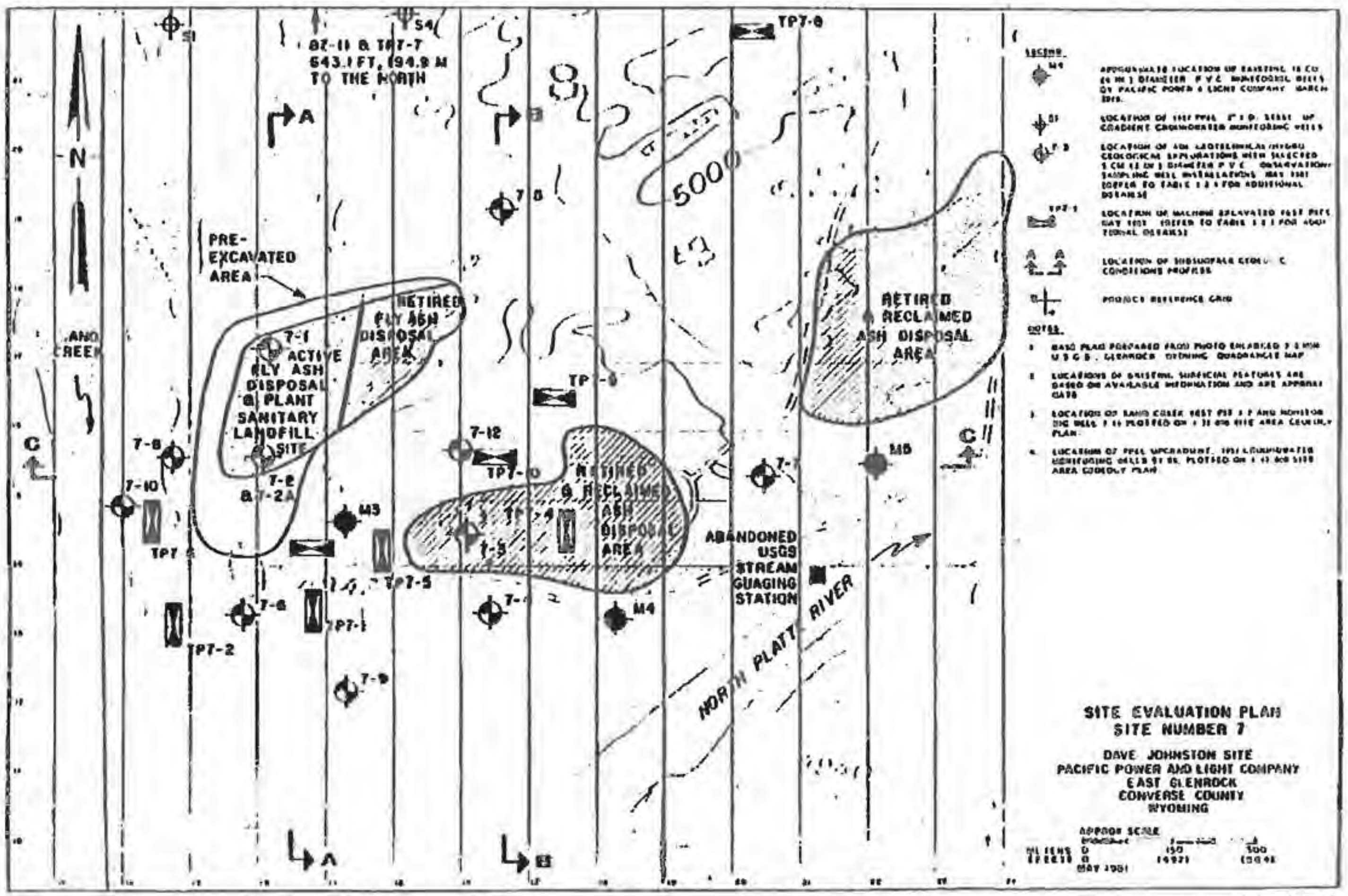

N
BZ-11 & TP7-7
643.1 FT, 194.9 M
TO THE NORTH
PRE-
EXCAVATED
AREA
RETIRED
FLY ASH
DISPOSAL
AREA
ACTIVE
FLY ASH
DISPOSAL
& PLANT
SANITARY
LANDFILL
SITE
RETIRED
RECLAIMED
ASH DISPOSAL
AREA
RETIRED
& RECLAIMED
ASH
DISPOSAL
AREA
ABANDONED
USGS
STREAM
GUAGING
STATION
NORTH PLATTE RIVER
5000
M3
M4
M5
TP7-8
TP7-2
TP7-5
SITE EVALUATION PLAN
SITE NUMBER 7
DAVE JOHNSTON SITE
PACIFIC POWER AND LIGHT COMPANY
EAST GLENROCK
CONVERSE COUNTY
WYOMING
APPROX SCALE
MAY 1981

FIGURE 5.22

TABLE 5.17

SITE DEVELOPMENT SUMMARY

SITE: DAVE JOHNSTON PLANT
CONVERSE COUNTY, WYOMING

DATES: May 11, 1981 - May 28, 1981

TOTAL NO. EXPLORATIONS ON SITE: 16

FILE NO. 453507

Boring #	7-1	7-2	7-2A	7-3
Soils Classification [depth (m): class]	0-7.3: Ash Fill 7.3-11.3: Aeolian Deposit 11.3-18.6: Fluvial Deposit	0-0.3: Fill 0.3-14.6: Fly Ash Fill 14.6-14.9: Aeolian Deposit 14.9-17.7: Fluvial Deposit 17.7-18.3: Decomposed Rock	0-14.8: Fly Ash Fill 14.8-14.9: Aeolian Deposit	0-1.7: Fill 1.7-5.0: Fly Ash Fill 5.0-7.2: Aeolian Deposit 7.2-17.4: Fluvial Deposit 17.4-18.4: Decomposed Rock
Number of Samples Obtained	18	22	1	23
Field Permeability Tests [depth (m); results (m/sec)]	No Tests	No Tests	(CHT 1) 5.6-6.2; 16.56 GPM	(RHT-1) 7.2-10.3; 2.12×10^{-6}
Well Installation [Well point type; diameter (in); location (m)]	No Well	0.020" slot; 2.0 ID; 16.5'-17.6'	0.020" slot; 2.0 ID; 13.2'-14.8'	0.020" slot; 2.0 ID; 7.2'-10.3'

Boring #	7-4, 7-4A	7-5	7-6	7-7
Soils Classification [depth (m); class]	0-8.8: Alluvial Deposits 8.8-12.2: Decomposed Rock	0-16.2: Aeolian Deposits 16.2-20.0: Initial Deposit 20.0-20.1: Decomposed Rock	0-2.9: Aeolian Deposits 2.9-9.8: Alluvial Deposits 9.8-12.7: Decomposed Rock	0-10.4: Aeolian Deposits 10.4-11.9: Alluvial Deposits 11.9-13.4: Residual Soils 13.4-13.6: Decomposed Rock
Number of Samples Obtained	15	27	14	10
Field Permeability Tests [depth (m); results (m/sec)]	(RHT 1) 2.6-5.7; 3.17×10^{-6}	Well bailed with immediate recharge	Well bailed with immediate recharge	0.020" slot; 2.0 ID; 10.1-13.2 9.63×10^{-7}
Well Installation	0.020" slot; 2.0 ID; 2.6'-5.7'	0.020" slot; 2.0 ID; 16.1'-19.2'	0.020" slot; 2.0 ID; 5.5'-8.6'	0.020" slot; 2.0 ID; 10.1'-13.2'

Notes: *Chem sample; CHT = Constant Head Test; RHT = Rising Head Test.

5-18

(continued)

TABLE 5.17

SITE DEVELOPMENT SUMMARY

SITE: DAVE JOHNSTON PLANT

Boring #	7-8	7-9	7-10	7-11
Soils Classification [depth (m): class]	0-3.0; Fluvial Deposits 3.0-4.3; Alluvial Deposits 4.3-6.7; Fluvial Deposits 6.7-9.1; Decomposed Rock	0-7.3; Alluvial Deposits 7.3-12.8; Decomposed Rock	0-1.8; Alluvial Deposits 1.8-5.0; Fluvial Deposits	0-9.4; Alluvial Deposits
Number of Samples Obtained	8	13	1	1
Field Permeability Tests [depth (m); results (m/sec)]	(RHT-1) 3.7-4.8; 1.37×10^{-5}	Well bailed with immediate recharge	No test performed	Well bailed with immediate recharge
Well Installation [Wellpoint type; diameter (in); location (m)]	0.020" slot; 2.0 ID; 1.7'-4.8'	0.020" slot; 2.0 ID; 2.7'-5.8'	0.020" slot; 2.0 ID; 2.7'-4.2'	0.020" slot; 2.0 ID; 5.4'-8.5'

Boring #	7-12
Soils Classification [depth (m): class]	0-1.8; Aeolian Deposits 1.8-6.2; Fluvial Deposits
Number of Samples Obtained	1
Field Permeability Tests [Depth (m); results (m/sec)]	(FHT-1) 4.1-4.6; 5.77×10^{-6}
Well Installation [Wellpoint type; diameter (in); location (m)]	0.020" slot; 2.0 ID; 2.7'-5.8'

Note: * Chem Sample; FHT = Falling Head Test; RHT = Rising Head Test.

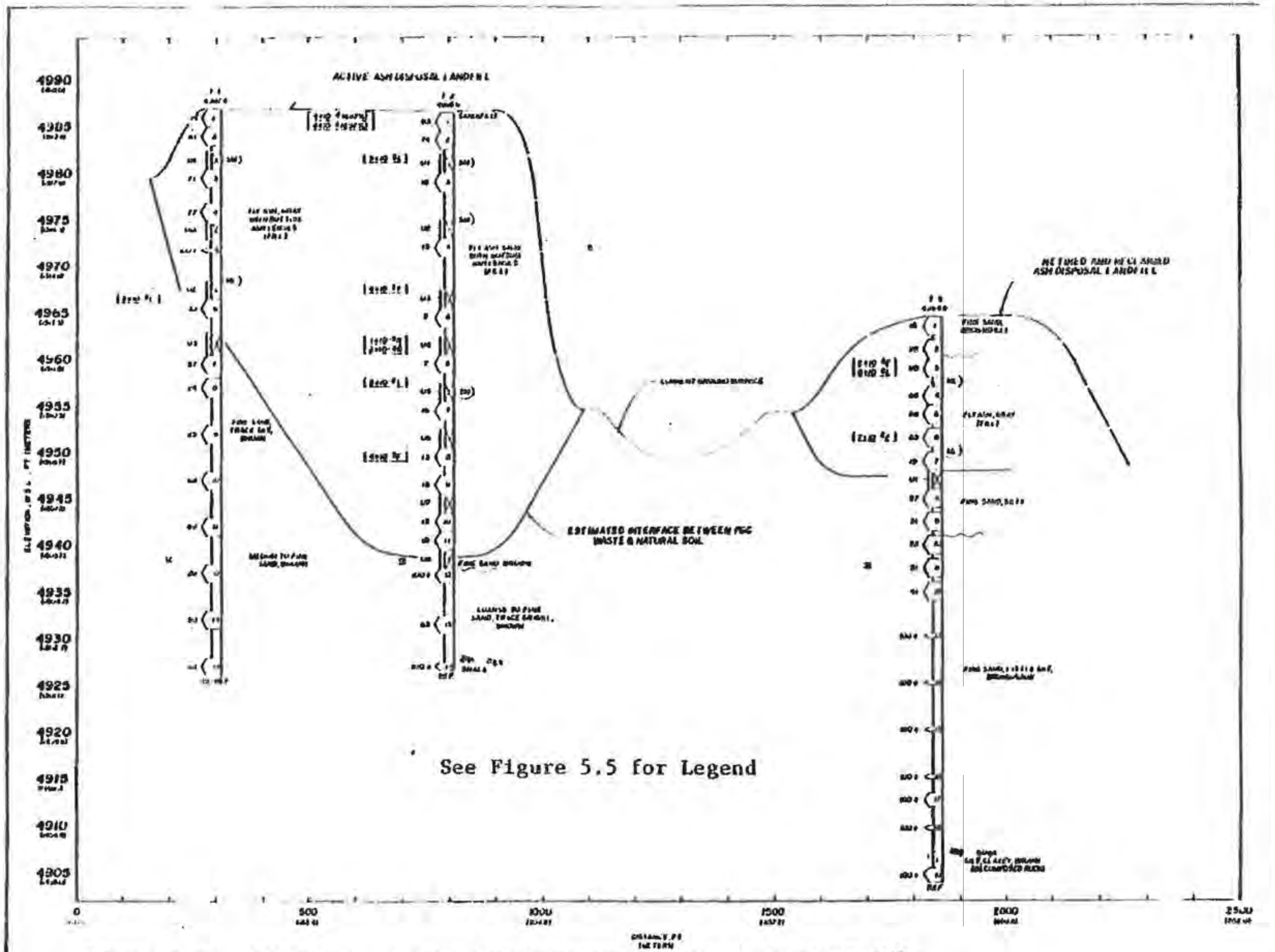


FIGURE 5.23 GEOTECHNICAL EVALUATION RESULTS, DAVE JOHNSTON PLANT, PACIFIC POWER AND LIGHT COMPANY, CONVERSE COUNTY, WYOMING

TABLE 5.18

SELECTED PHYSICAL TESTING RESULTS

DAVE JOHNSTON PLANT [a]

Maximum Dry Density (kg/m^3; lb/ft^3)	1370; 85.3
Optimum Moisture Content at 60°C (Weight Percent)	16.5
Permeability (cm/sec)	2×10^{-7} - 6×10^{-5}
Specific Gravity	2.22 - 2.33
Grain Size Distribution (Weight Percent)	
• > 74 µm	32 - 99
• 2 - 74 µm	1 - 67
• < 2 µm	0 - 9
Moisture Content (Weight Percent)	0.4 - 31.9

[a] See Appendix E for individual sample results.

Source: Arthur D. Little, Inc., and Bowser-Morner Testing Laboratories, Inc.

Selected results of groundwater and surface water chemical analyses, along with a comparison with applicable EPA drinking water stands, are presented in Table 5.19. Selected soil attenuation test results are presented in Table 5.20. A more detailed presentation of chemical analysis results is provided in Appendix F.

5.4.5 Environmental Assessment

5.4.5.1 Approach for the Dave Johnston Plant--
The environmental assessment of the Dave Johnston site results focused on one major issue, the effect of fly ash landfill disposal on downgradient groundwater quality in an arid floodplain environment.

The steps employed in the environmental assessment for this site were as follows:

- A site subsurface geological profile and a preliminary site water balance were prepared.
- The values and trends in chemical sampling and analysis results for the various areas of the site were compared with each other, the results of previous sampling by Pacific Power and Light Company and relevant EPA standards for groundwater protection.
- The water balance, geologic profiles and chemical and physical testing results were considered together to structure and evaluate hypotheses concerning the nature of leachate generation and movement at the site.
- The broader implications of the Dave Johnston site results were considered in terms of their applicability to similar combinations of waste types, disposal methods and environmental settings.

5.4.5.2 Geological Profiles and Water Balance--
Figures 5.24 and 5.25 illustrate the subsurface geological profiles and preliminary water balance, respectively, for different areas of the Dave Johnston waste disposal site. These profiles and waterbalance were prepared from the site development results from this program along with the available site background information.

5.4.5.3 Evaluation of Testing Results--
The chemical analysis results for samples gathered at the Dave Johnston Site, in conjunction with available background data, indicate the following:

- Values measured on different dates at the same sampling locations were extremely similar. (See Table 5.19 illustrating results for selected parameters.)
- Groundwater concentrations of a number of typical coal ash chemical "tracers" were quite high at most locations, including background, in-waste, and peripheral/downgradient wells. The sulfate, boron and calcium concentration values in Table 5.19 illustrate this trend. The

TABLE 5.19

SELECTED DATA FOR REPRESENTATIVE SAMPLING LOCATIONS AT THE DAVE JOHNSTON PLANT

Locations	CONCENTRATION[a]					
	SO_4 (mg/ℓ)	B (mg/ℓ)	As (µg/ℓ)	Se (µg/ℓ)	Ca (mg/ℓ)	Sr (mg/ℓ)
Well 7-5 (Background)	880-1280	0.683-0.692	1.4	<0.4	278-296	1.67-2.06
Well 7-11 (Creek Area Background)	38.6-144	0.056-0.064	<0.5	4.2-5.7	70.8-74.2	0.40-0.447
Well 7-7 (Far-Peripheral)	44-87.5	0.014-0.032	<0.5	1.3	59.4-61.0	0.952-1.0
Well 7-2 (Under Ash)	1010-1560	1.71-1.94	0.5-0.7	0.8-1.7	401-449	2.77-3.33
Well 7-2A[b] (In Ash)	1780	4.96	--	--	720	5.6
Well 7-6 (Downgradient Active Area)	1100-1450	0.659-0.840	--	--	322-358	2.73-3.15
Well 7-8 (Near-Peripheral)	920-1510	1.67-2.24	0.6	2.3	335-444	2.63-3.55
Well 7-10 (Near Peripheral)	960-1630	1.92-2.79	--	--	348-481	2.77-4.13
Surface Water (Drainage from Landfill)	2450	3.82	--	--	648	4.1
Waste Solids	--	--	2.6-17.6 ppm	2.4-11.3 ppm	98,400-167,000	720-1350
Boring 7-5 (Background Soils)	--	--	--	--	3,350-6,000	78-144

[a]Proposed EPA Secondary Drinking Water Standard for Sulfate = 250 mg/ℓ
Proposed EPA Interim Primary Drinking Water Standard for As = 50 µg/ℓ
Proposed EPA Interim Primary Drinking Water Standard for Se = 10 µg/ℓ
EPA Criterion for Protection of Sensitive Crops for B = 0.750 mg/ℓ

[b]Small-volume grab sample, well was dry on 2 of 3 trips.

TABLE 5.20

SELECTED RESULTS OF SOIL ATTENUATION STUDIES
DAVE JOHNSTON SITE[a]

Element	Solution Concentration (ppb)	Soil Capacity (μg/gm)	Soil Capacity ÷ Solution Concentration
Arsenic	10-485 17.9-514	1.1-7.9 1.1-7.5	110-161 61-15
Selenium	26-124 59-123	0.1-0.2 0.16-0.15	3.8-1.6 2.7-1.3
Cadmium	50-150	0.22-1.20	4.4-8
Chromium	250	0.04 ± 0.04	< 0.2
Copper	30-272	0.74-127	25-467
Nickel	180	0.14 ± 0.02	0.8
Vanadium	58-79 14-25	0.05-0.7 0.04-0.11	0.9-9 2.9-4.4

[a]Soils used for testing were from background boring 7-3.

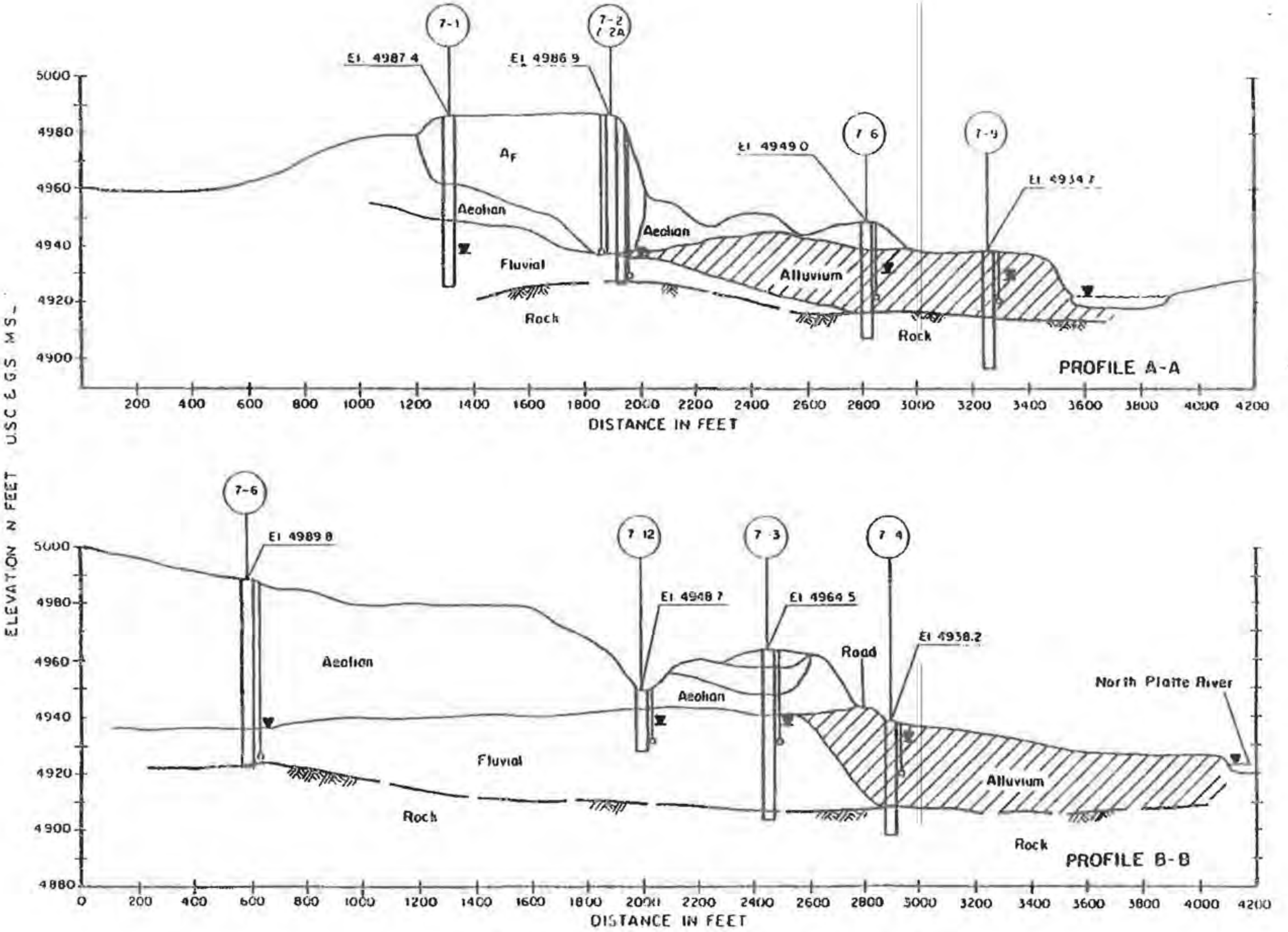


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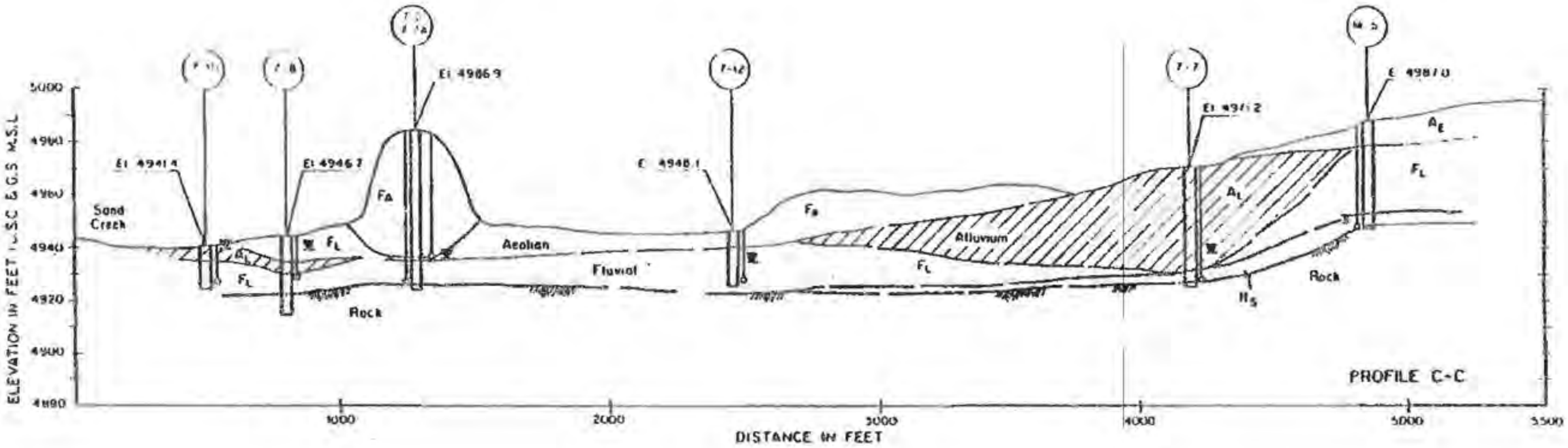
FIGURE 5.24 SUBSURFACE GEOLOGICAL PROFILES - DAVE JOHNSTON SITE
PACIFIC POWER AND LIGHT COMPANY - CONVERSE COUNTY, WY.
(Continued)



LEGEND

Fills Relatively recent overburden materials associated with on site construction and disposal of ash.

Loose to very compact, brown, coarse to fine sand with varying amounts of gravel and trace amounts of silt

F_A - Loose to very compact, gray, fly ash fill

Aeolian Deposits

A_E Medium compact to very compact, brown to white fine sand, with varying amounts of medium and coarse sand, trace silt.

Alluvial Deposits

A_L Medium compact to very compact, brown to gray, fine sands and silty fine sands, with varying amounts of medium sands, and trace amounts of coarse sand and clay. Some pockets of loose sand may exist.

Fluvial Deposits

F_L Medium compact to very compact, oxidized brown to brown, coarse to fine sand, with varying amounts of fine gravel and trace amounts coarse gravel and silt

Residual Soils

R_S Very compact, and very stiff, gray brown, silt and fine sandy silt, trace amounts clay and medium sand

Rock

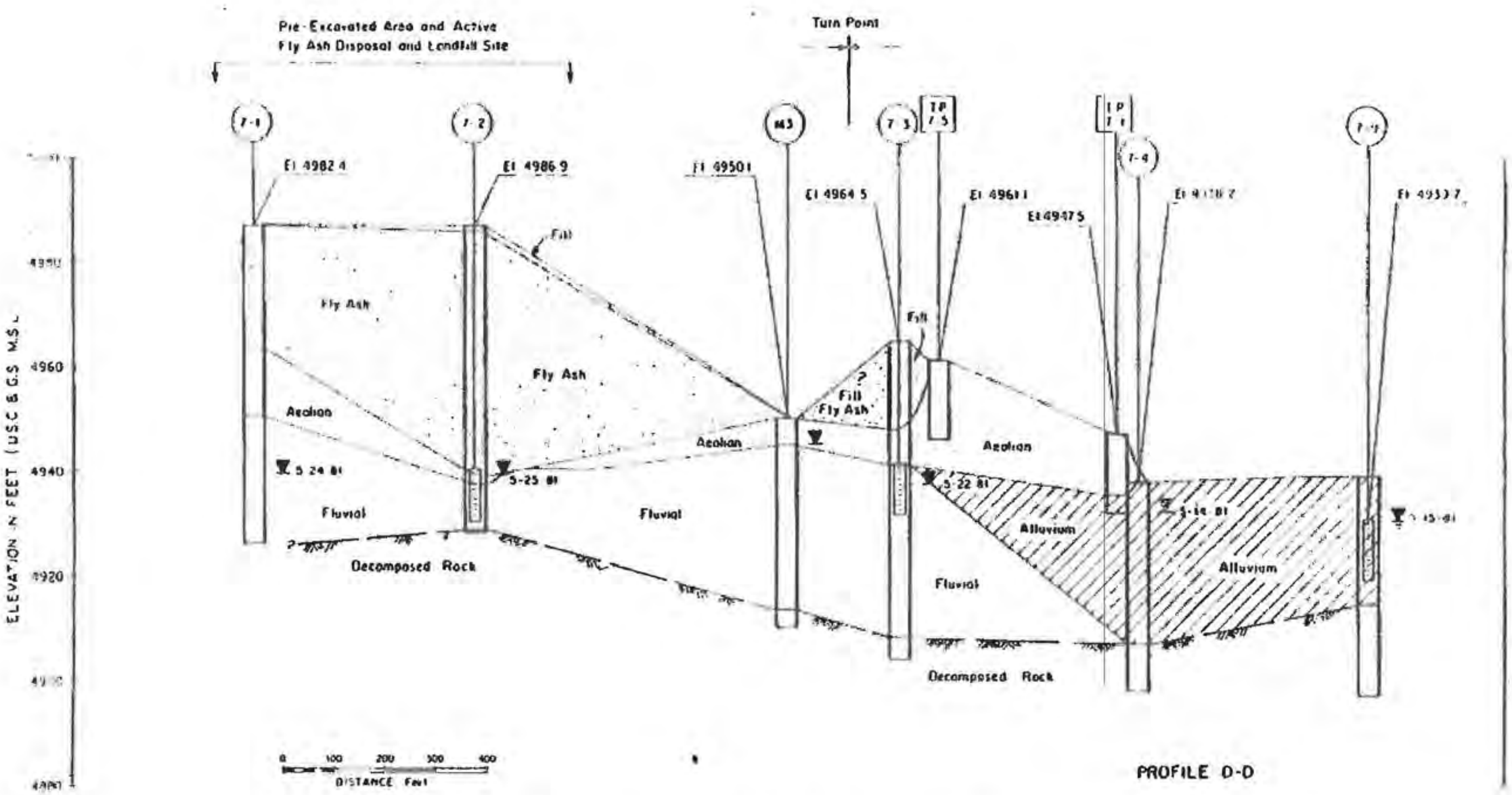
R - In test borings where abrupt auger penetration "refusal" was encountered at depths, it is assumed to be the top of the very compact to very stiff brown gray, silt and clayey silt varying from moderately to completely weathered, as classified from "split spoon" samples

Symbol representing water depth in completed borehole or groundwater monitoring well at the time of installation.

Symbol representing location of installed groundwater monitoring well or piezometer

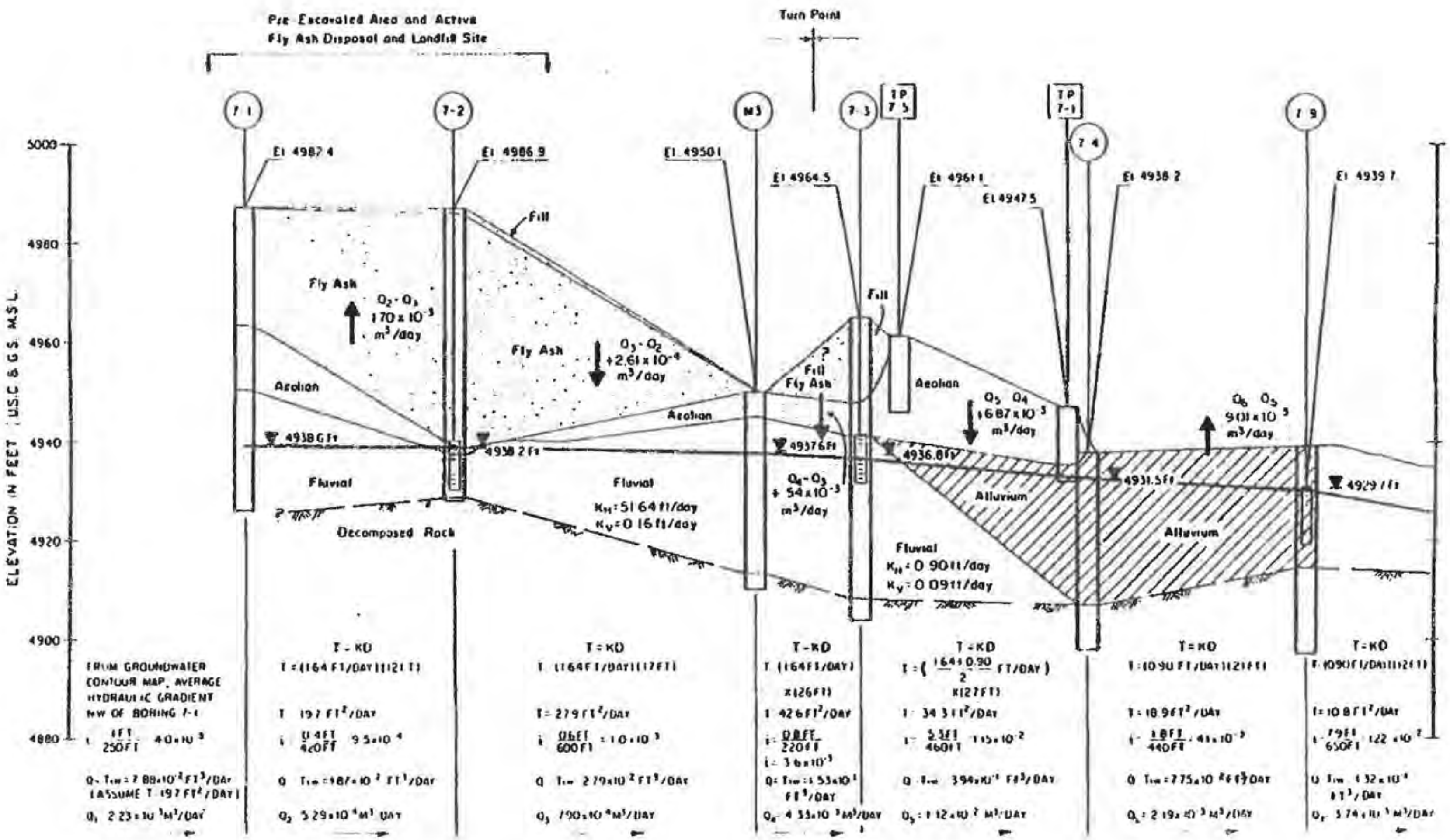
SUBSURFACE GEOLOGICAL PROFILES – DAVE JOHNSTON SITE
PACIFIC POWER AND LIGHT COMPANY – CONVERSE COUNTY, WY.

FIGURE 5.24 (Continued)



SUBSURFACE GEOLOGICAL PROFILES - DAVE JOHNSTON SITE
PACIFIC POWER AND LIGHT COMPANY - CONVERSE COUNTY, WY.

FIGURE 6.24



DAVE JOHNSTON PLANT WATER BALANCE

FIGURE 5.26

secondary drinking water standard for sulfate was exceeded by a factor of three to five times in groundwater obtained at background well 7-5.

- The elevated background, in-waste and peripheral/downgradient concentrations of the potential tracer species generally varied within one order of magnitude and sometimes overlapped (e.g., sulfate). However, the concentrations of calcium, strontium and boron generally exhibited the following pattern: concentrations were higher in the wastes than in surrounding soils, and those measured at well 7-2A placed in the waste were greater than those measured under the waste (sampling point 7-2) and at near-peripheral locations (sampling points 7-8 and 7-10); all these water samples obtained near the waste showed higher concentrations than background (sampling point 7-5) and further downgradient groundwaters.

- This pattern is consistent with the relative concentrations of calcium and strontium measured in the waste solids versus background soil samples; these concentrations were 10 to 30 times higher in the wastes (see Table 5.19).

- There were consistently much lower levels of the same species in waters analyzed from one background and one peripheral well (see data for wells 7-7, 7-11, Table 5.19).

- During one trip, standing surface water at the base of the landfill was sampled and analyzed for selected parameters. Levels of the ash-related constituents (sulfate, calcium, boron, strontium) were comparable in all cases to the levels found in groundwater samples from the "in ash" well (well 7-2A).

- Levels of some attenuation-prone trace metals in the ash solids (i.e., chromium and vanadium) were three to ten times higher than in background soils.

- Supplemental attenuation experiments with background soils from boring 7-5 showed these soils to have less attenuative capacity for a variety of trace metals than the various soils from any of the other five study sites (see Appendix F and Table 5.20).

5.4.5.4 Cause and Effect Relationships--

For arid western sites in general, including Dave Johnston, the limited potential for water movement creates a study focus on leachate plume identification in the area immediately adjacent to the waste deposit. At this site, the active landfill was reportedly developed in an excavation that may have intersected the underlying water table. Thus, one could not a priori rule out either the likelihood of very little plume movement (due to the arid conditions) or the possibility of some contaminant migration via direct contact between the bottom of the fill and the water table. It appears that the measured results reflect some combination of these factors.

- The water balance and estimate of plume arrival time support the hypothesis that the widespread measurement at the site of what might elsewhere be considered elevated contaminant levels is not due to the waste landfills. The preliminary estimates of plume arrival time for the peripheral wells downgradient of (not directly under) the active landfill are in excess of 100-300 years considering only travel time in the saturated zone. Travel time in the unsaturated zone would add to these estimates. Travel time from the 20-year old inactive landfill, (which was not excavated to the watertable) to the downgradient well was not separately estimated, but would be to be in excess of the time between disposal and the measurements made in this project.

- The results support the hypothesis that most of the "elevated" concentration measurements reflect pervasively high background levels characteristic of western settings.

- The lower measured values at the one background well and one peripheral well may reflect the sampling of discrete, chemically different water masses at these locations.

- The trace metals present in greater concentrations in waste solids versus background soils (e.g., chromium, vanadium) are unavailable for leaching under the prevailing conditions.

5.4.5.5 Environmental Effects Implications--

The evaluation of testing results at the Dave Johnston disposal site indicates that the landfill will not have a significant impact on groundwater quality. Coal ash constituents that under other circumstances could migrate and have an adverse effect on usable groundwater, are moving too slowly, due to the arid setting, to be significant. Additionally, these would not have a perceptible effect, in this particular setting, given the comparably high background concentrations of the same species that already limit the quality of the receiving groundwater. At another site where background water quality was less degraded, the potential for incremental impact would be greater. The findings at the Dave Johnston site support conclusions 1,2,4, and 5 persented in Section 5.1 and have the following broader implications for similar disposal practices:

1. Disposal of coal ash wastes in highly mineralized, arid western settings is facilitated by the prevalence of conditions minimizing leachate formation and movement. It is also facilitated by the opportunity for leachates to admix with groundwater already contaminated by most of the same major and minor species that characterize the waste leachate. In such circumstances, the presence of leachate may be detectable using such tracers as calcium, but the leachate would be expected to have little, if any, potential for significant incremental impact on receiving water quality.

2. The order of magnitude variations in background water quality over relatively short distances at the Dave Johnston site demonstrate that even in highly mineralized arid settings there are isolated areas of excellent groundwater quality that may require protection in disposal site planning and management.

3. The capacity of at least one soil type at the site to attenuate various leachate trace metals appears extremely poor, suggesting that in similar settings one may have to rely on the inherent and/or supplemental restriction of water movement rather than chemical attenuation to mitigate potential impacts of leachable trace metals.

5.4.6 Engineering Cost Assessment

5.4.6.1 Engineering Assessment--

The Dave Johnston Plant is a baseload facility, consisting of four pulverized coal-fired units with a total nameplate generating capacity of 750 MW. Two 100 MW capacity boilers, Units 1 and 2, were commissioned in 1959 and 1961, respectively. During 1964, operation of Unit 3, with a 220 MW nameplate generating capacity, commenced. The final unit to be installed at this plant was Unit 4, with a 330 MW capacity, which started up in 1972. The annual average capacity factors reported in 1978 for each of Units 1 through 4 were 91.5, 78.8, 81.8, and 65.5 percent, respectively.

Air Pollution Control--In 1976, Units 1, 2, and 3 were each retrofitted with cold-side electrostatic precipitators to collect dry fly ash; these operate at 99.4 percent efficiency. A mechanical collector servicing Unit 3 with 86 percent collection efficiency remains in service, although similar collectors have been removed from Units 1 and 2. Units 3 and 4 are equipped with an economizer ash removal system (soot blowers, hoppers, etc.). No economizer ash is removed from Units 1 and 2.

The air pollution control system servicing Unit 4 consists of three venturi scrubbers. Although the primary purpose of these scrubbers is to collect fly ash, some sulfur oxides are also removed from the flue gas. However, the percentage removal is too small to equate these scrubbers with a flue gas desulfurization (FGD) system. Because dry fly ash is the waste of interest at this plant, the wet scrubber and its associated waste handling/disposal systems are not discussed further.

Coal Consumption--Subbituminous Powder River Basin coal used by the David Johnston Plant is obtained from a strip mine owned and operated by Pacific Power and Light Company and located in Wyoming, 24 km (15 miles) north of the plant. Coal consumption between 1976 and 1980 ranged from 2.54 to 3.34 million metric tons/yr (2.79 to 3.67 million tons/yr). The annual average sulfur content of the coal used at this plant was reported to be nearly constant at 0.45 weight percent. The annual average heat content of the coal ranges from 17.4 to 18.0 million joules/kg (7,460 to 7,740 Btu/lb). Similarly, the coal ash content has varied, ranging from a low of 8.97 weight percent to a high of 10.76 weight percent.

Waste and Water Management--As much as 253,000 metric tons/yr (278,000 tons/yr) of fly ash has been produced at the Dave Johnston Plant, of which approximately 132,000 metric tons (145,000 tons) is in dry form. A portion of the dry fly ash generated has been sold for use as an additive in the production of concrete. In 1980, approximately 20 to 35 percent, or 27,000 to 45,000 metric tons (30,000 to 45,000 tons) of the dry fly ash generated was sold.

Dry fly ash collected from Units 1, 2, and 3 and dry economizer ash generated by Units 3 and 4 are pneumatically conveyed (pressure system) to ash storage silos. Separate conveyors service each of the three units. Separate conveyors are also used to transport economizer ash collected from Units 3 and 4. The dry fly ash storage silos are equipped with rotary drum unloaders in which a water spray is employed for dust control. Heavy off-the-road trucks are used to transport this dry ash to a landfill. Process flow diagram F-300, Figure 5.26 depicts the fly ash handling system and provides a material balance for this operation.

Disposal Operation--A number of sites have been used for the purpose of dry fly ash disposal. The total area of the Dave Johnston Plant site that can be used as a landfill is 1.6 million m^2 (400 acres). At any given time, only a small portion of this area is active. The current active landfill is 100,000 m^2 (25 acres) in surface area and is less than 1.6 km (1.0 mile) from the plant. This landfill is a licensed sanitary landfill which receives plant refuse in addition to dry fly ash. Water trucks are used on a continuing basis to keep the landfilled material wet and thereby control fugitive dust emissions. Ash is placed in this landfill by end-dumping from the top of the deposit in approximately 6 m (20 ft) lifts. This minimizes the disturbed area of the landfill, thereby controlling the formation of dust by the prevailing wind. End-dumping results in loose placement of the ash and relatively little compaction of the ash occurs after placement.

In addition to the engineering information presented herein, a list of modular area accounts for the Dave Johnston Plant dry fly ash handling and disposal system was developed. Detailed equipment lists were also prepared. These are provided in Appendix G, Tables G-3 and G-9, respectively.

5.4.6.2 Cost Assessment--

The process description and process flow diagrams provided above served as the basis for the estimation of capital and annual costs for the dry fly ash handling and disposal operation at the Dave Johnston Plant. However, to provide consistency among the cost estimates developed for the six sites, it was necessary to specify certain engineering design premises which were consistent for all study sites (e.g., plant service life, load factor, heat rate, etc.). The engineering design premises for the Dave Johnston cost estimates are listed in Table 5.21.

Detailed capital cost estimates for the Dave Johnston Plant dry fly ash handling and disposal operation are presented in Appendix G, Table G-15. A summary of modular capital cost estimates is presented in Table 5.22. The major capital cost element of the waste handling and disposal system is the

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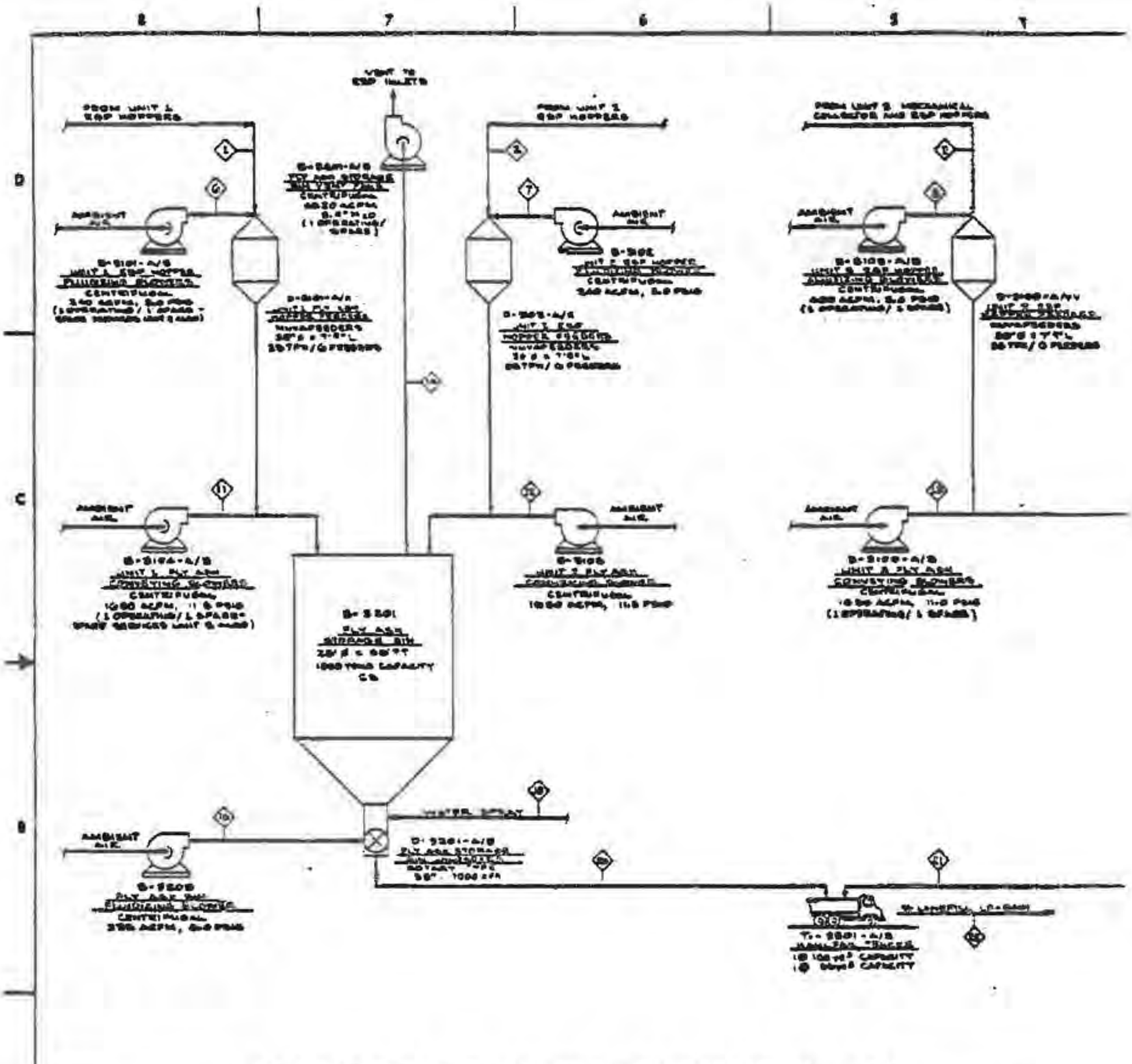


DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24-HOUR OPERATING DAY*

DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TON FLY ASH/DAY	150	150	310	20	30	—	—	—	—	—	—	—	—	—	—	—	—	—
TON AIR/DAY	—	—	—	—	—	6	16	32	56	110	154	189	56	286	107	28	21	—
% REQ'D AIR	—	—	—	—	—	415	445	890	7160	2905	4185	4183	4106	6888	2819	746	500	—
TON WATER/DAY	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	72

* - MASS BALANCE FOR AIR WILL NOT BALANCE, DUE TO THE FACT THAT AIR FLOWS ARE FOR DESIGN (MAXIMUM) BLOWER OUTPUT CONDITIONS. IN ACTUAL OPERATION, FLY ASH / ECONOMIZER ASH CONVEYING BLOWERS ARE INTERMITTENTLY DEAD-HEADED.

FIGURE 5.26

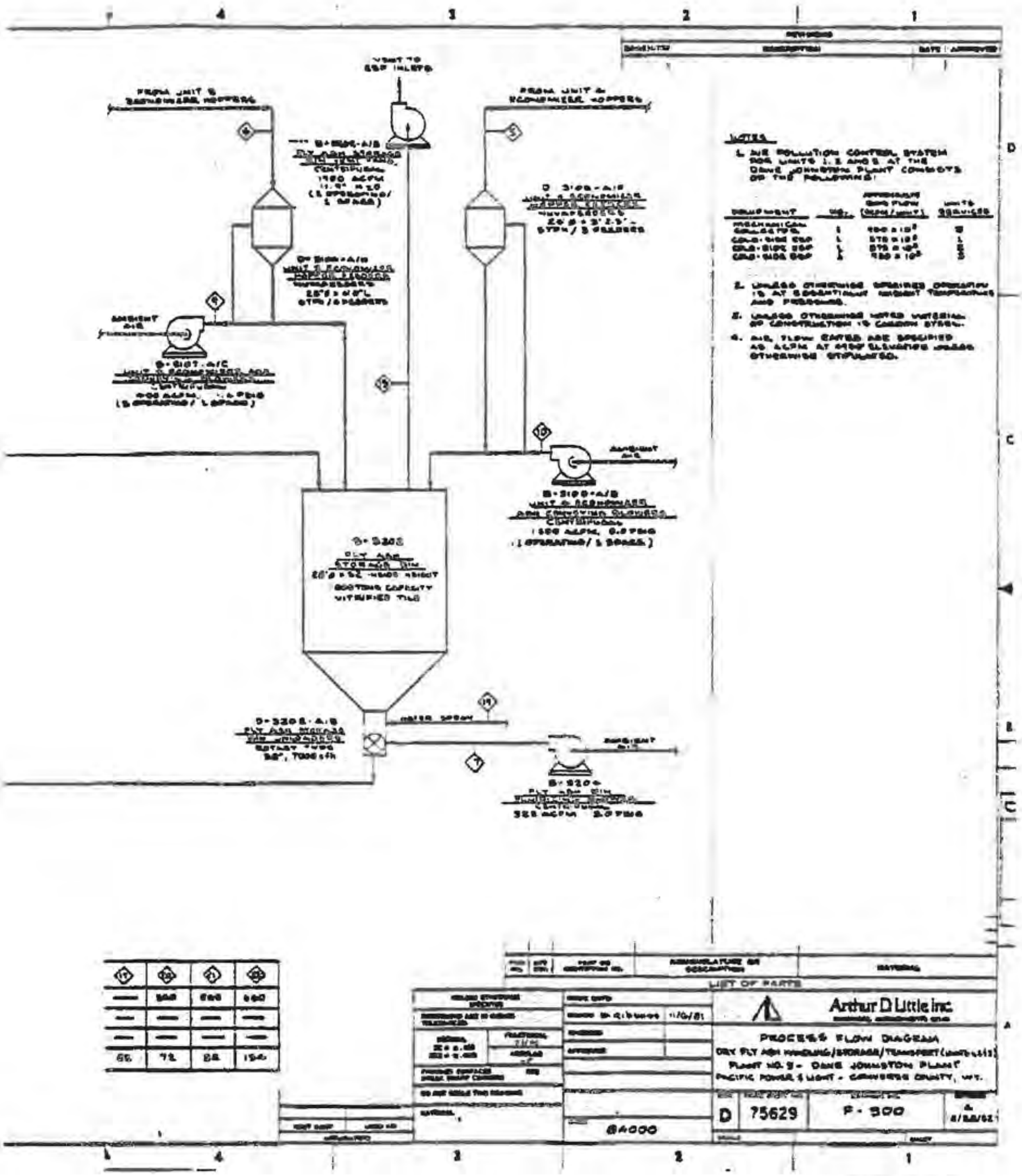


FIGURE 5.26

TABLE 5.21

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR
DAVE JOHNSTON PLANT (Units 1, 2 and 3)
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES	
Power Plant	
Plant Size (MW)	420
Boiler Type	Pulverized Coal
Heat Rate (M joules/kWh; Btu/kWh)	12; 11,400
Location	Wyoming
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Waste Generated (dry basis)	
Fly Ash/Bottom Ash Ratio	75/25
Fly Ash Generation (metric tons/yr; tons/yr)	153,000; 168,700
Bottom Ash Generation (metric tons/yr; tons/yr)	--
FGD Waste Generation (metric tons/yr; tons/yr)	--
Ash Utilization	None
Coal Properties	
Coal Type	Subbituminous
Sulfur Content (Percent)	0.45
Ash Content (Percent)	11.0
Heating Value (M joules/kg; Btu/lb)	17.4; 7500
Air Pollution Control	
Particulate Control	ESP's (Units 1-3); Mechanical Collector (Unit 3)
Particulate Removal (Percent)	>99
Sulfur Oxides Control	None
Disposal Site	
Type	Landfill
Design Life (yr)	30
Land Area (m^2; acre)	493,700; 122
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner (type; m; ft)	None
Distance from Plant (km; mile)	1.6; 1.0

TABLE 5.22

CAPITAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Dave Johnston
Plant Location: Converse County, Wyoming
Utility Name: Pacific Power & Light Company
Nameplate Generating Capacity (MW): 420

WASTES	CAPITAL COSTS ($1000) Fly Ash	Bottom Ash
MODULES		
• Waste Handling and Processing	$6,912	$ [b]
• Waste Storage	2,512	
• Waste Transport	689	[b]
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	4,596	[b]
SUBTOTAL - MODULAR COSTS	$14,709($35/KW)	$ - [b]
RELATED ENVIRONMENTAL SYSTEMS		
• Air Pollution Control	45,448	$ - [b]
TOTAL CAPITAL COSTS	$60,157($143/KW)	$ [b]

[a] ENR Cost Index = 3931.11 (1913=100)
365.97 (1967=100)

[b] The bottom ash waste handling, transport and disposal systems at the Dave Johnston Plant were not considered in this study.

Source: Arthur D. Little, Inc. estimates.

waste handling system ($16/kW). This is partly because the plant uses a pressure pneumatic conveying system which incorporates very expensive equipment for feeding ash from the electrostatic precipitator and economizer ash hoppers into the pressurized conveying lines. As a result, the waste handling/processing module costs constitue nearly 50 percent of the total waste handling/disposal capital costs ($35/kW), exclusive of air pollution control-related capital costs. The capital costs for these systems at the Elrama Plant ($68/kW) and Powerton Plant ($54/kW) are considerably greater than the Dave Johnston Plant costs. This is due to the fact that the capital costs for the Elrama and Powerton Plants include costs for fly ash, bottom ash and in the case of the Elrama Plant. FGD waste, However, if one looks at the costs for fly ash only, since this is the only waste under consideration at the Dave Johnston Plant, the capital cost at Dave Johnston ($35/kW) is higher than those at both the Elrama ($26/kW) and Powerton ($22/kW) Plants. This is primarily due to the following :

- The pressure-type pneumatic conveying system used at the Dave Johnston Plant is considerably more costly than the pressure/vacuum or vacuum systems in use at the other two plants; hence, the associated total capital costs are similarly relatively high.

- The Dave Johnston Plant uses off-the-road ash hauling trucks which are more expensive to purchase than on the road trucks.

- The quantity fly ash produced per unit of electric power generation capacity at the Powerton Plant is significantly less than that at the Dave Johnston Plant. This is because cyclone-fired boilers are used at the Powerton Plant which results in a fly ash/bottom ash ratio of 30/70.

A detailed annual cost estimate was also prepared for the Dave Johnston fly ash handling and disposal system. This estimate is provided in Table G-21, Appendix G. A simplified summary of these estimates is provided in Table 5.23. On a unit cost basis, the annual cost of waste handling and disposal for the Dave Johnston Plant ($24.90/dry metric ton) was lower than for the other two sites (Elrama at $32.60/dry metric ton and Powerton at $27.30/dry metric ton) considered which practice landfill disposal. Reasons for these differences are that:

- One site (Elrama) practices FGD waste fixation, which is more expensive due to the greater complexity of the waste handling and processing system.

- The other site (Powerton) practices landfill disposal in lined gravel pits. The liner adds significantly to capital charges since it is both expensive and is used in relatively large quantities. Additionally, no economies of scale are realized, since a number of small gravel pits are used.

TABLE 5.23

ANNUAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Dave Johnston
Plant Location: Coverse County, Wyoming
Utility Name: Pacific Power & Light Company

Operating Load Factor (percent) 70
Nameplate Generating Capacity (MW): 420
Waste Generation (dry metric tons/yr):
Fly Ash 153,000

WASTES	ANNUAL COSTS ($1000) Fly Ash	Bottom Ash
MODULE		
• Waste Handling and Processing	$1,861.0	$ — [b]
• Waste Storage	579.2	— [b]
• Waste Transport	374.1	— [b]
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	1,000.1	— [b]
SUBTOTAL - MODULAR COSTS	$3,816.4 ($24.90/dry metric ton)	$ — [b]
RELATED ENVIRONMENTAL SYSTEMS		
• Air Pollution Control	NA[c]	— [b]
TOTAL ANNUAL COSTS	$3,816.4 + NA[c]	$ — [b]

[a] ENR Cost Index = 3931.11 (1913 = 100)

[b] The Dave Johnston Plant bottom ash handling, transport and disposal systems were not considered in this study.

[c] NA = Information not available.

Source: Arthur D. Little, Inc. estimates.

However, the difference between the annual costs at the Dave Johnston site and those for the Elrama and Powerton plants are not as significant as would be expected. This is due to the following:

- The pressure pneumatic conveying system used at the Dave Johnston Plant is considerably more capital intensive than the combination pressure/vacuum or vacuum systems employed at the other two plants, and, hence, the associated capital charges are similarly relatively high.
- The Dave Johnston Plant employs off-the-road ash hauling trucks which are more expensive to purchase than on-the-road trucks. Additionally, the trucks in use at the Dave Johnston Plant provide significant over-capacity.

5.5 SHERBURNE COUNTY PLANT

5.5.1 Plant Description

5.5.1.1 Background--

The Sherburne County Plant of Northern States Power Company is located in Sherburne County, Minnesota, approximately 2 km (1.3 miles) south of the town of Becker and 48 km (30 miles) northwest of Minneapolis. The plant site is adjacent to the northeast bank of the Mississippi River, as shown in Figure 5.27.

The Sherburne County Plant consists of two units, each equipped with fly ash alkali FGD scrubbers that use supplemental limestone. The combined fly ash/FGD waste effluent is thickened before disposal in a clay-lined pond. Bottom ash and mill rejects are sluiced to a separate clay-lined disposal pond. Each of these ponds has an associated clarifying pond which receives the overflow from that pond. The effluents from the overflow ponds are recycled for use as a scrubber medium or for waste sluicing.

The disposal ponds were constructed by excavating within each basin and using the granular outwash deposits to construct the earth retention dikes. A clay core was added to the dikes, and a 0.46 m (18 in) thick clay liner was placed at the bottom of each excavation and connected to the dike cores. Retirement and reclamation is planned for all disposal ponds after they have met designed storage capacity.

The following factors were important in the selection for study of the FGC waste ponding operations at the Sherburne County Plant:

- The waste management practice includes several features of interest and likely future importance. First, simultaneous removal of fly ash and sulfur oxides occurs in a mode of external forced oxidation at this plant. This produces a sulfate-rich waste material that is generally easy to dewater and handle. Therefore, forced oxidation has been broadly identified as a potentially mitigative measure to increase the number of available waste management options for FGD

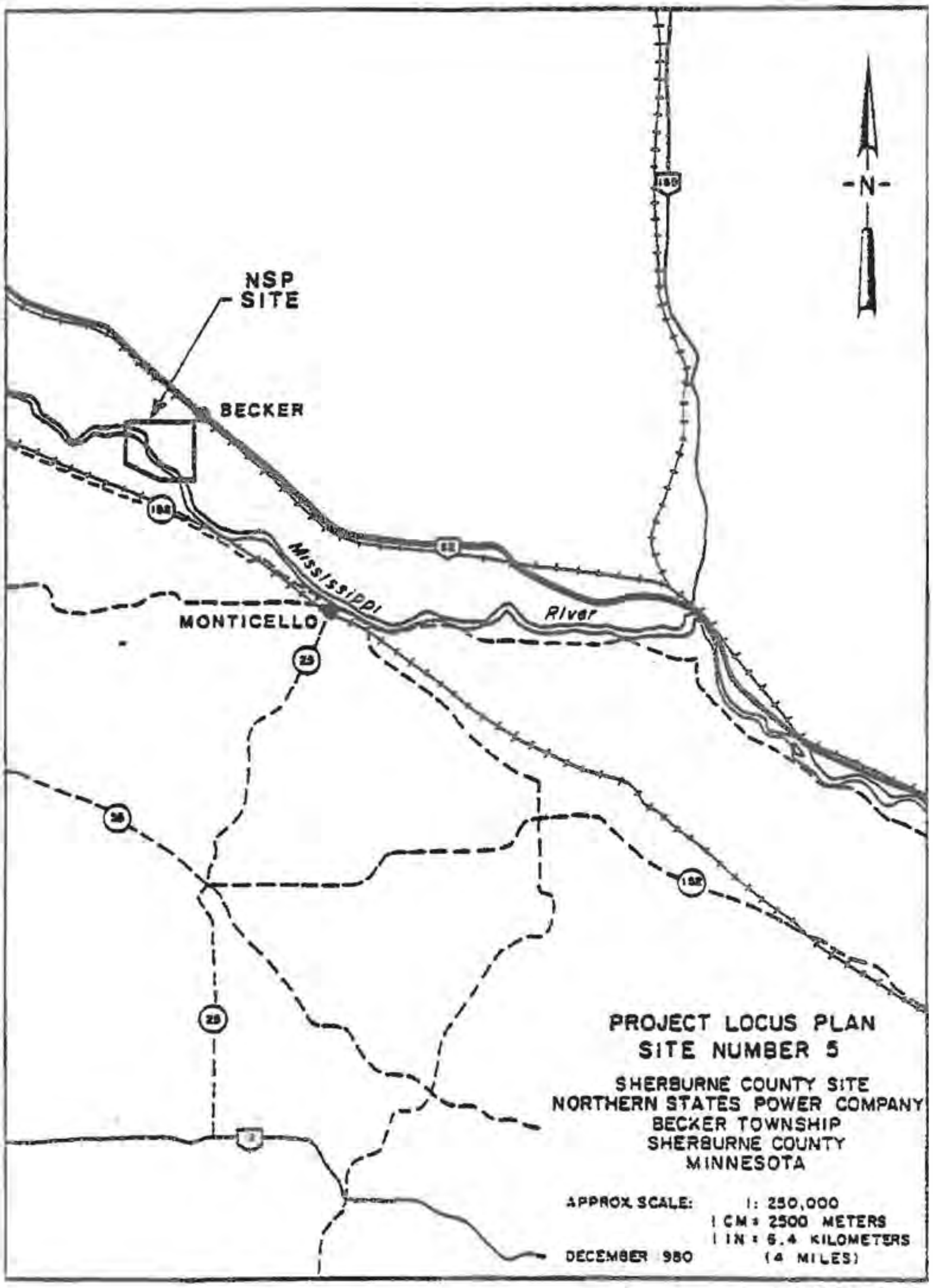

N
NSP SITE
BECKER
Mississippi River
MONTICELLO
PROJECT LOCUS PLAN
SITE NUMBER 5
SHERBURNE COUNTY SITE
NORTHERN STATES POWER COMPANY
BECKER TOWNSHIP
SHERBURNE COUNTY
MINNESOTA
APPROX. SCALE: 1: 250,000
1 CM = 2500 METERS
1 IN = 6.4 KILOMETERS
(4 MILES)
DECEMBER 980

FIGURE 5.27

wastes. Few other plants practiced forced oxidation at full-scale in 1980, although it is expected to be a growing practice in the future.

- Secondly, the disposal system consists of separate, adjacent, clay-lined ponds for the FGC waste/fly ash mixture and for bottom ash, with recycle of the waste transport water. The pond lining and water recycle provisions are modern, potentially mitigative features of general interest to the study program; they were represented at very few locations in 1980. In particular, this site afforded an opportunity to study liner performance in the ponding of wastes with potentially high ranges of major dissolved species (e.g., sulfate and boron).

- Thirdly, western coal is employed at the Sherburne County Plant. Given the anticipated growth in generating capacity based on use of western coal with FGD systems, this factor also broadens the potential applicability of findings from work at this site.

- Additionally, the environmental setting is isolated from any other sources of potential contamination and combines modest precipitation, local high-quality groundwater and seasonal temperature extremes (i.e., very cold winters). It was expected that this setting would facilitate the identification of any waste-related groundwater contamination.

5.5.1.2 Geologic Conditions--

The Sherburne County Plant is located within the Superior Uplands Physiographic Province on the southern margin of the Canadian Shield. The Uplands are characterized by irregular and undulating glacially derived drift overlying relatively shallow crystalline rock.

The project site area is underlain by pre-Cambrian granites that vary from 15 to 45 m (50 to 150 ft) below ground surface. The major overburden soil throughout the site area consists of glacially derived, permeable outwash sands and gravels with minor amounts of silt and cobbles. These glacial drift sediments were deposited from meltwater streams which issued from the terminus of wasting ice lobes. However, due to major fluctuations in temperature during the close of the glacial period, minor readvances of the ice occurred in the site vicinity. The readvances caused the deposition of lobes of a very dense, heterogenous mixture of silt, sand and clay over the previously deposited outwash deposits. These sediments, referred to as glacial till, occur as discontinuous lenses and layers of varying thickness within the outwash sands and gravel.

The adjacent Mississippi River has locally deposited various river terrace and flood plain sands and silts over the glacial drift deposits. These deposits, although in close proximity to the disposal area, are encountered only in the downgradient portions of the site, adjacent to the river.

Figure 5.28 summarizes the site area surficial geologic conditions and Figure 5.29 presents a general subsurface geologic profile in the site area.

5.5.1.3 Hydrologic Conditions--

The Sherburne County Plant site lies within the Mississippi River Groundwater Province and the Sauk River Watershed. The principal water bearing units in the watershed are the unconsolidated glacial outwash sands and gravels. The pre-Cambrian bedrock units do not constitute any developable aquifer potential. The plant obtains its operational waters from the Mississippi River and its fresh water requirements from large diameter wells in the outwash deposits.

Annual precipitation is approximately 0.71 m (28 in). In general, there is no surface runoff in the site area with all precipitation infiltrating rapidly through the granular overburden soils to the groundwater table. The groundwater table is located approximately 10.7 to 12.2 m (35 to 40 ft) below the existing ground surface in the site area. All groundwater flow is southwesterly towards the Mississippi River.

5.5.2 <u>Site Evaluation Plan and Site Development</u>

Thirteen groundwater monitoring wells or piezometers had been previously installed throughout the plant site by Northern States Power Company to evaluate potential disposal pond seepage during the period 1977-1979. Information obtained from these well installations, in addition to test boring data obtained for geotechnical purposes, provided a valuable basis for developing the project site evaluation and development plan.

Northern States Power Company has conducted groundwater monitoring at the Sherburne County Plant site since 1977. Their program indicated elevated concentrations of sulfate (in the range of 1500 ppm), boron (up to 16 ppm) and selenium (up to 32 ppb) in downgradient groundwater to the west and southwest of the FGC waste pond. These elevations were attributed by the utility to leakage from sheet piling and/or drainage conduits along the western edge of the pond complex, rather than to permeation of the pond liner by leachate. It was also hypothesized by contractors to Northern States Power Company that much of the predicted movement of leachate through the liner would be recycled through the plant water use system. This hypothesis was related to a judgement that the pond was at least seasonally in the cone of depression for the plant water supply well and the fact that soils below the liner are relatively pervious. With these factors in mind, the site monitoring infrastructure for this program was developed in late August 1981 to emphasize downgradient areas near the ponds but east of the path of the plume from the reported leakage.

The site development plan for the Sherburne County disposal pond complex included the installation of multi-purpose observation wells, piezometers and exploratory test borings for hydrogeological and geotechnical evaluation purposes. Two upgradient observation wells were installed for background monitoring purposes and six downgradient wells were installed at various locations and elevations to determine the presence and extent of movement of

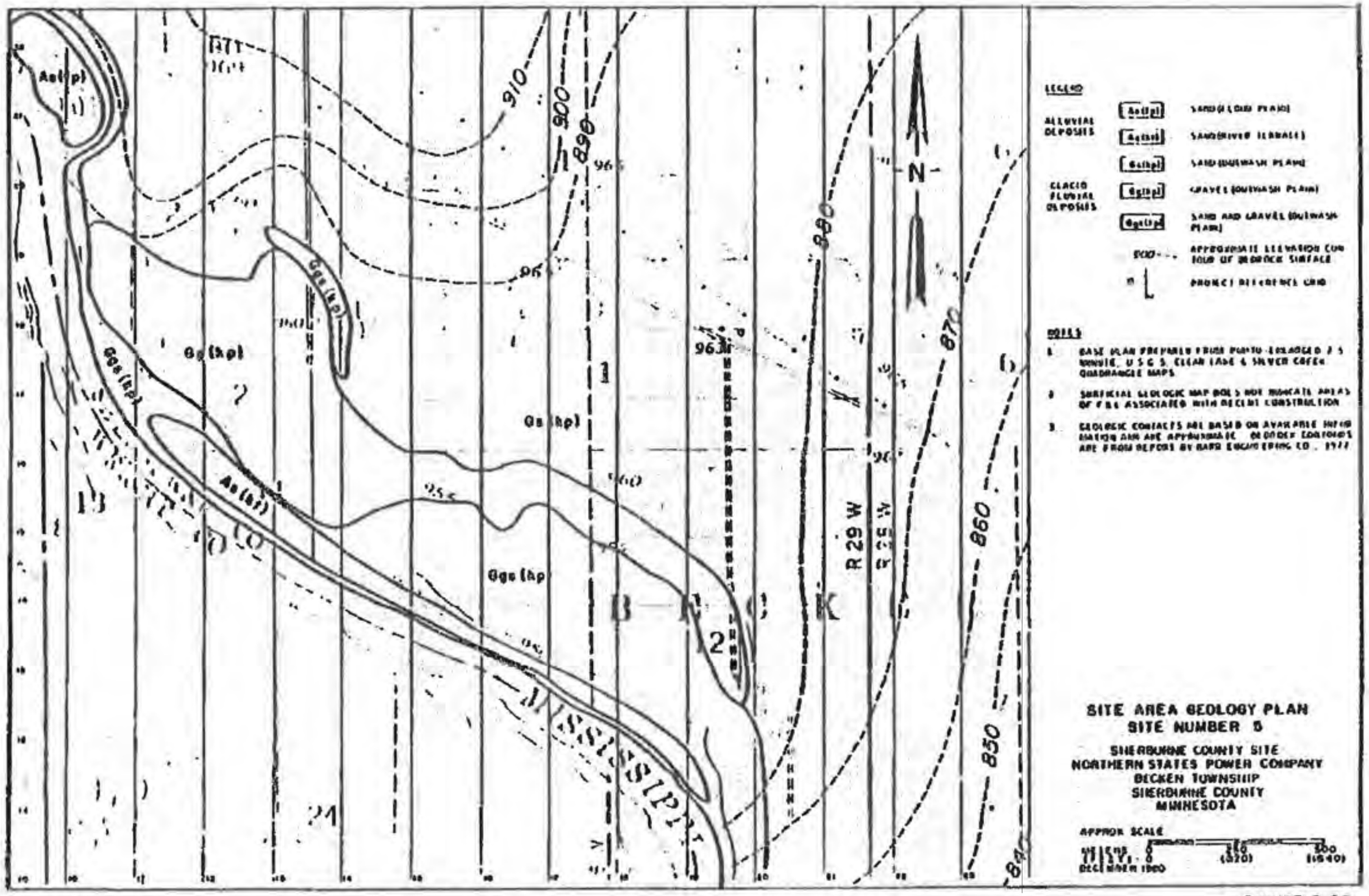
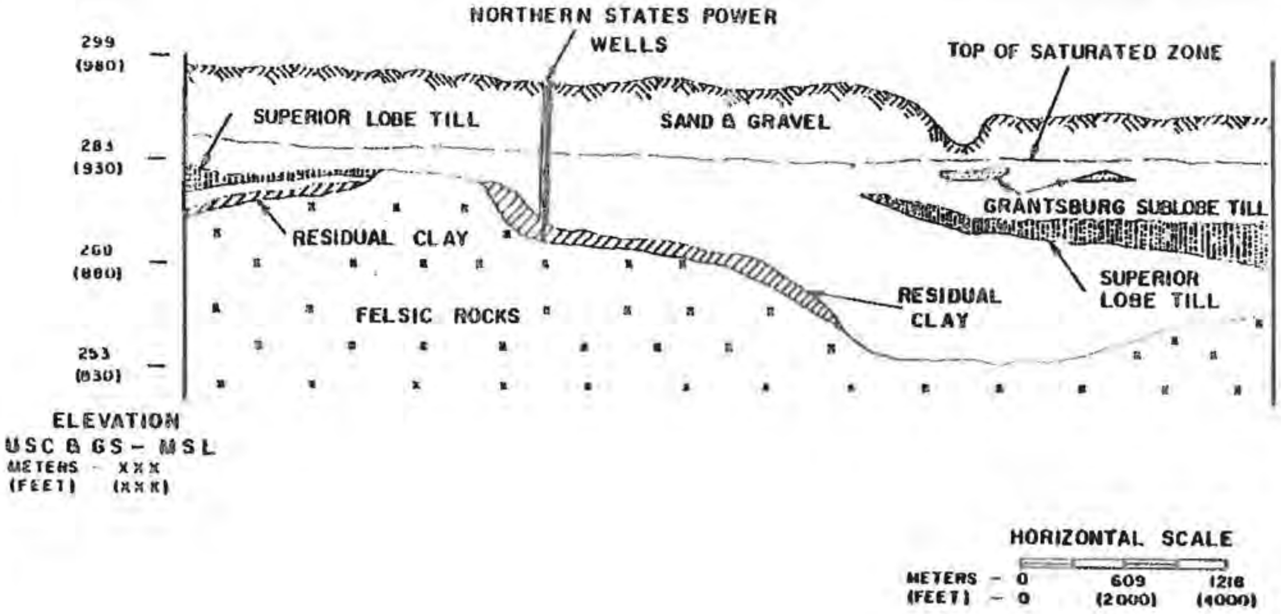

910
900
890
880
870
860
850
N
R 29 W
LEGEND
SITE AREA GEOLOGY PLAN
SITE NUMBER 5
SHERBURNE COUNTY SITE
NORTHERN STATES POWER COMPANY
BECKEN TOWNSHIP
SHERBURNE COUNTY
MINNESOTA
APPROX SCALE

FIGURE 5.28



GENERAL GEOLOGIC CROSS-SECTION THROUGH SHERBURNE COUNTY PLANT
SHERBURNE COUNTY MINNESOTA
(GROUNDWATER INVESTIGATION, BARR ENGINEERING CO.,1977)

FIGURE 5.29

any leachate. Two continuously sampled borings were obtained from floating equipment on the fly ash/FGD waste pond. Special procedures were utilized to penetrate the underlying clay liner, and the boreholes were pressure-tremie grouted upon completion to insure resealing.

The locations of all explorations and monitoring/sampling installations are indicated on Figure 5.30 and a summary of all field results are indicated on Table 5.24.

At the completion of all monitoring installations, the wells were flushed, bailed and an initial sample obtained for chemical evaluation purposes.

5.5.3 Physical Testing Results

Results of permeability tests, Standard Penetration Tests, and Unified Soil Classification Tests performed on FGC waste from the Sherburne County waste pond are presented on Figure 5.31. This Figure also indicates the results of tests performed on the earthfill liner located beneath the fly ash/FGD waste pond.

The results of tests performed on samples of the FGC waste indicate the following:

1. No significant stratification of the FGC waste was observed and, therefore, the coefficient of permeability of the waste was fairly uniform throughout the deposit ranging from 7×10^{-5} to 5×10^{-6} cm/sec.

2. The upper 3.6 m (15 ft) of waste in the pond was cemented; however, the cementation did not appear to have a substantial effect on the coefficient of permeability of the waste.

3. Increasing the dry density of the FGC waste substantially reduces its coefficient of permeability.

Particular care was taken in sampling the earthfill located beneath the pond while still maintaining the liner integrity. Testing of the liner consisted of field permeability tests in addition to laboratory permeability tests performed on samples of the liner obtained from both beneath the ponds and the dikes. Based on these test results, it is estimated that the earthfill liner has a coefficient of permeability which ranges from 5×10^{-7} to 1×10^{-7} cm/sec.

Selected physical testing results are presented in Table 5.25. A more detailed compilation of these results for the Sherburne County Site is provided in Appendix E.

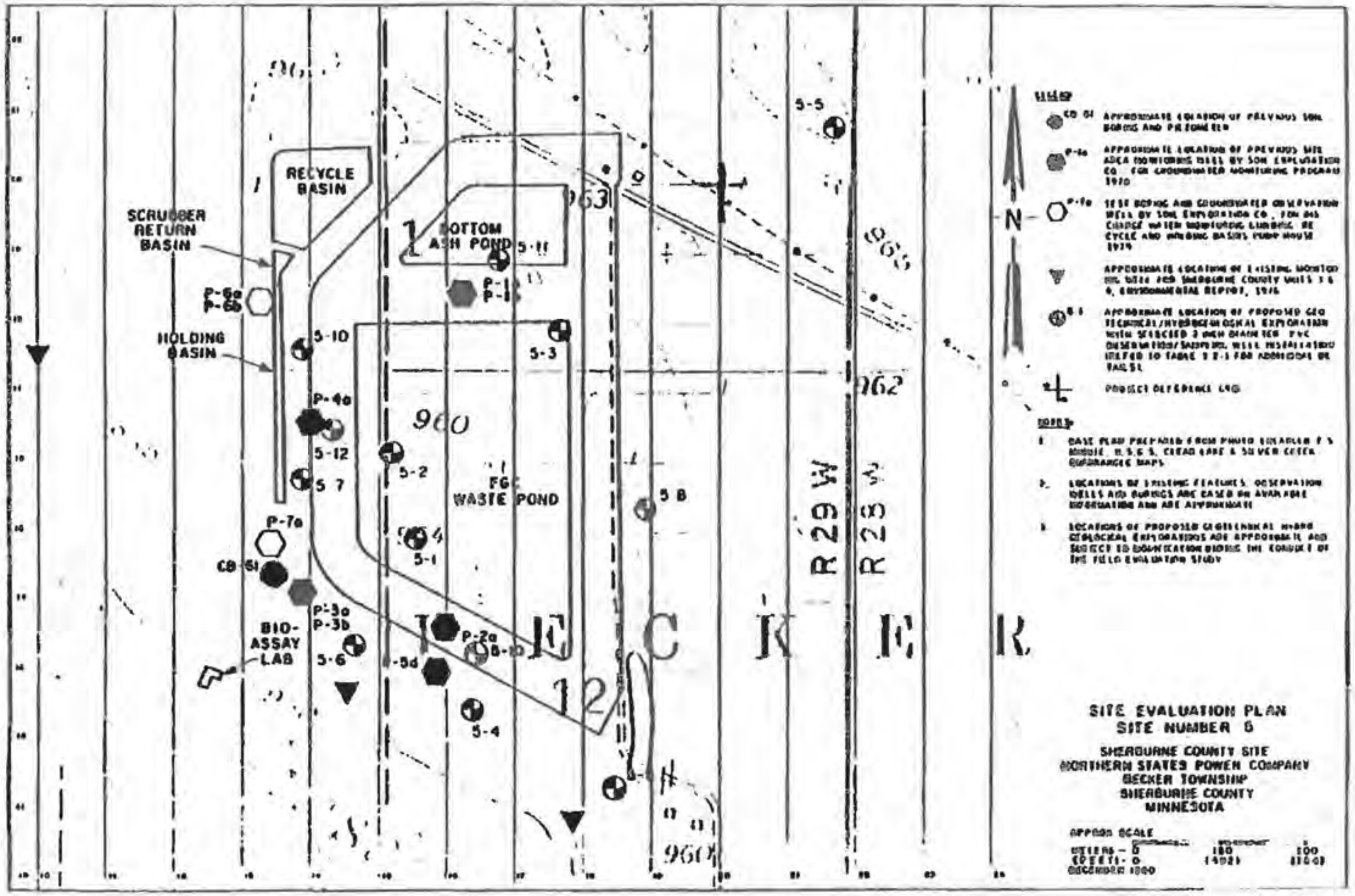

RECYCLE BASIN
SCRUBBER RETURN BASIN
BOTTOM ASH POND
HOLDING BASIN
FGC WASTE POND
BIO-ASSAY LAB
R 29 W
R 28 W
N
SITE EVALUATION PLAN
SITE NUMBER 5
SHERBURNE COUNTY SITE
NORTHERN STATES POWER COMPANY
BECKER TOWNSHIP
SHERBURNE COUNTY
MINNESOTA

FIGURE 5.30

TABLE 5.24

SITE DEVELOPMENT SUMMARY

SITE: SHERBURNE COUNTY POWER PLANT
SHERBURNE COUNTY, MINNESOTA

DATES: August 20, 1981 August 26, 1981

TOTAL NO. EXPLORATIONS ON SITE: 11

Boring #	S-1	S-2	S-4
Soils Classification [depth (m): Class]	0-0.3: Water Surface 0.3-8.4: FGD Sludge 8.4-8.7: Clay (Liner) 8.7-10.2: Sand	0-2.0: Water Surface 2.0-2.1: FGD Sludge 2.1-8.4: Layering; Light FGD/Fly Ash 8.4-8.9: Clay (Liner) 8.9-9.6: Dark Sand	0-0.1: Sand, med. grain, dark brown, loose, dry trace silt 0.1-0.8: Sand, med. grain, brown, loose, damp, little grained, little cobbles 0.8-2.4: Sand, fine-med. grain, brown, very dense, damp, little ground 2.4-17.4: Sand, fine grain, brown very dense, damp, trace ground, some cobbles wet at 7.8 damp below wet at 11.7 17.4-19.8: Sand med-coarse gr light brown, very dense, wet some gravel, trace silt
Number of Samples Obtained	12	13	15
Field Permeability	-	—	—
Well Installation	No Well	No Well	Well
Remarks			Ground Elev. = 290.9M

(continued)

TABLE 5.24

SITE DEVELOPMENT SUMMARY

SITE: SHERBURNE COUNTY PLANT

Boring #	5-5	5-6	5-7	5-8
Soils classification [depth (m): class]	0-0.3: Sandy Silt 0.3-2.4: Sand, fine-med. gr. reddish brown, med. dense, damp, some gravel 2.4-23.2: Sand, med.-coarse gr. dark brown, loose-dense damp, wet at 7.9m some gravel, some cobbles from 7.3m	0-0.3: Sand, fine-med. gr. black, loose, dry little silt 0.3-0.8: Sand, med. gr., dark brown, very loose, damp 0.8-5.2: Sand, fine-med. gr. brown, dense very little gravel, some cobbles 5.2-7.2: Sand, med-coarse gr. light brown, med. dense, some cobbles, boulders @ 6.4M 7.2-11.3: Sand, fine gr., brown, dense-very dense, damp moist, trace silt ground, water @ 10.7M 11.3-14.9: Sand, coarse gr. brown, very dense, wet, some gravel cobbles, boulders at 14.0M 14.9-16.2: Sand, fine-med. gr., dark brown, very dense, wet some gravel 16.2-17.8: Sand, coarse gr., brown, very dense, wet some gravel, cobbles, boulder 17.8 - : 1st hole abandoned after losing sample 3m rod. Bottom of boring 17.8 on boulder	0-0.3 Fill material, silty sand, med. gr. 0.3-0.8 Sand, light brown, dry, med coarse gr. 0.8-4.0 Sand, med. gr. brown, moist rock layer @ 3.7-4.0M 4.0-6.7 Sand, fine gr., brown very dense, damp @ 5.9-clay, light brown, damp 6.7-21.6 light brown, moist little gravel below 8.8M, wet, brown @ 11.6M cobbles @ 13.7M refusal @ 21.6M	0-0.3 Silty sand, dark brown damp 0.3-1.8 Sand, fine gr., dense very dense, light brown, moist 1.8-4.6 Sand, fine grained, dark brown, very dense, moist some gravel 4.6-18.0 Sand, coarse gr., brown very dense, moist, some gravel, cobbles from 6.4M, wet below 11.3M
Number of Samples Obtained	9	12	15	9
Field Permeability	--	--	--	--
Well Installation	Well	Well	Well	Well
Remarks	Ground Elev.=293.4m	Elev.=291.6m	Elev.=292.7m	Elev.=292.9m

(continued)

TABLE 5.24

SITE DEVELOPMENT SUMMARY

SITE: SHERBURNE COUNTY PLANT

Boring #	5-9	5-10	5-11
Soils Classification [depth (m): Class]	0-0.3: Silty sand, dark brown, loose damp 0.3-2.4: Sand, med. gr., brown, coarse damp 2.4-2.9: Silty sand, light brown damp 2.9-5.9: Sand med. gr., light brown, very dense, moist, some gravel, loose cobbles 5.9-6.7: Silty sand, brown damp, very dense 6.7-17.7: Sand, med. to coarse gr., brown, very dense, moist, some gravel, trace cobbles, wet @ 10.4M, boulders from 14.3 17.7-19.2: Sand, fine to med. grain, brown, very dense, wet 19.2-22.6: Sand, coarse gr., brown, very dense, wet 22.6-24.2: Sand, med-coarse gr. brown, very dense, wet 24.2-25.6: Sand fine gr. brown, very dense, wet 25.6-28.6: Sand, coarse gr., brown very dense, wet little gravel	0-1.2: Sand, fine-med. gr. dark brown, mix colors, damp fill material 1.2-3.7: Sand, med. grain, dark brown, loose med. dense, damp 3.7-5.9: Sand, coarse gr., dark brown, dense damp, trace gravel 5.9-8.2: Sand, med. gr., brown, dense very dense, moist cobbles @7.2M 8.2-18.0: Sand, coarse gr. light brown brown, moist wet @ 11.3M some cobbles	0-0.5: Sand, med. gr., brown, dry 0.5-0.8: Silty sand, light brown very dense, dry trace gravel 0.8-5.2: Sand, med. gr., brown, med.-very dense, damp trace gravel & silt 5.2-7.5: Sand, coarse gr., light brown, med. dense, damp 7.5-15.8: Sand, med. gr., brown very dense, damp, trace silt & gravel, moist @ 11.9M 15.8-23.8: Sand, coarse gr., brown, very dense, wet trace silt & gravel refusal @ 23.8m
Number of Samples Obtained	20	11	11
Field Permeability Tests		—	—
Well Installation	Well		Well
Remarks	Elev. = 291.1m	Elev. = 293.1m	Elev. = 294.3m

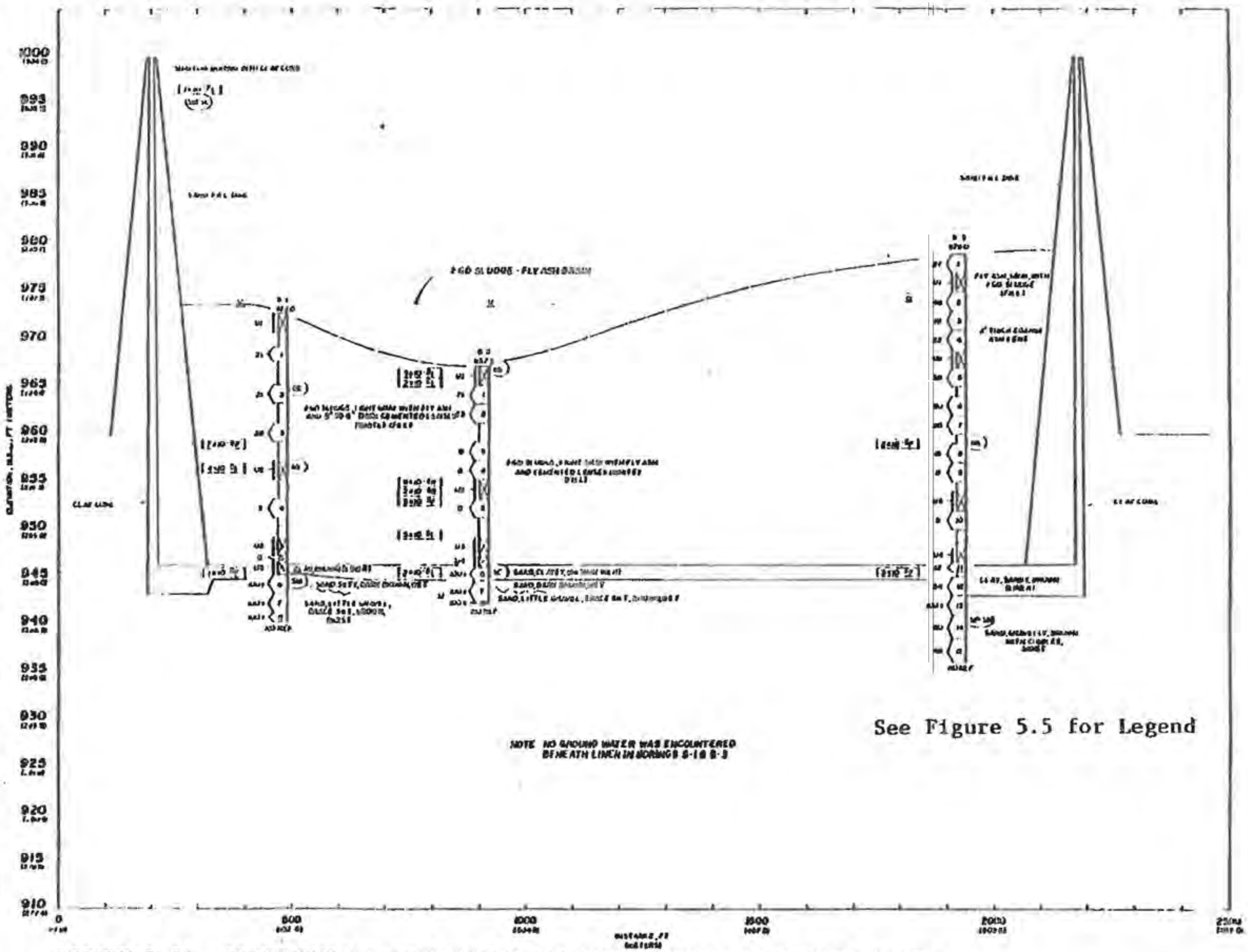


FIGURE 5.31 GEOTECHNICAL EVALUATION RESULTS, SHERBURNE COUNTY PLANT, NORTHERN STATES POWER COMPANY, SHERBURNE COUNTY, MINNESOTA

TABLE 5.25

SELECTED PHYSICAL TESTING RESULTS

SHERBURNE COUNTY PLANT[a]

Permeability (cm/sec)	1×10^{-7} x $3 \times 10^{-[illegible]}$
Specific Gravity	2.34 - 2.73
Grain Size Distribution (Weight Percent)	
• > 74 μm	5 - 93
• 2 - 74 μm	[illegible] - 95
• < 2 μm	0 - 16
Moisture Content (Weight Percent)	1.4 - Saturated
Effective Strength Parameters	
• Angle of Internal Friction	58.4°
• Effective Cohesion (pa; psi)	39,000; 5.7

[a] See Appendix E for details of individual tests.

Source: Arthur D. Little, Inc., and Bowser-Morner Testing Laboratories, Inc.

5.5.4 Chemical Testing Results

In August 1981 samples of wastes, liner materials, and soils were obtained for physical and chemical testing. Groundwaters were sampled for chemical testing. These included samples obtained by three borings through the pond liner, which were immediately sealed. Subsequent groundwater and pond supernatant sampling took place in October 1981 and May 1982. Precipitation was reasonably typical at the times of sample collection and covered the extreme wet and dry seasons.

Table 5.26 provides data on selected components of groundwater and pond liquors at the Sherburne County site, including comparison with selected results of EP extract analysis and with relevant EPA water use criteria. Chemical analysis results for selected constituents of liquids from within the pond liner and from soils beneath the liner are presented in Table 5.27. Selected chemical attenuation test results are presented in Table 5.28. A more detailed presentation of chemical testing results is provided in Appendix F.

5.5.5 Environmental Assessment

5.5.5.1 Approach for the Sherburne County Plant--

The environmental assessment of the Sherburne County Site results focused on the following issues:

- effects of the pond leachates on downgradient groundwater quality; and
- effectiveness of the pond liner as a mitigative feature for the protection of groundwater quality.

The steps employed in the environmental assessment at this site were as follows:

- Site subsurface geological profiles and a site water balance were prepared.
- The values and trends in chemical sampling and analysis results for the various areas of the site were compared with each other, the results of previous work by Northern States Power Company, and relevant EPA criteria for wate use protection.
- The water balance, geological profiles, and chemical and physical testing results were considered together to structure and evaluate hypotheses concerning the nature of leachate generation and movement at the site. Particular emphasis was placed on consideration of chemical sampling and analysis results for pond liquor and interstitical waters from within the wastes, pond liner, and underlying unsaturated zone.
- The results of soil attenuation tests were evaluated along with the water balance, geological profiles, physical and other chemical

TABLE 5.76

SELECTED DATA FROM POND AND WELLS AT THE SHERCO SITE

(all in mg/ℓ except Se (μg/ℓ))

Constituents:	Cl				SO_4				B				Ca			
Trips:	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Locations																
5-5 (Background Well)	18	27	21	71	22	20	14	15	.04	.009	.004	.019	59.7	66.9	64.3	66.2
5-11 (Background Well Directly North of Ponds)	19	2	9	10	110	7	37	46	.03	.004	<.004	.013	107	78.8	69.6	78.4
5-7 (W. Peripheral Well)	14	16	19	21	70	52	39	41	.334	.334	.233	.326	101	87	79.6	81.7
5-8 (E. Peripheral Well)	15	13	18	17	35	24	20	20	<.004	<.004	<.004	.013	60.1	60.2	65.7	64.4
5-4 (Downgradient Well)	15	19	17	17	30	28	23	23	0.56	.005	.004	.014	68.9	68.1	73.7	72
5-6 (Downgradient Well)	16	20	13	13	76	59	41	49	.189	.158	.113	.188	83.1	81.6	75.9	78
5-9 (Downgradient Well)	6	3	2.5	3	22	16	18	15	<.004	<.004	<.004	<.006	53.1	53.4	51.1	52
Waste Liquors: (FGD)																
5-1 (12.5-14.5 feet)	82				512				90.3				742	--	--	--
5-1 (20.5-22.5 feet)	336				3057				63.9				591	--	--	--
5-1 (24-26.5 feet)	261				2420				50.3				624	--	--	--
Waste Liquors: (Bottom Ash)																
5-11 A	--	--	60	56	--	--	2305	2200	30.4	--	--	--	775	--	--	--
(FGD Pond Liquor)	--	--	150	155	--	--	8367	9900	--	--	105	132	--	--	566	493
5-18 (FGD Recycle Basin)	--	--	56	58	--	--	2345	2200	--	--	20.9	19.9	--	--	623	613

(Continued)

TABLE 5.26

Locations	Constituents: Mg				Na				Se			
Trips:	1	2	3	4	1	2	3	4	1	2	3	4
5-5 (Background Well)	17.6	19.2	18.6	19.5	5	4	4	5	.26	.26	--	--
5-11 (Background Well Directly North of Ponds)	28.8	22.2	18.6	21.9	6	2	2	3				
5-7 (W. Peripheral Well)	33.2	23.7	21.6	22.5	6	4	3	4	--	<.26		
5-8 (E. Peripheral Well)	17.2	16.9	17.5	18.2	4	3	4	4				
5-4 (Downgradient Well)	19.2	18.7	21.3	20.1	3	3	2	3	--	<.26	--	--
5-6 (Downgradient Well)	24.2	22.7	20.6	21.1	6	3	3	4	--	<.26		--
5-9 (Downgradient Well)	14.7	14.9	14.1	15.2	4	<1	2	3	<.26	--	--	--
Waste Liquors: (FGD)												
5-1 (12.5-14.5 feet)	1530				857				49			
5-1 (20.5-22.5 feet)	436				468				21			
5-1 (24-26.5 feet)	165				330				5			
Waste Liquors: (Bottom Ash)												
5-11 A	344	--	--	--	234	--	--	--		246		
(FGD Pond Liquor)			2050	2150	--	--	262	284				
5-18 (FCD Recycle Basin)			297	207			102	98				

Note: Potentially applicable water quality standards and criteria include:

Se: 10 μg/l (EPA Interim Primary Drinking Water Standard)
Cl: 250 mg/l; SO_4: 250 mg/l (EPA Proposed Secondary Drinking Water Standard)
B: .750 mg/l (EPA criterion for protection of sensitive crops)

TABLE 5.27

SELECTED VALUES FROM ANALYSES AND ESTIMATES OF CONSTITUENTS IN LIQUIDS FROM POND LINER AND SOILS BELOW THE LINER AT THE SHERBURNE COUNTY PLANT

Sample Type/Location	CONCENTRATION (ppm except where noted)							
	Cl	SO_4	B	Ca	Mg	Na	Zn	As(ppb)
Liner Pore Water[a] (Boring 5-3)								
• 0.48-0.14m (19-25 in) into liner	150	2070	16.6	643	212	80	1.2	3
• 0.71-0.91m (28-36 in) into liner	122	1957	16.1	625	186	70	0.5	6.8
Water from Soils Under Liner (Boring 5-3)								
A. Water Extract								
• 11-12m (36-38 ft) below liner	4	6	0.244	41.6	10.8	6	0.06	4
• 12-13m (40-43 ft) below liner	3	62	0.38	8.7	7.7	<20	0.2	3
B. Estimate of Actual Soil Concentration								
• 11-12m (36-38 ft)	(88)	(132)	(5.37)	(91[illegible])	(238)	(132)	(1.32)	(88)
• 12-13m (40-43 ft)	(45)	(930)	(5.7)	(130)	(116)	(<300)[b]	(3)	(<45)[b]

[a] "Liner Pore Waters" represent concentrations of constituents found in water removed from the liner. Because too little water was present in underlying soils, water was used to extract constituents, and the values are reported here. To compare with liner pore water concentrations, an estimate was calculated using the extract data and measured moisture data.

[b] Because actual extract levels were below a detection limit, estimate is not very useful or necessarily realistic.

TABLE 5.28

SELECTED RESULTS OF SOIL ATTENUATION STUDIES
SHERBURNE COUNTY SITE[a]

Element and Soil Sample	Solution Concentration (ppb)	Soil Capacity (μg/gm)	Soil Capacity ÷ Solution Concentration
Arsenic (A)	4.8-454	1.1-119	229-262
(A)	7.8-473	1-59	128-125
(B)	14-454	1.1-121	79-267
(B)	18-477	1-53	56-111
Selenium (A)	9-120	0.2-0.8	25-6.7
(A)	14-137	0.25-7.4	18-54
(B)	30-97	0.3-2.4	10-24.7
(B)	37-149	0.23-0.8	6.2-5.4
Cadmium (A)	40-110	0.24-5.16	6-47
(B)	50-130	0.22-3.20	4.4-24.6
Chromium (A)	180	0.06	< 0.35
Copper (A)	32-154	0.73-246	23-1600
(B)	35-251	0.73-148	21-590
(B)	12-13	0.14-1.28	11-98
Nickel (A)	0.18-0.21	0.14-0.43	0.8-2.1
(B)	0.20-0.21	0.10-0.45	0.5-2.1
Vanadium (A)	47-73	0.07-1.26	1.5-17
(A)	18-26	0.03-1.00	1.6-38
(B)	64-76	0.04-1.00	0.6-13
(B)	16-20	0.04-0.16	2.5-8

[a]Soils tested were from two borings: (A) 5-3, in the clay liner, and (B) 5-8, gravelly, silty sand east of the ponds.

testing data to describe the potential for longer-term leaching of contaminants from the waste ponds to downgradient monitoring well locations.

- The broader implications of the Sherburne County site results were considered in terms of their applicability to similar combinations of waste types, disposal methods and environmental settings. For this site, this step had particular importance because of the significance of the lined pond disposal method in a typical interior setting of high-quality groundwater.

5.5.5.2 Geological Profiles and Water Balance--

Geological Profiles--Figure 5.32 illustrates the subsurface geological profiles for two areas of the Sherburne County waste disposal site. These profiles were prepared on the basis of the site development results for this program along with the available site background information.

Water Balance--The estimated water balance for the Sherburne County Site, based on the hydrologic information from the site development work, is summarized in Table 5.29 and illustrated in Figure 5.33.

5.5.5.3 Evaluation of Testing Results--

The chemical analyses results for this site, in conjunction with available background data, indicate the following:

- The values measured on different dates at the same sampling locations were remarkably similar. Nitrates were a minor exception, with concentration elevations found only in the August 1981 site development samples from a background boring and a peripheral well boring.

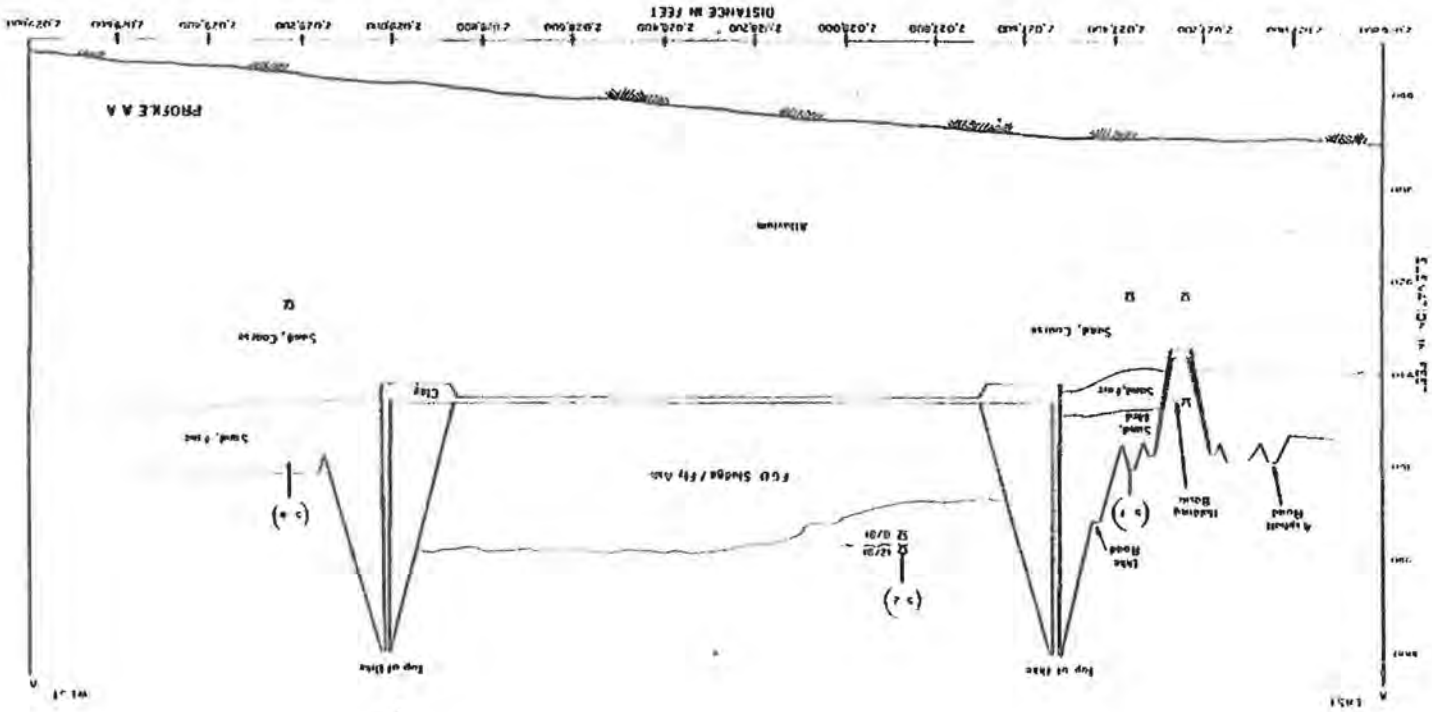
- As illustrated in Table 5.26, the measured concentrations of several components were significantly higher in the FGC pond supernatant and FGC waste interstitial waters than in background groundwaters. These components included sulfate, boron, chloride, calcium, magnesium, sodium, selenium. Sulfate, boron, and chloride show the most consistently pronounced waste-related groundwater concentration elevations. Sodium and magnesium showed a similar pattern, although less consistent relative differences in concentrations were exhibited. Selenium concentrations were also elevated in the waste liquors (up to 250 ppb), which is 25 times the EPA Interim Primary Drinking Water Standard and about 30 times higher than the value obtained by the EP test (see Table 5.26). However, selenium decreased with depth in the waste liquor to 49, 21, and 5 μg/l. Thus, sulfate and boron appear to be likely "chemical tracers" for a leachate plume, with the other parameters providing supplementary data.

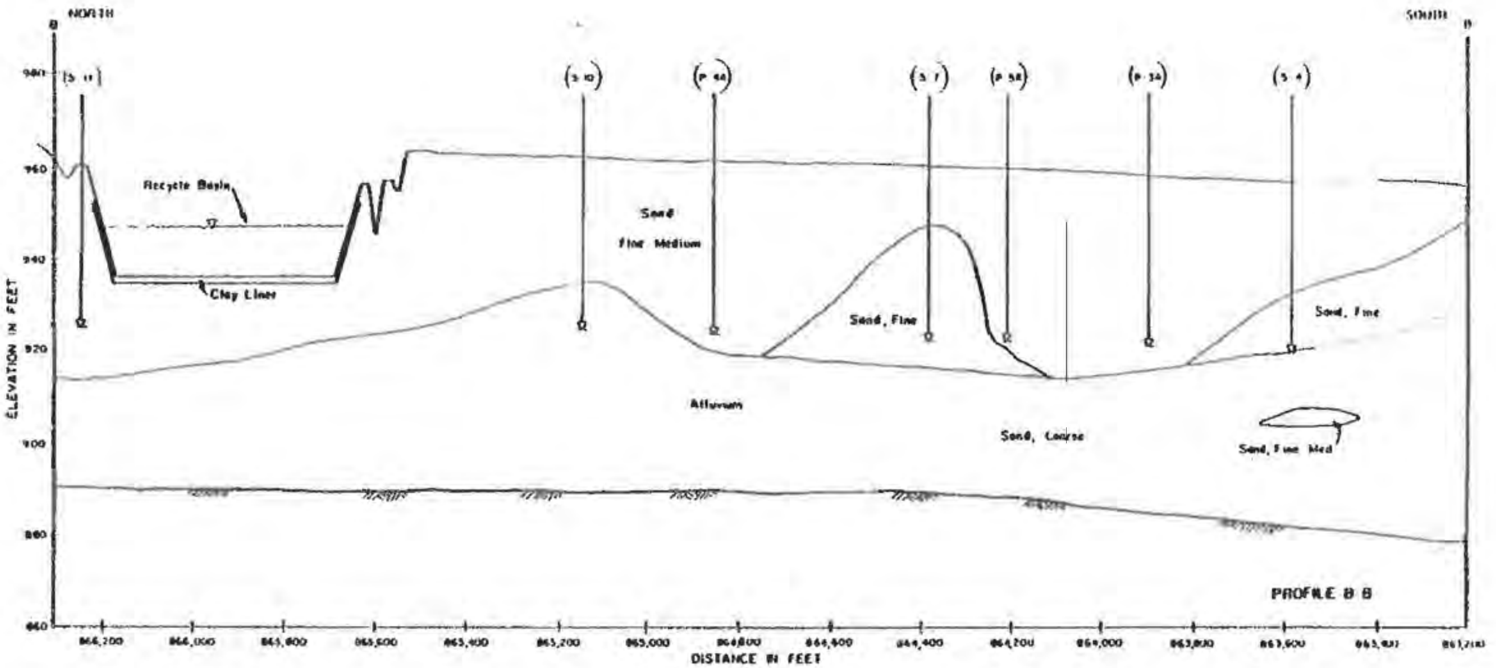
- While both sets of concentrations were elevated, the likely chemical tracer concentrations measured in the FGC pond supernatant were higher

- Doc. Ex. 8488 -

FIGURE 6 32

SUBSURFACE GEOLOGICAL PROFILES - SHERBURNE COUNTY SITE
NORTHERN STATES POWER COMPANY - SHERBURNE COUNTY, MN.





SUBSURFACE GEOLOGICAL PROFILES - SHERBURNE COUNTY SITE
NORTHERN STATES POWER COMPANY - SHERBURNE COUNTY, MN

FIGURE 8.32 (Continued)

5-121

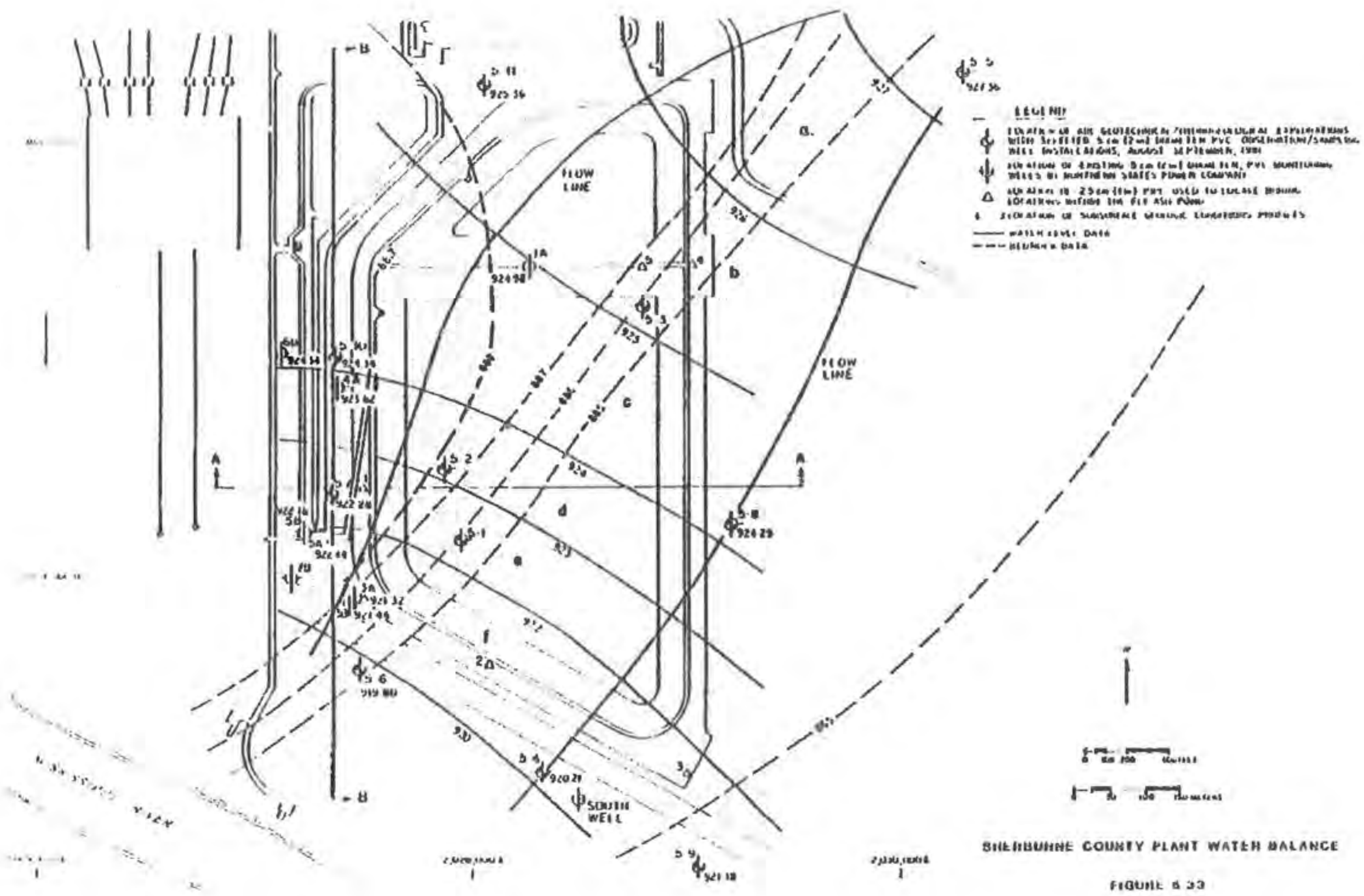
TABLE 5.29

SHERBURNE COUNTRY SITE WATER BALANCE

Section	a	b	c	d	e	f	g
Contour Interval	927-926	926-925	925-924	924-923	923-922	922-921	921-920
Flow Length, (m)	265	244	213	114	107	100	71
Width (m)	287	460	493	454	436	387	362
Water Elev. (m)	282.4	282.1	281.8	281.5	281.2	280.9	280.6
Bedrock Elev. (m)	270.4	269.7	269.4	268.8	268.5	267.9	267.5
Sat. Thick (m)	12.0	12.4	12.4	12.7	12.7	13.0	13.1
K, $\frac{cm}{sec}$	3.6×10^{-2}	3.6×10^{-2}	3.6×10^{-2}	3.6×10^{-2}	3.6×10^{-2}	3.6×10^{-2}	3.6×10
T = KD $\frac{cm^3}{sec}$	43	44	44	46	46	47	47
i = $\frac{ch}{h}$	1.15×10^{-3}	1.25×10^{-3}	1.43×10^{-3}	2.67×10^{-3}	2.84×10^{-3}	3.05×10^{-3}	4.16×10
Q Tiw $\frac{m^3}{DAY}$	1.2×10^2	2.2×10^2	2.7×10^2	4.8×10^2	4.8×10^2	4.8×10^2	6.2×10^2

Recharge $\frac{m^3}{DAY}$	1.0×10^2	0.5×10^2	2.1×10^{-2}	0	0	1.4×10^2
Length, (m)	255	229	164	111	104	87
Width, (m)	373	477	474	440	407	375
Recharge Rate (m/day)	1.1×10^{-3}	4.6×10^{-4}	2.7×10^{-3}	0	0	4.3×10^{-3}
$\frac{mm}{day}$	1.1	0.46	2.7	0	0	4.3
(m/day)	0.041	0.018	0.11	0	0	0.17
m/yr.	15	66	39	0	0	62

Source: Eugene A. Hickock



SHERBURNE COUNTY PLANT WATER BALANCE

FIGURE 6 33

than those measured in interstitial waters within the FGC waste deposits (e.g., over 10,000 ppm sulfate in the supernatant versus 2,000 ppm in the interstitial waters).

- As illustrated in Table 5.27, the "tracer" concentrations were similar in both the waste interstitial waters and the interstitial water squeezed from various locations and depths within the pond liner. However, the amount of moisture decreased with depth in the same samples (i.e. 40 percent moisture in the fully saturated waste, 15 percent in the 80 percent saturated liner, and less than four percent in the underlying unsaturated zone soils).

- None of the groundwater samples from background, downgradient or peripheral wells showed concentration elevations of prospective tracers in the ranges found in the waste and liner interstitial waters. The concentrations in the background, east and southeast peripheral, and south downgradient wells were similar; the concentrations in the west and southwest downgradient wells were slightly elevated (i.e., sulfate 5 to 30 ppm, boron 0.004 to 0.06 ppm in the background versus sulfate 50 to 80 ppm, boron 0.05 to 0.35 ppm in the west/southwest downgradient wells).

- Nitrate exceedance of the EPA Interim Primary Drinking Water Standard was widespread at various locations around the site (including background) and appears unrelated to the disposal operation. As indicated here or on Table 5.26, the waste contained concentrations of fluoride (up to 18 ppm), chloride, iron (up to 1.8 ppm), sulfate, manganese (up to 15 ppm) and selenium that could exceed the applicable federal primary or secondary standards if they reached drinking water unattenuated. However, there were no such exceedances recorded for any of these parameters at the saturated zone sampling locations beyond the pond itself.

- As presented in Table 5.28 and Appendix F, attenuation tests conducted with site soils and various waste liquors indicate that the sandy, relatively inorganic soils that prevail over much of this site (e.g., from boring 5-8) have relatively poor capacity to attenuate trace metals. A sample of "clay core" liner soil (with about 20 percent clay-sized particles (versus 10 to 15 percent elsewhere at the site) had somewhat better attenuative capacity that was still in the lower end of the range exhibited at the various study sites.

5.5.5.4 Cause and Effect Relationships--

Flow through the liner and unsaturated soils at the Sherburne County disposal pond was investigated using assessment methods developed by McWhorter and Nelson (1980) and subsequently restated and simplified by Bouwer (1982).

From the data developed in this study, the steady state seepage rate in the unsaturated zone underlying the ponds was estimated in the range of 1.2×10^{-6} to 2.2×10^{-6} cm/sec. By this method, the rate of leachate flow through the entire pond bottom is estimated at 350 to 400 m^3/day (92,000 to 106,000 gal/day). This estimate compares favorably with the results of the preliminary site water balance [i.e., leachate flow of 500 m^3/day (132,000 gal/day)].

The travel time through the clay liner is sensitive to the liner thickness, ranging from about 140 days for the 0.46 m (1.5 ft) thick liner base to approximately 470 days for the 0.90 m (3.0 ft) thick "clay core" liner edges. Thus, some leachate is expected to break through the liner after approximately 150 days, although steady state may not be achieved for approximately 500 days.

Estimated travel time through the unsaturated zone may vary from 500 to 850 days, based on variation in the seepage rate (function of liner thickness) as well as in the soil moisture content. Travel times in the saturated zone toward downgradient wells 5-4 and 5-6 would be about 400 days from the southwest side of the pond, 2800 days from the northeast.

Combining the above estimates, leachate from the southwest corner of the pond could have begun to affect wells 5-4 and 5-6 as early as March 1979, and probably no later than February 1981. Observations at these wells, on the contrary, indicate little contamination in 1981 and 1982. Here some possible explanations are explored.

The first arrival of contaminants at wells 5-4 and 5-6 will not be nearly so concentrated as would develop later. There are two essential reasons:

- Initially, only a small quantity of leachate has mixed with larger amounts of uncontaminated groundwater. Groundwater reaching wells 5-4 and 5-6 in 1982 had already flowed under a large fraction of the pond before the first leachate trickled down to the water table (by these estimates at the approximate time of January 1978). Water sampled at well 5-4 in May 1982 was roughly midway along its flow path under the pond when it was first affected by leachate.

- Leachate that originally permeated the liner may have been less contaminated than the leachate currently found in the FGC waste or liner pore waters. The leachate may not have come to chemical equilibrium with the wastes, and early plant operations did not involve recycling as much plant water as in later years. Some evidence for this is in the decrease in chloride, sulfate, calcium and other major ions in samples deeper in the waste deposit. This observation is not consistent with either dilution, chemical attenuation or plume "front" hypotheses.

These considerations can only explain the observations at well 5-4 if initial leachate concentrations of sulfate were no more than 100 ppm. Such a low concentration does not seem likely from available information.

Another possible explanation is that flow in the liner, unsaturated zone, or saturated zone is slower or less vigorous than has been estimated above. A number of assumptions and/or measurement errors could contribute to errors in the hydraulic estimates:

- the flow system as observed may not be representative of the life of the facility (pond water level was occasionally lower, pumping rate of plant water supply well may have been greater, liner thickness greater than 0.46 m (1.5 ft) under most of the pond, etc.); and

- hydraulic conductivities used in the estimates may be too high.

Relative differences in the hydraulic conductivities of the liner versus underlying materials could result in different relative contribution of leachate and underflowing groundwater. All other possible explanations for the discrepancies between the findings of this analysis and the observed absence of contamination at downgradient wells would not affect the long term steady state concentrations that would obtain at those wells. They only affect estimates of when these concentrations would be observed.

In this context, the water balance indicates that values for steady-state concentrations of conservative species at downgradient wells may be estimated using the following equation:

downgradient conc. = 0.7 (leachate conc.) + 0.3 (background conc.)

Such steady-state concentrations would be expected by the end of 1988. In the meantime, steadily increasing concentration levels from those observed in 1982 to the projected value are expected. Since it appears that leachate had already penetrated the liner as of August 1981, elevated concentrations should be observable at well 5-4 no later than summer of 1985.

The groundwater effects of the Sherburne County pond would be quite different had no liner been used. Applying equations provided by Bouwer (1982), the seepage rate would be 3.7×10^{-5} cm/sec, corresponding to a leachate release rate of roughly 7000 m^3/day through the pond bottom. This is roughly 15 times the existing seepage rate. The unsaturated zone beneath the pond would exhibit a soil moisture content of approximately 12 percent, and a substantial groundwater mound would develop forcing leachate in all directions from the pond area.

In this hypothetical case, it would take only a year for leachate to travel to downgradient locations, and the groundwater quality at points adjacent to the pond would already closely approximate the leachate quality.

5.5.5.5 Environmental Effects Implications--

The evaluation of testing results for the Sherburne County site can be summarized as follows:

- Leachate movement from the pond has been physically retarded to preclude development of contaminant concentation elevations at the southern downgradient wells. However, one may expect such elevations to occur eventually.

- Waste-related chemical constituents appear at slightly elevated levels in the peripheral/downgradient wells to the west and southwest of the pond, but it is not clear whether this is due to the remnants of past leakage from the sheet piling/conduit sources, leachate that has moved through the liner, or a combination of both.

- The higher concentrations of waste constituents in FGC pond supernatant versus underlying waste interstitial waters may be due to two factors. First, the conversion by the utility to a system involving recycle of the FGC waste transport water would have resulted in increased concentrations of chemicals in the water, and second, the evaporation of water in the pond would also increase remaining chemical concentrations.

The findings at the Sherburne County site support conclusions 1, 2, and 3 presented in Section 5.1 and have the following broader implications for similar disposal operations:

1. For similar wastes, the trace constituent of greatest concern relative to primary drinking water standards may be selenium, which was present in the Sherburne County pond at levels up to 25 times the drinking water standard. However, program results indicate that selenium may be chemically attenuated in soils with a prevalence of fine particles or high organic content.

2. If underlying or intervening soils are relatively impermeable and the site is well-removed from potential drinking water and small surface water bodies, it appears that the types of wastes generated at the Sherburne County Plant can be acceptably disposed of by ponding or landfilling methods.

5.5.6 Engineering Cost Assessment

5.5.6.1 Engineering Assessment--

The Sherburne County Plant is a cyclic load facility which operates at full load approximately 10 to 12 hours per day. Two pulverized coal-, tangentially-fired units (each of which has a 729 MW nameplate generating capacity) are in use; the total nameplate generating capacity is 1458 MW. The first unit started up in May 1976, and the second was commissioned in April of the following year. The utility is planning to expand this plant with the addition of an 800 MW unit in 1988.

Air Pollution Control--Flue gas cleaning has been in use since startup of the two units at the Sherburne County Plant. Initially, sulfur oxides and particulates removal was achieved simultaneously employing limestone/fly ash alkali scrubbing. However, a variety of materials have been tested as scrubber additives in addition to limestone, including municipal water treatment plant sludge, dust collector fines from a lime production plant, and calcium hydroxide from acetylene production plants.

Twelve venturi-rod scrubbers service each of the two units at this plant. A design sulfur dioxide removal efficiency of 50 percent is stipulated. Forced oxidation is also provided. Initially, marble bed absorbers were installed on the scrubbers, although the manufacture of marbles was discontinued, and the absorbers were subsequently converted to spray towers. The operational desulfurization efficiency of the FGC system was increased to 70 percent by the change to spray tower absorbers. Actual operating particulate removal efficiency is reported to be 99.0 percent. Economizer ash is collected separately in dry form.

Coal Consumption--Subbituminous Colstrip and Absolaka coals used by the Sherburne County Plant are obtained from the state of Montana. Annual coal consumption at the Sherburne County Plant in years that both units were operating ranged from 4.0 to 4.4 million metric tons/yr (4.4 to 4.8 million tons/yr). The heat content of coal used at this plant has essentially remained constant, ranging from 19.9 to 20.1 million joules/kg (8,550 to 8,640 Btu/lb). The annual average coal sulfur and ash contents have remained constant at 0.8 weight percent (dry basis) and 9.2 weight percent (dry basis), respectively. Coal moisture contents were reported to range from 24.5 to 25.6 weight percent.

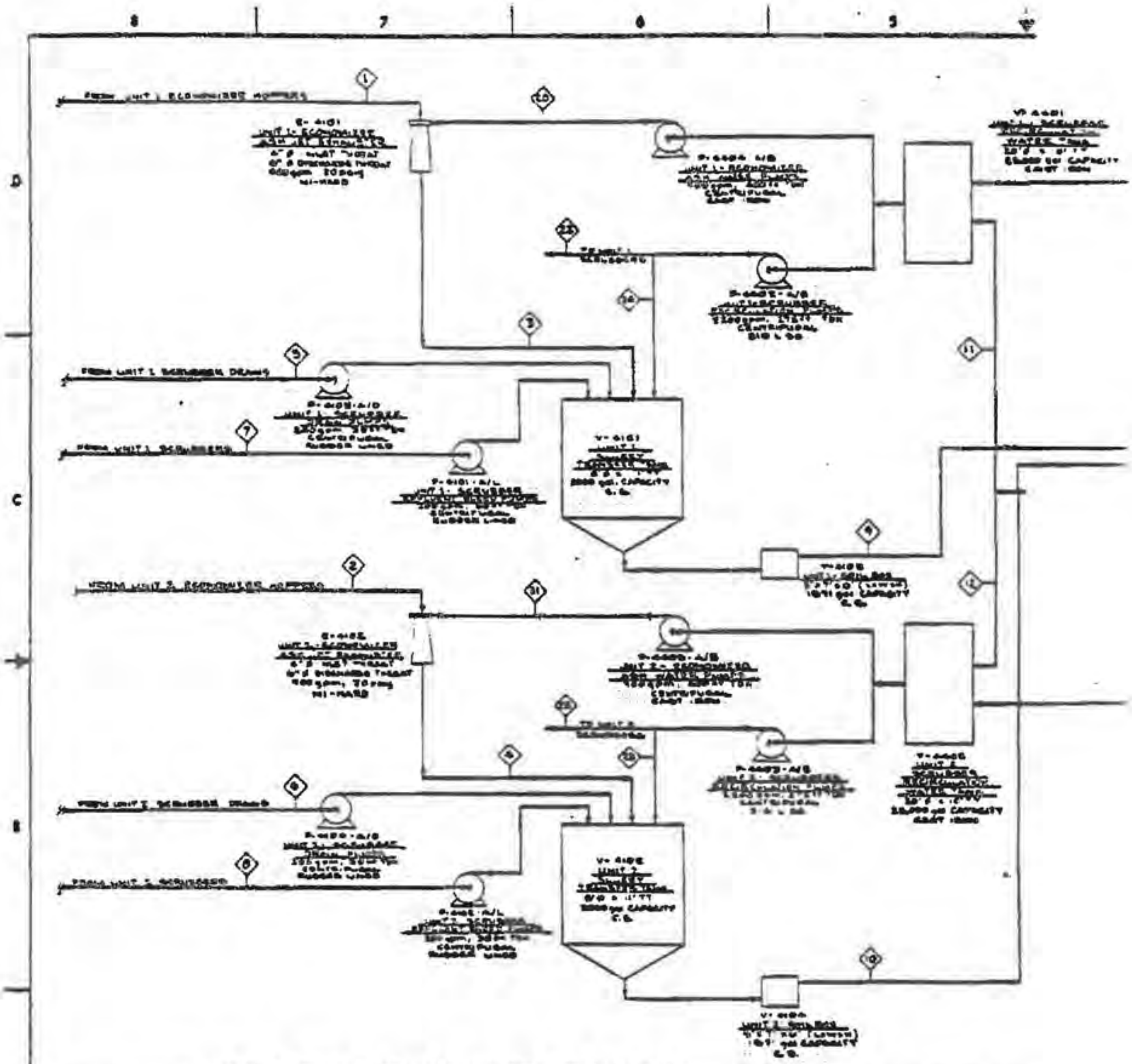
Waste and Water Management--FGC waste (fly ash and FGD waste) generation rates range from 255,000 to 315,000 m^3/yr (9.0 to 11.1 million ft^3/yr). The combined fly ash and FGD wastes, along with the economizer ash, (which is slurried and handled in wet form), are thickened to approximately 30 to 35 percent solids. The thickener overflow is recycled for use in the scrubber. The thickened sludge is sluiced to a disposal pond by way of two pipelines. Figure 5.34, process flow diagram F-400, illustrates the fly ash and FGD waste handling, processing, and transport scheme.

Bottom ash and mill rejects are sluiced by pipeline to the bottom ash disposal pond. Between 1,600 and 2,000 m^3/yr (55,000 and 70,000 ft^3/yr) of bottom ash is generated annually. Figure 5.35, process flow diagram F-401, depicts the bottom ash handling and transport system.

Disposal Operation--Combined fly ash and FGD waste, as well as boiler and scrubber cleaning wastes, are disposed in a 250,000 m^2 (62 acre), 14 m (45 ft) deep pond. This pond has a design life of ten years. The pond is lined with 0.46 m (18 in) of clay which was obtained locally.

With the proposed addition of Unit 3, this fly ash and FGD waste disposal pond is not considered by plant personnel to be capable of providing adequate disposal capacity for all of the fly ash and FGD waste generated by the Sherburne County Plant. A new pond will be constructed for this purpose.

A clarifying pond (denoted the scrubber recycle basin) receives overflow from the fly ash and FGD waste disposal pond. This pond is adjacent to (to the west of) the fly ash and FGD waste disposal pond. It has a surface area of 1,000 m^2 (0.25 acre) and is 3 m (10 ft) in depth. This pond is lined with 0.45 m (18 in) of clay. The effluent from this pond is recycled to the plant for use in the scrubber system.



DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY

DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TONS ASH PER/DAY	30	30	144	100	72	28	855	850	1950	1020	230	230	1000	—	—	—	—	—
TONS WATER/DAY	—	—	5450	5450	105	63	6432	6032	17,020	17,620	16,220	16,220	2000	—	125	2400	45	400
MGPD	—	—	1.30	1.30	0.04	0.04	1.52	1.62	4.60	4.60	3.89	3.89	0.62	—	0.05	0.64	0.09	0.54
% SOLIDS	100	80	2	2	2	2	2	12	5	5	1	[illegible]	30	—	0.01	0.01	0	0.01
SPECIFIC GRAVITY	2.4	2.4	1.01	1.01	1.08	1.02	1.08	1.08	1.08	.95	1.01	1.01	1.20	—	1.06	1.00	1.00	1.00

FIGURE 5.34

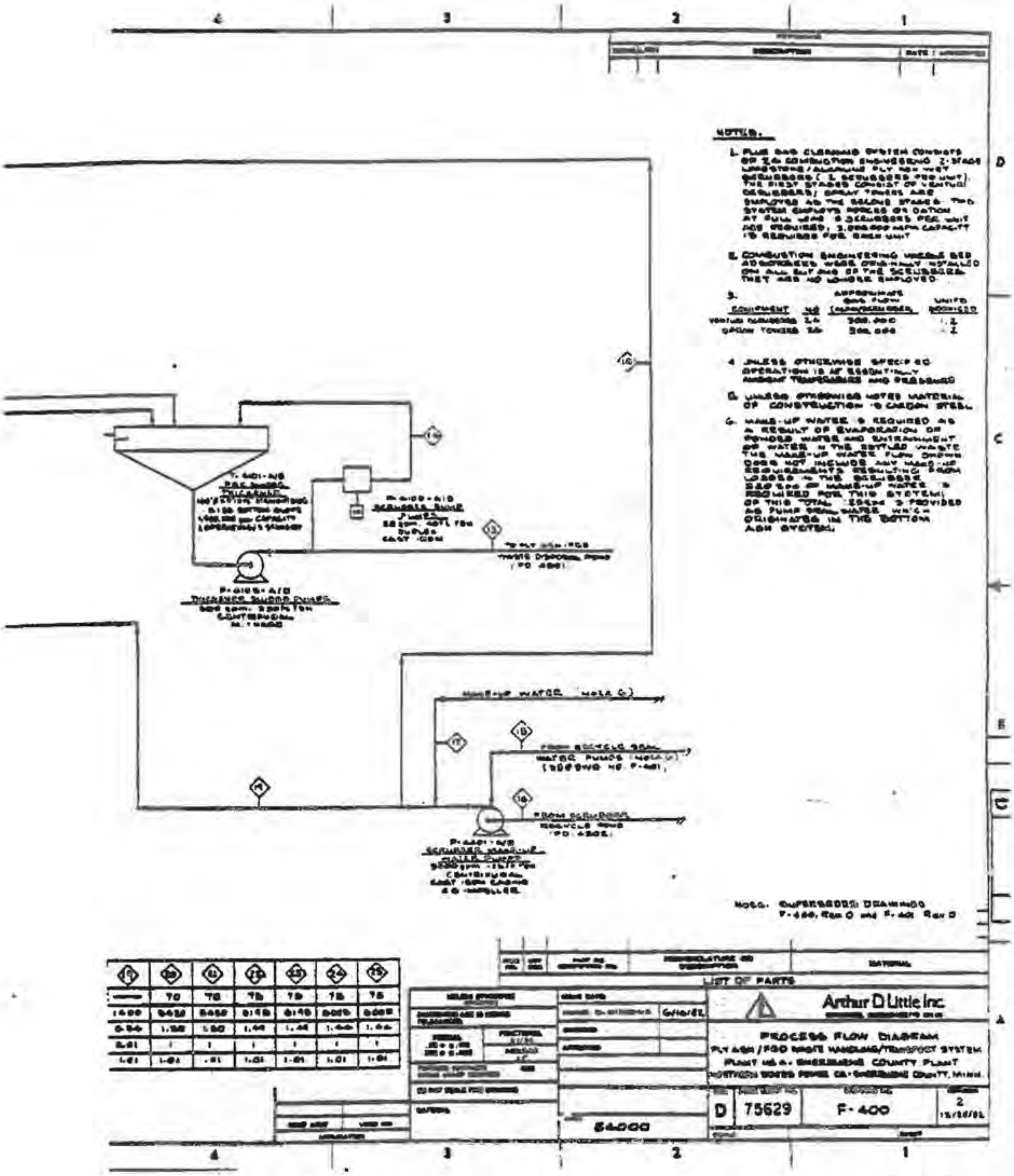
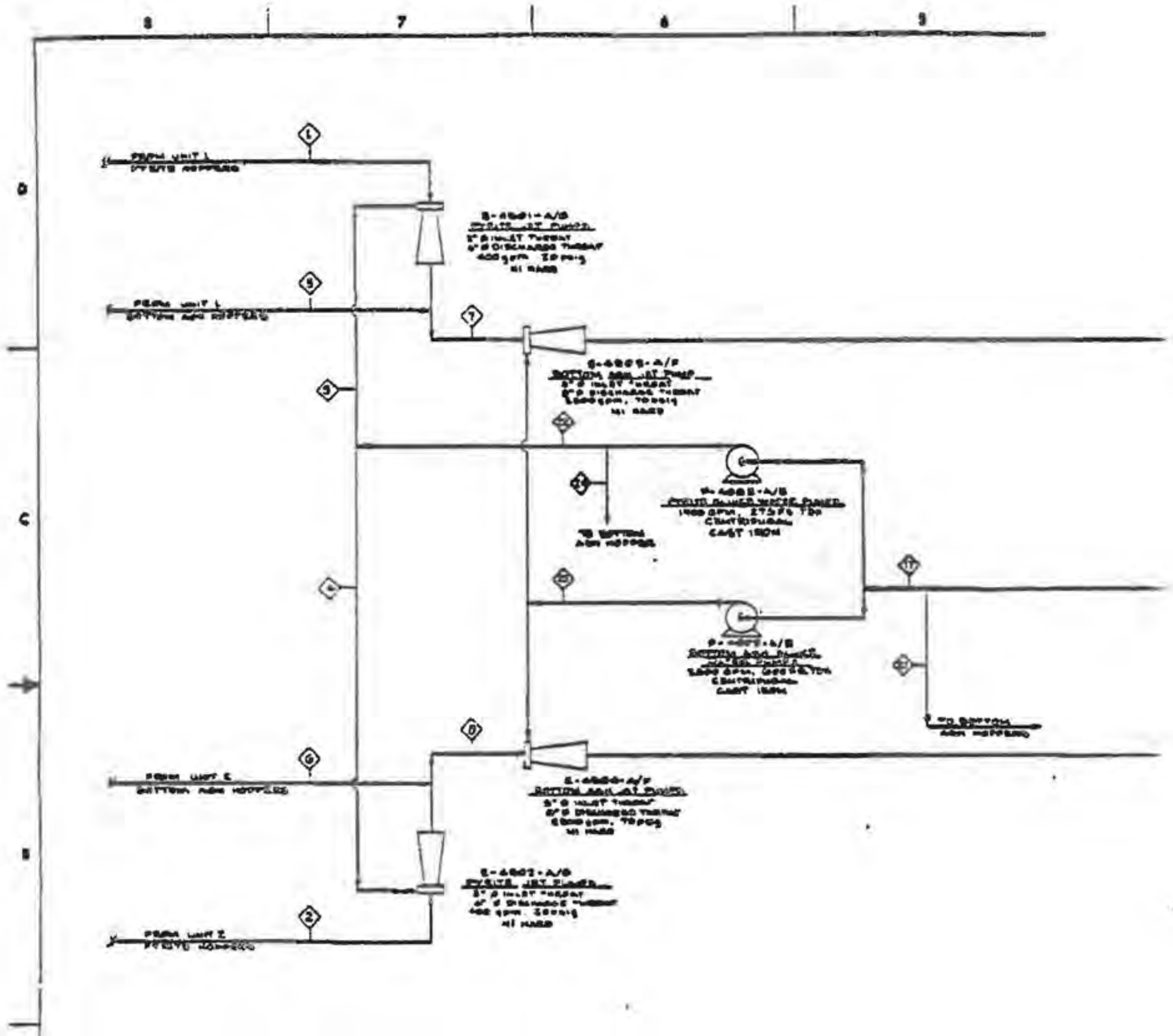

NOTES:
MAKE-UP WATER
LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
D
75629
F-400
54000

FIGURE 5.34



DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY FULL LOAD (NOTE 5)

DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TONS SOLIDS/DAY	9	9			250	250	259	259	259	259	—	—	—	—	—	—	—	—
TONS WATER/DAY	4	4	900	900	289	289	589	889	4848	4248	12	12	[illegible]	192	0	9008	2190	[illegible]
MGPD	0.006	0.002	0.072	0.072	0.092	0.092	0.166	0.166	1.050	1.050	0.003	0.003	2.072	0.047	0.082	2.159	.950	0.075
% SOLIDS	69	69	0.01	0.01	46	46	30	30	5	5	0.5	4.6	0.01	0	0.01	0.01	0.01	0.0
SPECIFIC GRAVITY	1.98	1.98	1.00	1.00	1.25	1.05	1.50	1.20	1.02	1.02	1.01	1.04	1.00	1.00	1.00	1.00	1.00	1.00

FIGURE 5.35

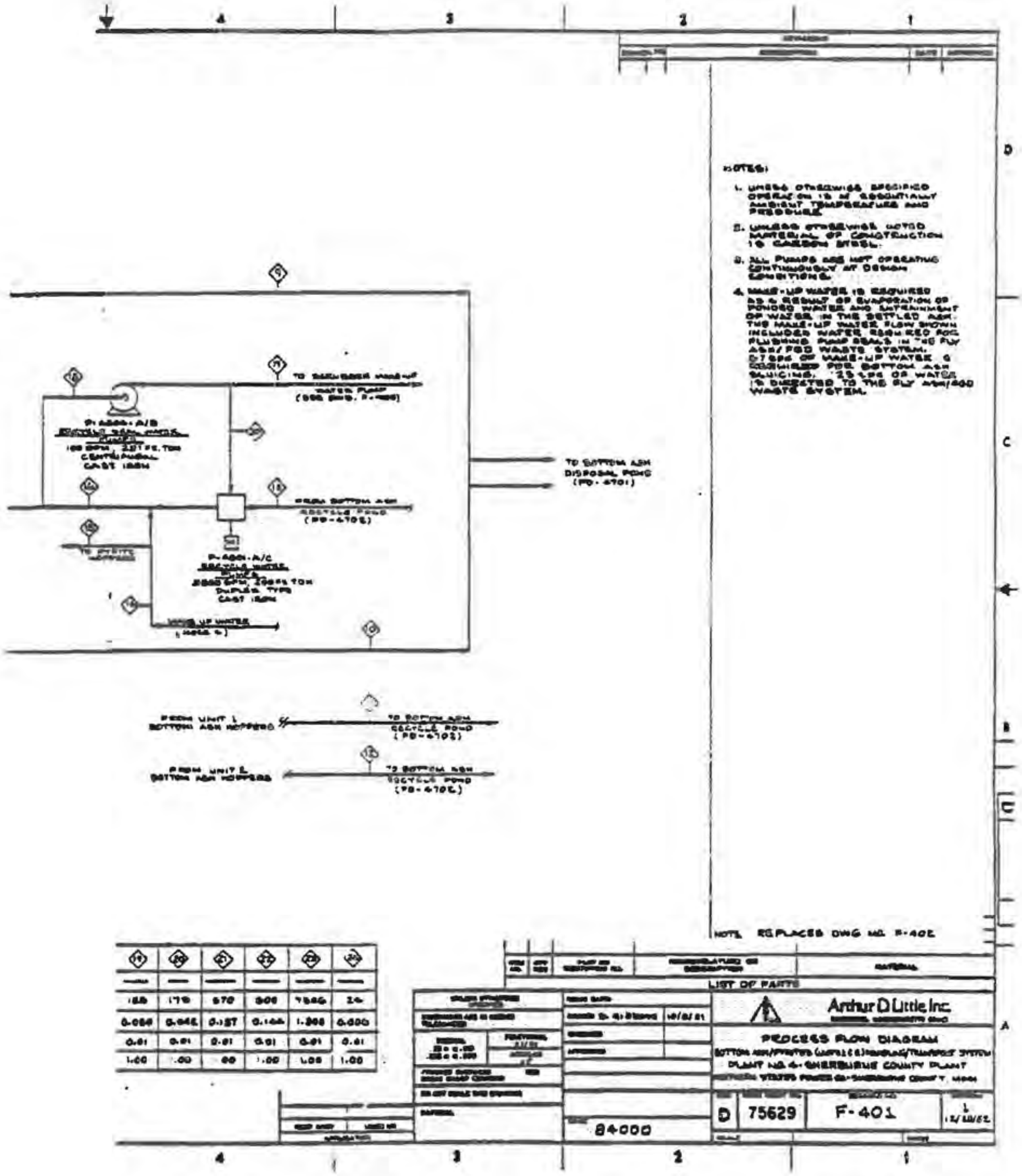

NOTES:
2. UNLESS OTHERWISE NOTED MATERIAL OF CONSTRUCTION IS CARBON STEEL.
3. ALL PUMPS ARE NOT OPERATING CONTINUOUSLY AT DESIGN CONDITIONS.
TO BOTTOM ASH DISPOSAL POND (PD-4701)
NOTE: REPLACES DWG NO. F-402
LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
PLANT NO. 4 - SHERBURNE COUNTY PLANT
D
75629
F-401
84000

FIGURE 5.35

Bottom ash and mill rejects are disposed in a separate 74,000 m^2 (18 acres) pond. As a market becomes available, some of the ash is periodically dredged and sold. The depth of this pond is 14 m (45 ft). The pond is lined with 0.45 m (18 in) of clay that was obtained locally.

Overflow from the bottom ash pond and wastes from the coal yard and plant sumps are directed to a clarifying pond which is denoted the recycle basin. This pond is adjacent to (to the west of) the bottom ash and fly ash/FGD waste disposal ponds. The recycle basin has a design life equal to that of the plant (35 years). This pond is lined with 0.45 m (18 in) of clay and is 3 (10 ft) deep. It is dredged intermittently at 2 to 3 year intervals, as needed. The effluent from this pond is recycled to the bottom ash sluice system.

A list of area accounts for the waste handling and disposal operation at the Sherburne County Plant is provided in Appendix G, Table B-4. Additionally, a detailed equipment list for each area account is provided as Table G-10, also in Appendix G.

5.5.6.2 Cost Assessment--

The engineering assessment results for the Sherburne County Plant provided a basis for the development of capital and annual costs for the solid waste handling and disposal operation. To provide consistancy among the cost estimates for the six sites, it was necessary to develop certain specifications which were consistent for all study sites; these include plant service life, load factor, heat rate, etc. The design premises for the Sherburne County Plant cost estimates are listed in Table 5.30.

Detailed capital cost estimates for the Sherburne County Plant waste handling and disposal operation are provided on a modular basis, by waste type in Appendix G, Table G-16. A summary of these capital costs is presented in Table 5.31. As was the case with the other two study sites practicing pond disposal [Plant Allen ($36/kW) and the Smith Plant ($47/kW)], the waste handling and disposal scheme at the Sherburne County Plant is highly capital intensive ($43/kW) when air pollution control costs are not considered. This is due to the high cost of pond construction. This situation is compounded at the Sherburne County Plant where costly clay liners were installed in the ponds. The liner cost is particularly high since the clay was not available on-site, but rather was excavated and hauled to the pond area from an off-site location.

Detailed annual cost estimates are provided for each of the Sherburne County Plant waste handling and disposal modules in Appendix G, Table G-22. A summary of these costs is presented in Table 5.32. The unit annual cost for ponding at the Sherburne County Plant ($26.60/dry metric ton) is higher than the unit costs for the other two study plants practicing pond disposal (Allen at $23.70/dry metric ton and Smith at $25.10 dry metric ton). The annual cost for waste handling and disposal at the Sherburne County Plant is slightly more expensive than that for Plant Allen, primarily due to the fact that the Sherburne County ponds are lined, unlike the ponds at Allen, resulting in increased capital charges. In addition, the Sherburne County Plant practices water recycle which additionally adds to the capital costs of the system and

TABLE 5.[illegible]

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR
SHERBURNE COUNTY PLANT
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES	
Power Plant	
Plant Size (MW)	1458
Boiler Type	Pulverized Coal
Heat Rate (M joules kWh; Btu kWh)	12; 11,400
Location	Minnesota
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Waste Generated (dry basis)	
Fly Ash/Bottom Ash Ratio	70/30
Fly Ash Generation (metric tons/yr; tons/yr)	267,000; 294,400
Bottom Ash Generation (metric tons/yr; tons/yr)	110,800; 122,200
FGD Waste Generation (metric tons/yr; tons/yr)	103,900; 114,600
Ash Utilization	None
Coal Properties	
Coal Type	Subbituminous
Sulfur Content (Percent)	0.8
Ash Content (Percent)	9.2
Heating Value (M joules kg; Btu lb)	20.0; [illegible]
Air Pollution Control	
Particulate Control	See Below
Particulate Removal (Percent)	>99
Sulfur Oxides Control	Limestone Alkaline Fly Ash Scrubbing with Forced Oxidation
Alkali Stoichiometry	Not Available
SO_2 Removal (Percent)	70
Disposal Site	
Type	Pond
Design Life (yr)	30
Land Area (m^2; acre)	655,600; 162
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner (type; m; ft)	placed clay; 0.45; 1.5
Distance from Plant (km; mile)	0.40; 0.25

TABLE 5.31

CAPITAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Sherburne County
Plant Location: Sherburne County, Minnesota
Utility Name: Northern States Power Company
Nameplate Generating Capacity (MW): 1458

	CAPITAL COSTS ($1000)				
WASTES	Fly Ash	Bottom Ash	FGD Waste	Coal Pile Runoff and Plant Wastes	Total
MODULES					
• Waste Handling and Processing					
System Exclusive of Recycle Water Provisions	$10,354	$ 111	$ 4,026	$	$14,49[illegible]
Recycle Water System	7,649	2,833	1,030		6,51[illegible]
• Waste Transport	1,158	995	450		[illegible],60[illegible]
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	19,027	11,980	7,399	—	38,406
SUBTOTAL MODULAR COSTS	$33,188	$15,919	$12,905	$	$62,012($43/KW)
RELATED ENVIRONMENTAL SYSTEMS					
• Miscellaneous Plant Waste Handling and Transport System	-	-		49	49
• Air Pollution Control	151,603	-	58,957	-	210,560
TOTAL CAPITAL COSTS	$184,491	$15,919	$71,862	$ 49	$272,621($187/KW)

[a] ENR Cost Index = 3931.11 (1913=100)
365.97 (1967=100)

Source: Arthur D. Little, Inc. estimates.

TABLE 5.32

ANNUAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Sherburne County
Plant Location: Sherburne County, Minnesota
Utility Name: Northern States Power Company

Operating Load Factor (percent): 70
Nameplate Generating Capacity (MW): 1558
Waste Generation (dry metric tons/yr):
Fly Ash - 267,000
Bottom Ash - 110,800
FGD Waste - 101,900

	ANNUAL COSTS ($1000)				
WASTES	Fly Ash	Bottom Ash	FGD Waste	Coal Pile Runoff and Plant Wastes	Total
MODULE					
• Waste Handling and Processing System Exclusive of Recycle Water Provisions	$2,452.1	$ 159.4	$ 953.8	$ -	$3,565.3
- Recycle Water System	697.5	703.1	271.1	-	1,671.9
• Waste Transport	278.1	257.2	108.3		643.6
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	1,376.7	2,239.2	1,313.8	-	6,929.7
SUBTOTAL MODULAR COSTS	$6,804.4	$3,359.1	$2,647.0	$	$12,810.5 ($26.60/dry metric ton)
RELATED ENVIRONMENTAL SYSTEMS					
• Miscellaneous Plant Wastes Handling and Transport	-	-	-	17.8	17.8
• Air Pollution Control	NA[b]	-	NA[b]		NA[b]
TOTAL ANNUAL COST	$6,804.4 +NA[b]	$3,359.1	$2,647.0 +NA[b]	$17.8	$12,838.3 +NA[b]

[a] ENR Cost Index 3931.11 (1913=100)
365.97 (1967=100)

[b] NA = Information not available.

Source: Arthur D. Little, Inc. estimates.

likewise to capital charges. One might expect that the waste handling and disposal system at the plant, with a capacity of 1458 MW), would have a lower unit annual cost than that of the much smaller 340 MW Smith Plant, due to economies of scale. However, the cost of the liner at the Sherburne County Plant tends to overshadow such expected differences.

5.6 POWERTON PLANT

5.6.1 Plant Description

5.6.1.1 Background--

The Powerton Power Plant of Commonwealth Edison Company is located in Tazewell County, Illinois, approximately 16 km (10 miles) south of the city of Peoria. The site is located 1.6 km (1 mile) from the Illinois River, as shown on Figure 5.36.

The existing Powerton facility began operation in 1972, although a smaller plant had previously operated at the site. Dry fly ash is collected by cold-side electrostatic precipitators and stored on an interim basis in silos prior to removal to the landfill disposal area. Boiler slag is collected from wet bottom boilers, sluiced to hydrobins for dewatering, and transported by trucks to the disposal site.

The Powerton disposal site, approximately 1.6 km (1 mile) south of the plant, is actually two abutting landfills operated by American Admixtures, Inc. The older landfill was used from 1972 to 1977. It reportedly has a 0.20 m (8 in) thick liner composed of a stabilized fly ash-slag mixture called Poz-O-Pac®. Embankments up to 9 m(30 ft) in height, constructed of Poz-O-Pac®, retain the landfill on an original sloping ground surface. The older landfill was reclaimed with an addition of a 0.6 m (2 ft) top soil layer and seeded. The newer landfill site, which began operation in 1977, occupies an adjacent, abandoned borrow pit and has a designed 1.5 m (5 ft) thick Poz-O-Pac® liner. This disposal area was anticipated to be retired by mid-1982.

The following factors were important in the selection for study of the coal ash landfill operation of the Powerton Plant:

- Collection, handling and managed landfill disposal of ash as practiced at Powerton is one of the prevalent nationwide practices in the utility industry; it is an even more prevalent practice at newer plants.

- The Powerton site provided an opportunity to study the effects of landfill disposal of coal ash from combustion of a western coal in a typical interior climatic and geohydrologic setting. The site is in an area of relatively permeable soils and relatively moderate, regular precipitation.

- The initially available information indicated that two adjacent, artificially lined fly ash/slag disposal areas might be available for

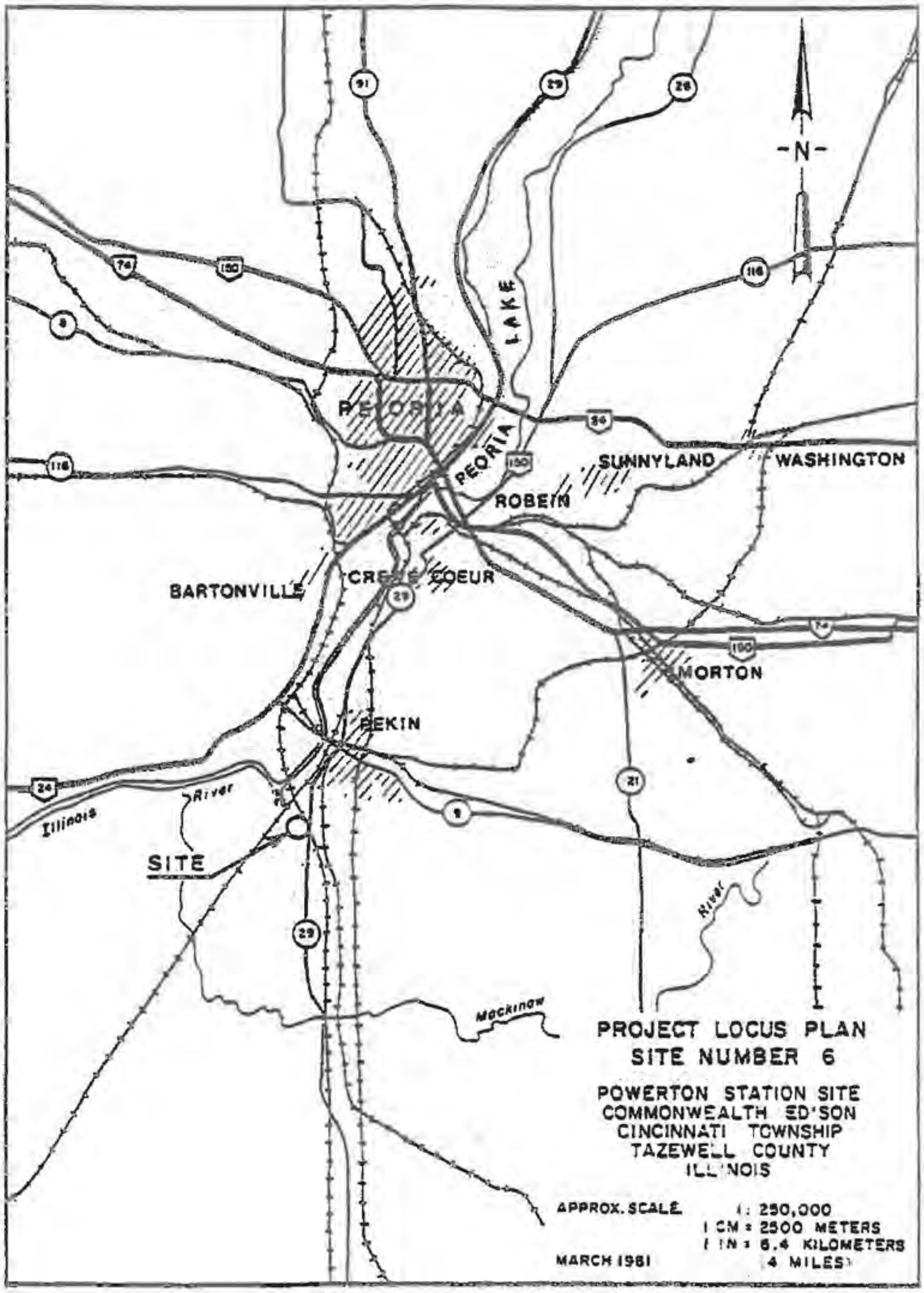

-N-
LAKE
PEORIA
PEORIA
SUNNYLAND
WASHINGTON
ROBEIN
BARTONVILLE
CREVE COEUR
MORTON
PEKIN
Illinois
River
SITE
River
Mackinaw
91
29
26
74
150
116
8
116
24
150
29
74
150
21
24
9
29
PROJECT LOCUS PLAN
SITE NUMBER 6
POWERTON STATION SITE
COMMONWEALTH ED'SON
CINCINNATI TOWNSHIP
TAZEWELL COUNTY
ILL'NOIS
APPROX. SCALE
1 : 250,000
1 CM = 2500 METERS
1 IN = 6.4 KILOMETERS
(4 MILES)
MARCH 1981

FIGURE 5.36

study. One site is the original, recently retired disposal area reportedly underlain by a 0.20 m (8 in) thick Poz-O-Pac® liner, and the other is an active area underlain by a 1.5 m (5 ft) Poz-O-Pac® liner. While artificial lining of managed coal ash landfills is not a prevalent practice nationwide (and is not expected to be in future), this was considered a useful opportunity to study a potentially mitigative practice.

- The retired landfill is bordered on one downgradient face by a small, permanent stream (Lost Creek) with mean flows estimated at 0.028 to 0.28 m^3/sec (4500 to 45,000 gal/min). Lost Creek receives upgradient runoff loadings from a variety of land uses, including agricultural (active corn fields border most of the disposal site) and a mix of light industrial and commercial uses. Because there are no major point source discharges to Lost Creek, this was considered an excellent opportunity to study potential non-point source impacts of coal ash disposal on both groundwater quality and water quality in a small surface water body.

5.6.1.2 Geologic Conditions--
The Powerton Plant is located within the Havana Lowland Region of the Central Lowland Physiographic Province of west-central Illinois. The Lowland is characterized by glacially-derived, rolling topography with numerous erosional and depositional stream channels.

The project site is underlain by a broad bedrock channel of the ancestorial Mississippi River and consists of Pennsylvanian shales with interbedded limestones, sandstones and coal units. The bedrock surface in the site area is approximately 15 to 30 m (50 to 100 ft) below ground surface.

The Wisconsin glacier, which terminated approximately 3 km (2 miles) east of the site, caused thick sequences of outwash sands and gravels to be deposited directly over the decomposing bedrock surface. With the development of modern surface drainage courses, flood plain alluvium consisting of clay, silt and sand was deposited over the underlying and adjacent outwash deposits. Lost Creek, which abuts the disposal area on the east, deposited from 1.5 to 3.0 m (5 to 10 ft) of these finer alluvial deposits along the easterly portions of the landfill site. However, the clay units, varying from 0 to 2 m (0 to 7 ft) in thickness are generally discontinuous.

Figure 5.37 summarizes the site area surficial geologic conditions in the site area. General subsurface geologic profiles are described in Section 5.6.5.2.

5.6.1.3 Hydrologic Conditions--
The Powerton Plant site lies within the Glaciated Central Lowlands Groundwater Province and the Illinois River Basin. The main water bearing units are the sand and gravel outwash deposits; the underlying bedrock units are relatively impermeable. The Powerton Plant obtains its water supply from large diameter wells within the outwash deposits.

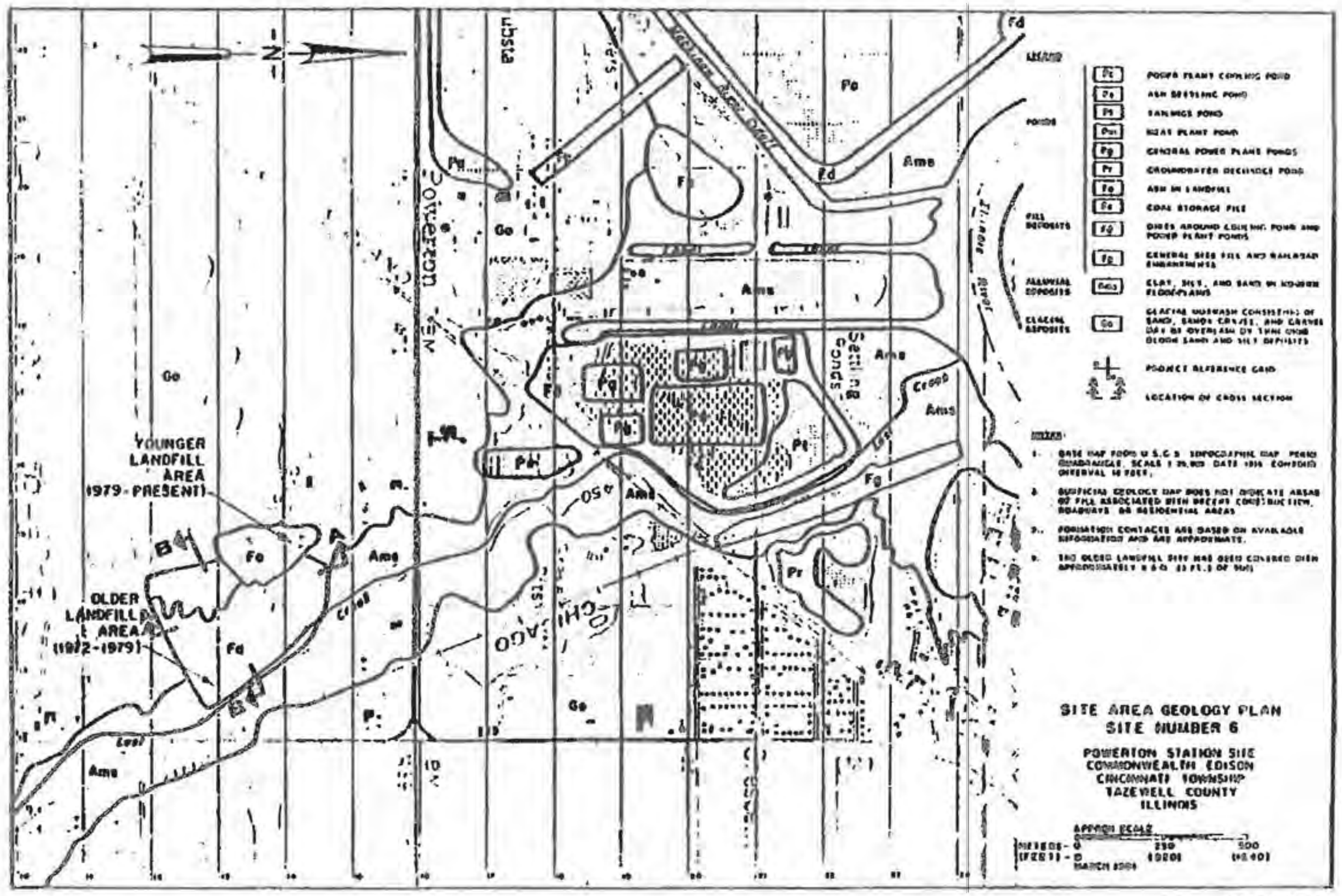

N
Powerton
Settling Ponds
YOUNGER LANDFILL AREA (1979-PRESENT)
OLDER LANDFILL AREA (1972-1979)
Fo
Fd
Ams
Go
Pr
Pt
Fg
SITE AREA GEOLOGY PLAN
SITE NUMBER 6
POWERTON STATION SITE
COMMONWEALTH EDISON
CINCINNATI TOWNSHIP
TAZEWELL COUNTY
ILLINOIS
APPROX SCALE
0
250
500

FIGURE 9.37

Annual precipitation is approximately 0.89 m (35 in), of which an average of 0.26 m (10 in) contributes to groundwater recharge and 0.21 m (8 in) is lost in annual stream discharge. Flooding of rivers and streams is a common occurrence and the adjacent Lost Creek has been known to rise as much as 2.1 m (7 ft).

The groundwater table in the site vicinity is very close to the original ground surface along its easterly boundary and was encountered within the base of the disposed ash in the retired landfill site. Considering the higher elevations of the original ground surface along the westerly landfill boundary, the water table is encountered at approximately 10 m (35 ft) below ground surface. All surface and groundwater flow is northeasterly towards Lost Creek which subsequently flows to the Illinois River.

5.6.2 Site Evaluation Plan and Site Development

Nine monitoring wells installed by the landfill contractor in the two landfill sites provided preliminary subsurface information and groundwater levels for a two-year period.

The project site development plan for the Powerton landfill site included the installation of multi-purpose wells, piezometers and exploratory test borings for hydrogeological and geotechnical evaluation purposes. One upgradient observation well was installed for background monitoring purposes and five downgradient wells were installed around the perimeter of the disposal area to determine the presence and vertical extent of any leachate. Four continuously sampled test borings were obtained in the older, retired landfill area to determine the presence and thickness of the compacted Poz-O-Pac® liner. Only the most westerly exploration (boring 6-3) encountered a liner which was 0.27 m (11 in) thick. A sealed piezometer was installed, utilizing special Illinois EPA-approved procedures, within the outwash deposits immediately below the disposed fill materials. Although the anticipated liner, which could have created "perched" groundwater conditions, was not present at this location, it was determined that groundwater mounding had occurred into the base of the landfill material. No explorations or wells were installed in the most recent, active ash disposal area, which reportedly was lined with 1.5 m (5 ft) of Poz-O-Pac®.

At the completion of all monitoring installations, the wells were flushed, bailed and an initial sample obtained for chemical evaluation purposes.

The location of all explorations and monitoring/sampling installations are indicated on Figure 5.38 and a summary of all field results, samples, locations, types, depths, and tests are indicated on Table 5.33.

5.6.3 Physical Testing Results

Results of physical characterization tests performed on samples from the Powerton site are included as Figure 5.39. Confirming the reports of Commonwealth Edison personnel, boiler slag and fly ash were found in separate

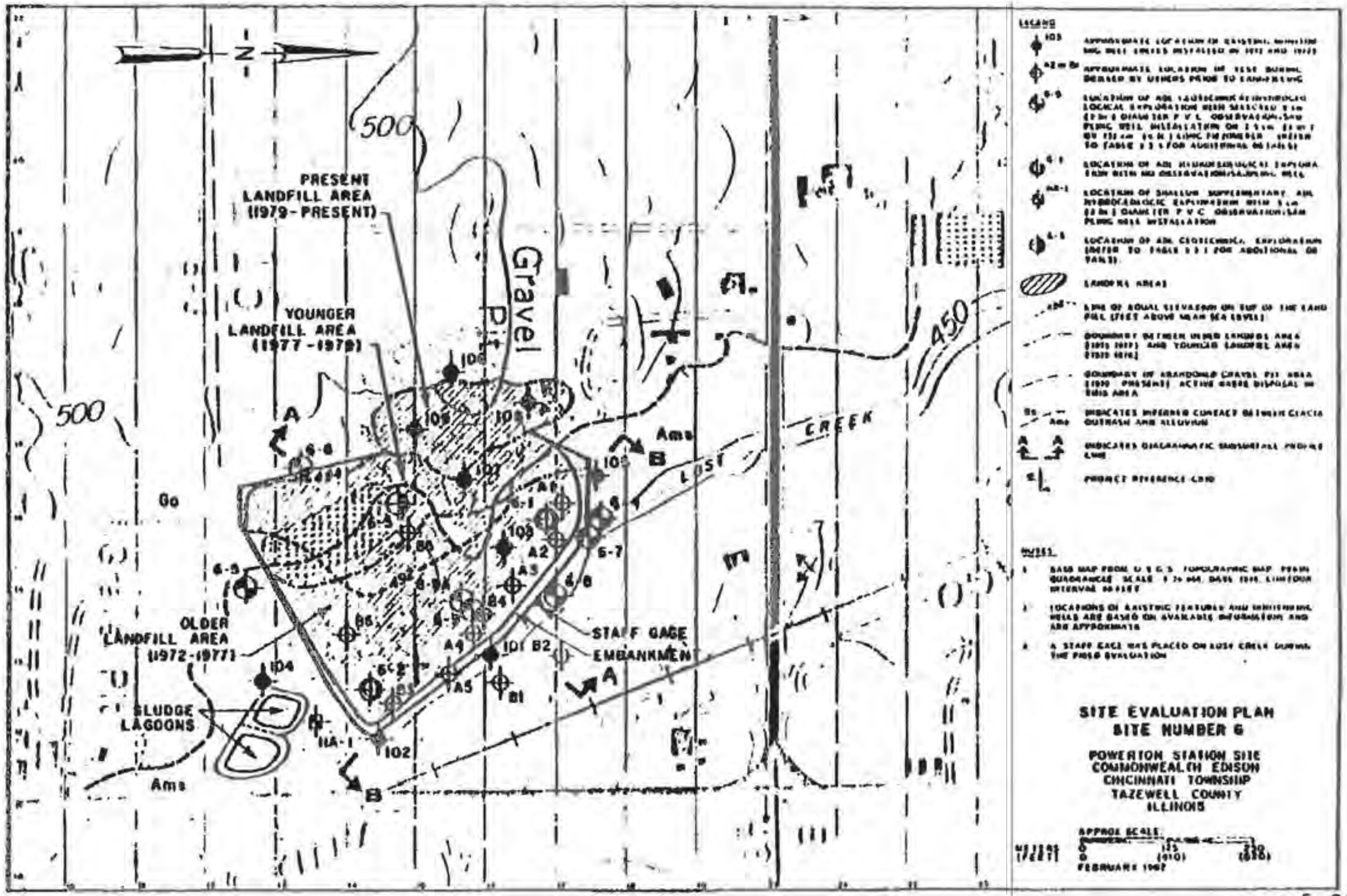

N
500
PRESENT
LANDFILL AREA
(1979 - PRESENT)
Gravel
Pit
YOUNGER
LANDFILL AREA
(1977 - 1979)
450
500
LOST
CREEK
Ams
Go
OLDER
LANDFILL AREA
(1972 - 1977)
SLUDGE
LAGOONS
STAFF GAGE
EMBANKMENT
A
B
SITE EVALUATION PLAN
SITE NUMBER 6
POWERTON STATION SITE
COMMONWEALTH EDISON
CINCINNATI TOWNSHIP
TAZEWELL COUNTY
ILLINOIS
APPROX SCALE
FEBRUARY 1982

FIGURE 5.38

TABLE 5.33

SITE DEVELOPMENT SUMMARY

SITE: POWERTON PLANT
TAZEWELL COUNTY, ILLINOIS

DATES: November 9, 1981 - November 24, 1981

FILE NO.: 453506

Boring #	6-1	6-2	6-3	6-4
Soils Classification [depth (m): Class]	0-0.8: Cover Fill 0.8-10.1: Ash Fill 10.1-12.0: Alluvium 12.0-12.2: Outwash	0-0.9: Cover Fill 0.9-9.6: Ash Fill 9.6-10.1: Fill 10.1-11.7: Alluvium 11.7-12.0: Outwash	0-0.8: Cover Fill 0.8-4.5: Ash Fill 4.5-4.8: Poz-o-Pac Liner 4.8-7.5: Alluvium 7.5-7.9: Outwash	0-0.3: Topsoil 0.3-4.0: Alluvium 4.0-20.1: Outwash 20.1-20.3: Decomposed Rock
Number of Samples Obtained	14	15	11	16
Field Permeability Tests	No Tests	No Tests	No Tests	No Tests
Well Installation [wellpoint type; diameter (in); location: (m)]	No Well	No Well	No Well	0.010: slot; 2.0 ID: 5.4-8.3

5-142

Boring #	6-5	6-6	6-7	6-8
Soils Classification [depth (m): class]	0-0.2: Topsoil 0.2-2.6: Alluvium 2.6-12.5: Outwash	0-0.3: Topsoil 0.3-29.3: Outwash 29.3-29.4: Glacial Till	0-2.9: Flood Plain Dep. 2.9-3.5: Alluvium	0-1.5: Flood Plain Dep 1.5-2.6: Alluvium 2.6-2.7: Outwash
Number of Samples Obtained	13	25	1	4
Field Permeability Tests [depth (m); results (m/sec)]	No Test	(CHT-1) 11.6-12.0; 4.55×10^{-6}	(RHT-1) 2.1-3.5; $2.945-3.609 \times 10^{-6}$	No Tests
Well Installation [wellpoint type; diameter (in); location (m)]	0.010" slot; 2.0 ID; 4.5-10.2	0.010" slot; 2.0 ID; 13.2-16.0	0.010" slot; 2.0 ID; 2.1-3.5	0.010" slot; 2.0 ID; 1.2-2.6

CHT = Constant head test; RHT = rising head test

(continued)

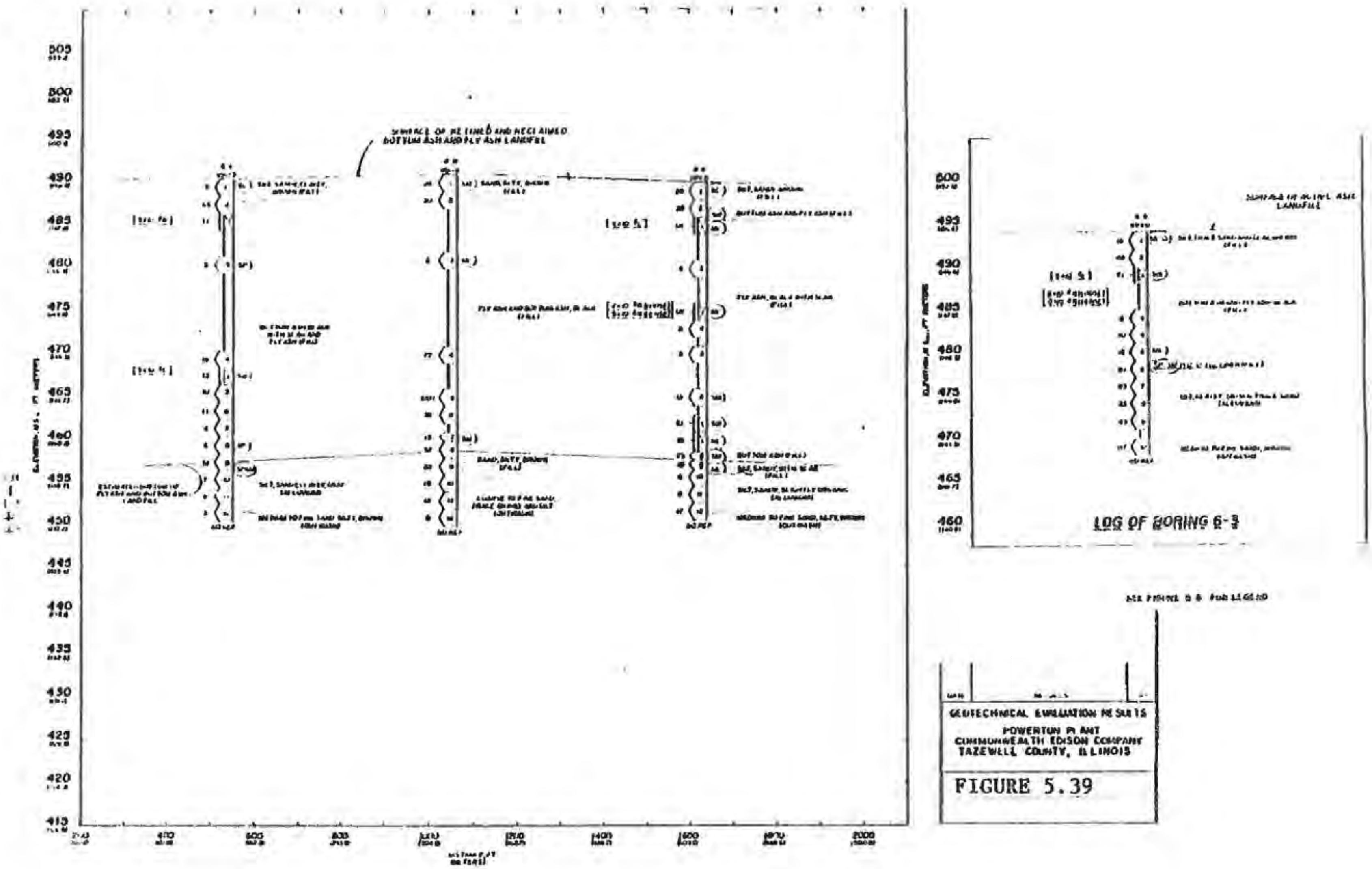
TABLE 5.33

SITE DEVELOPMENT SUMMARY

SITE: POWERTON PLANT
TAZEWELL COUNTY, ILLINOIS

Boring #	6-9	6-9A	HA-1
Soils Classification [depth (m): Class]	0-0.9: Cover Fill 0.9-9.8: Ash Fill 9.8-10.7: Fill 10.7-12.5: Outwash	0-9.4: Ash Fill	0-0.5: Flood Plain Deposits 0.5-1.2: Alluvium
Number of Samples Obtained	12	1	
Field Permeability Test	No Tests	No Tests	No Tests
Well Installation [wellpoint (in); location (m)]	Vyon pourous tip; 3/4 ID; 11.2-12.4	0.010" slot; 2.0 ID; 5.0-9.1	0.010" slot; 2.0 ID; 0-1.0

Remarks


SURFACE OF RETIRED AND RECLAIMED BOTTOM ASH AND FLY ASH LANDFILL
LOG OF BORING 6-3
SEE FIGURE 5.6 FOR LEGEND
GEOTECHNICAL EVALUATION RESULTS
POWERTON PLANT
COMMONWEALTH EDISON COMPANY
TAZEWELL COUNTY, ILLINOIS
FIGURE 5.39

areas of the older portion of the landfill (Borings 6-1 and 6-2, respectively). The coefficients of permeability ranged from a high of 3 x 10^{-2} cm/sec for the slag to a low of 1 x 10^{-4} cm/sec for the fly ash. In the more recent section of the ash landfill where slag and fly ash were mixed, the coefficient of permeability of the ash was approximately 5 x 10^{-4} cm/sec.

Samples of fly ash and mixed slag/fly ash were remolded to both loose and dense relative densities and subsequently subjected to laboratory permeability tests. Based on these analyses, it was determined that the coefficient of permeability of the fly ash from the older portion of the landfill can be decreased by increasing its density. However, only minimal permeability changes resulted by increasing the density of the more recently placed fly ash/slag mixture.

Table 5.34 summarizes selected physical testing results. A more detailed presentation is provided in Appendix E.

5.6.4 Chemical Testing Results

The site monitoring infrastructure was developed in November 1981. At that time samples of wastes and soils were obtained for physical and chemical testing. Subsequent groundwater and surface water sampling for chemical testing and measurement of water levels took place in December 1981, April 1982, and August 1982. Precipitation and water levels were at a (seasonally-representative) very low level for the December visit, were extraordinarily high for the April visit (because of storms), and were in the high-normal range for the August visit.

Selected chemical testing results are presented in Table 5.35, along with values for relevant EPA water are standards. Table 5.36 presents selected results of attenuation tests using Powerton site soils. A more detailed presentation of chemical testing results is provided in Appendix F.

5.6.5 Environmental Assessment

5.6.5.1 Approach for the Powerton Site--

The environmental assessment of the Powerton site results focused on the following issues:

- effects of the ash landfill leachate on downgradient groundwater quality;
- effects of the ash landfill leachate on Lost Creek surface water quality; and
- initially, effectiveness of the Poz-O-Pac® liner under the older disposal area. When site development efforts revealed a general absence of the liner, this emphasis was discontinued.

The steps employed in the environmental assessment at this site were as follows:

TABLE 5.34

SELECTED PHYSICAL TESTING RESULTS

POWERTON PLANT

Permeability (cm/sec)	$2.4 \times 10^{-6} - 5.3 \times 10^{-4}$
Specific Gravity	2.63 - 2.79
Grain Size Distribution (Weight Percent)	
• > 74 µm	15 - 98
• 2 - 74 µm	2 - 80
• < 2 µm	0 - 20
Moisture Content (Weight Percent)	0.3 - Saturated
Effective Strength Parameters	
• Angle of Internal Friction	30.2°
• Effective Cohesion (Pa; psi)	0.0; 0.0

Source: Arthur D. Little, Inc., and Bowser-Morner Testing Laboratories, Inc.

TABLE 5.35

SELECTED DATA FOR REPRESENTATIVE SAMPLING LOCATIONS AT THE POWER PLANT
CONCENTRATION (ppm except where noted)

Sample Description	NO_3	So_4	B	Na	Ca	A(ug/ℓ)
Wells 6-5, 6-6, 6-15 (Background)	7-49.9	11.5-58	0.72-0.63	4-14	82-104	<0.7-0.4
Well 6-9 (In Waste)	10.7-76.5	591-904.1	15.9-36.5	158-260	96-126	0.7-1.1
Wells 6-4, 6-7, 6-8 (Downgradient)	<0.6-34.4	120-688	2.1-18.1	19-178	109-247	<0.2-19.5
Borings 6-3, 6-9 (Waste Solids)	--	--	--	78,000-13,800	16,100-26,800	--
Location 6-1 (Landfill Surface 0.6-1.2m)	--	--	--	8,000	39,000	--
Wells 6-13, 6-14, 6-16 (Lost Creek Background)	15.8-54.3	60-83.7	0.02-0.23	8-18	74-97	0.4-0.6
Wells 6-11, 6-10, 6-12 (Lost Creek Downgradient)	18.2-52.6	58.4-96.2	0.05-0.78	11-19	77-104	0.5

EPA Interim Primary Drinking Water Standards: As = 50 ug/ℓ; Cr = 50 ug/ℓ; PB = 50 ug/ℓ; NO_3 10 mg/ℓ

EPA Interim Secondary Drinking Water Standards: SO_4 = 250 mg/ℓ ; Cu 1 mg/ℓ ; Zn = 5 mg/ℓ

EPA Criterion for Protection of Sensitive Crops: = 0.75 mg/ℓ

continued

TABLE 5.35

CONCENTRATION (ppm except where noted)

Sample Description	Cu	Cr	Pb	Zn	Sr
Wells 6-5, 6-6, 6-15 (Background)	<0.008-0.01	<0.01-0.05	<0.05	<0.05	0.029-0.115
Well 6-9 (In Waste)	0.024-0.112	<0.01-0.05	<0.05	<0.05-0.1	0.157-0.251
Wells 6-3, 6-7, 6-8 (Downgradient)	<0.008-0.051	<0.01-0.05	<0.05-0.2	<0.05-0.08	0.133-496
Borings 6-8, 6-9 (Waste Solids)	130-203	128-193	80-160	1,150-1,780	257-363
Location 6-1 (Landfill Surface 0.6-1.2m)	40.7	26.6	<5	124	347
Wells 6-13, 6-14, 6-16 (Lost Creek Background)	<0.008-0.013	<0.01-0.04	<0.05	<0.05	0.062-0.106
Wells 6-11, 6-10, 6-12 (Lost Creek Downgradient)	<0.008-0.011	<0.01-0.05	<0.05	<0.05	0.063-0.106

EPA Interim Primary Drinking Water Standards: As = 50 ug/ℓ; Cr = 50 ug/ℓ; PB = 50 ug/ℓ; NO_3 = 10 mg/ℓ

EPA Interim Secondary Drinking Water Standards: SO_4 = 250 mg/ℓ ; Cu = 1 mg/ℓ ; Zn = 5 mg/ℓ

EPA Criterion for Protection of Sensitive Crops: = 0.75 mg/ℓ

TABLE 5.36

SELECTED RESULTS OF SOIL ATTENUATION STUDIES
POWERTON SITE[a]

Element	Solution Concentration (ppb)	Soil Capacity (μg/gm)	Soil Capacity ÷ Solution Concentration
Arsenic	6.5-495	1.1-80	169-161
	2.2-495	1.0-32.5	454-66
Selenium	5.9-117	0.2-1.0	34-8.5
	8.5-106	0.26-3.3	31
Cadmium	30-150	0.26-12.0	9-80
Chromium	170	0.05	<0.35
Copper	15-99	0.76-300	51-3030
	12-13	0.14-1.28	11-98
Vanadium	48-75	0.07-1.3	1.5-17
	19-27	0.01-0.90	1.5-33

[a]Soil sample tested was from downgradient boring 6-4, brown, clayey sand.

- Site subsurface geological profiles and a site water balance were prepared.

- The values and trends in chemical sampling and analysis results for the various areas of the site were compared with each other, the results of previous sampling by the utility, and relevant EPA water use criteria.

- The water balance, geological profiles, and chemical and physical testing results were considered together to structure and evaluate hypotheses concerning the nature of leachate generation and movement at the site. These considerations were applied to leachate movement into downgradient groundwater and leachate movement/admixing into Lost Creek.

- The broader implications of the Powerton site results were considered in terms of their applicability to similar combinations of waste types, disposal methods, and environmental settings. Of particular importance in this step for Powerton were the following factors:

  - the presence of Lost Creek, an extremely small stream immediately adjacent to the landfill, represented a conservative reference point for judging environmental effects on surface water bodies; and

  - the location of the fill immediately adjacent to another offsite land use (in this case agricultural) was unique to this program.

5.6.5.2 Geological Profiles and Water Balance--

Figure 5.40 illustrates the subsurface geological profiles for several areas of the Powerton waste disposal site. These profiles were prepared on the basis of the site development results for this program along with the available site background information.

Water Balance--An initial site water balance, based mainly on data obtained during site development, is summarized briefly below and illustrated in Figure 5.41.

- Water Input (precipitation) to the Landfill =

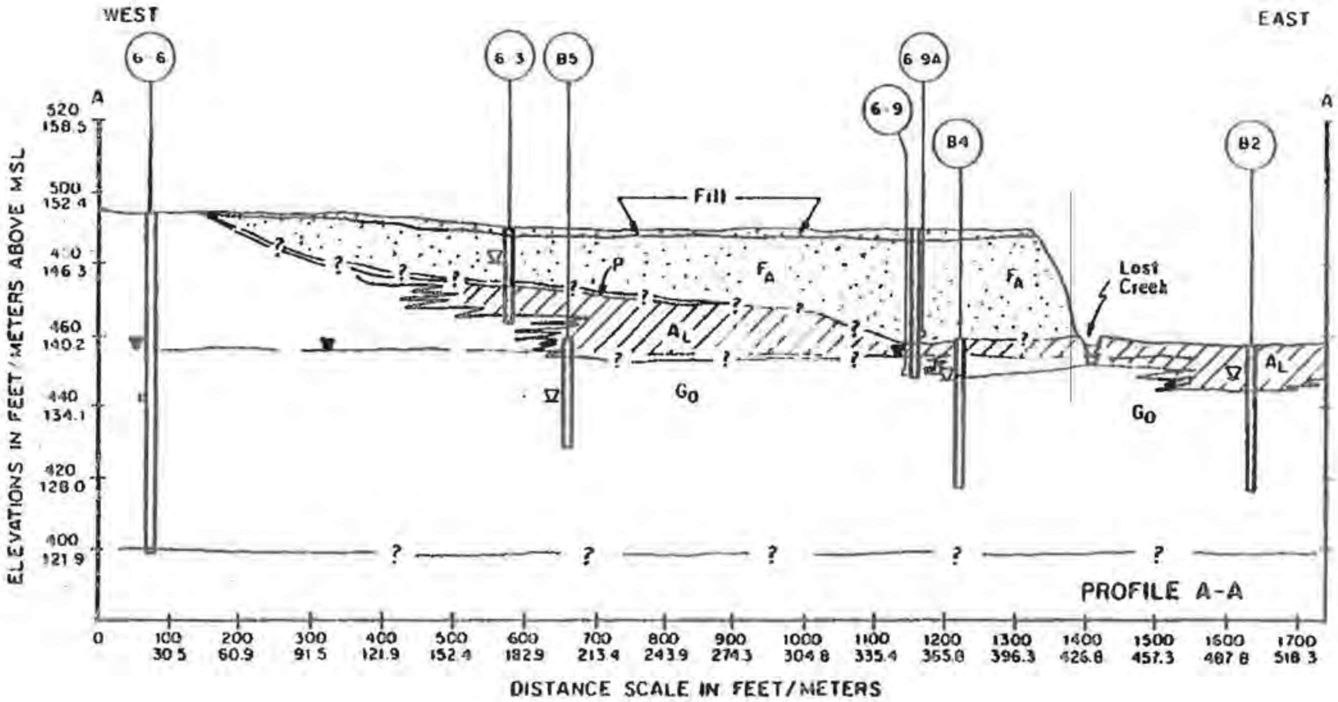
  2.9 ft/yr x landfill area = 8,390 ft^3/day.

- Water Output from the Landfill = Groundwater Recharge and Runoff and Evapotransperation.

- Groundwater Recharge = Groundwater Movement away from the Groundwater Mound = 80 m^3/day.

5.6.5.3 Evaluation of Testing Results--

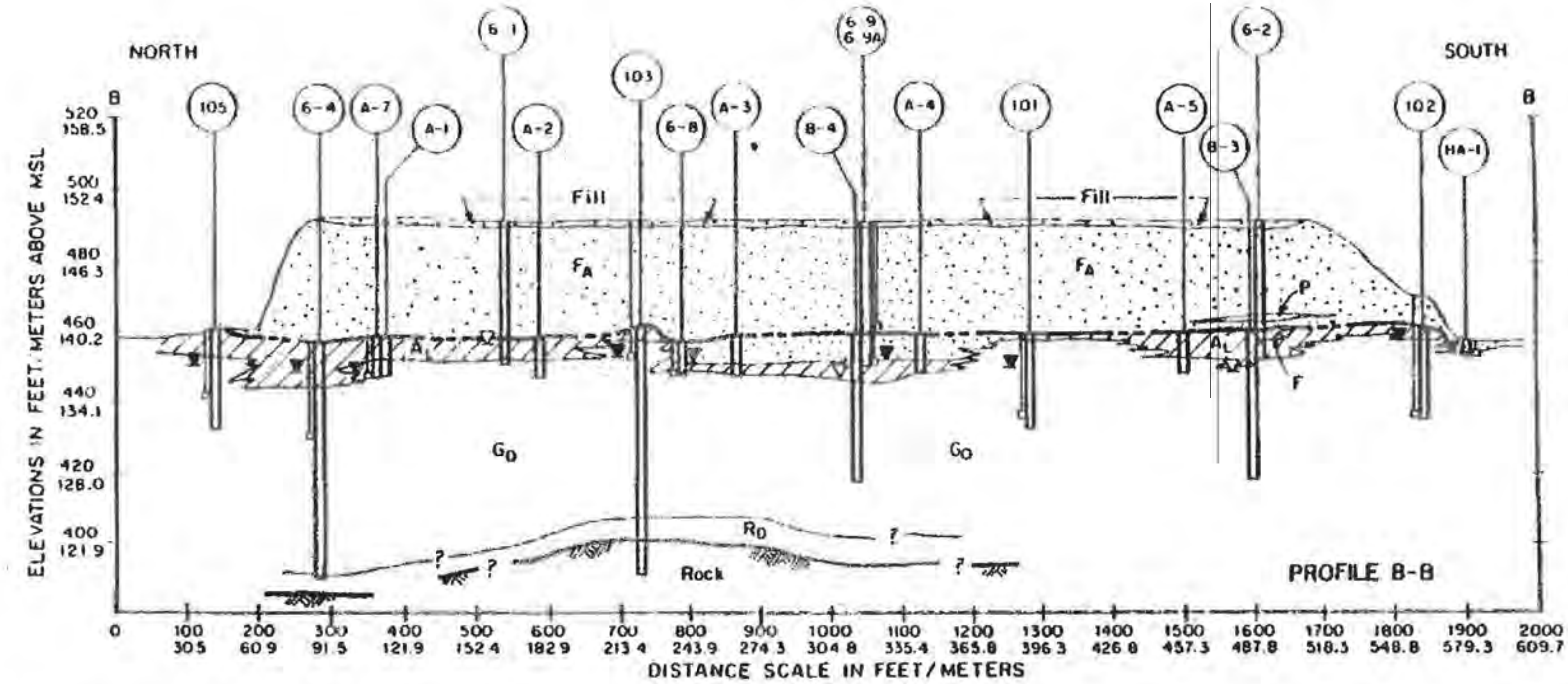
The results of chemical analyses of samples from this program along with available background data indicate the following:



SUBSURFACE GEOLOGICAL PROFILES - POWERTON SITE
COMMONWEALTH EDISON COMPANY - TAZEWELL COUNTY, IL.

FIGURE 5.40

(continued)



LEGEND

Fills Relatively recent overburden materials associated with on-site construction and disposal of ash

F Very stiff, brown, fine sandy silts and silts with trace amounts of fine and medium sand

F_A Loose to very compact, black, very fine silty fly ash and fine to coarse grained sandy bottom ash. Material tends to show lenses and layers of different ash materials.

Liner Material (POZ-O PAC)

P Very compact gray fine sandy ash and lime mixture with trace amounts of medium grained ash and bottom ash.

Alluvial Deposits

A_L Very stiff to soft, gray to brown, silts and clayey silts with varying amounts of fine to medium sands. Materials show frequent thin stratification.

Outwash Deposits

G_O Medium compact to very compact, brown, medium to fine sands to coarse to fine sand, with varying amounts of fine gravel and trace amounts of coarse gravel.

Glacial Till Deposits

G_T Very stiff, gray, clayey silt, with trace amounts of fine sand. Glacial till deposits were encountered on only one borehole on the site but are believed to underlie most of the site area.

Rock

R_D Sand and coarse gravel with gray clayey silt.

▽ Symbol representing groundwater depth as observed in completed borehole.

▼ Symbol representing groundwater depth as measured in groundwater monitoring well or piezometer

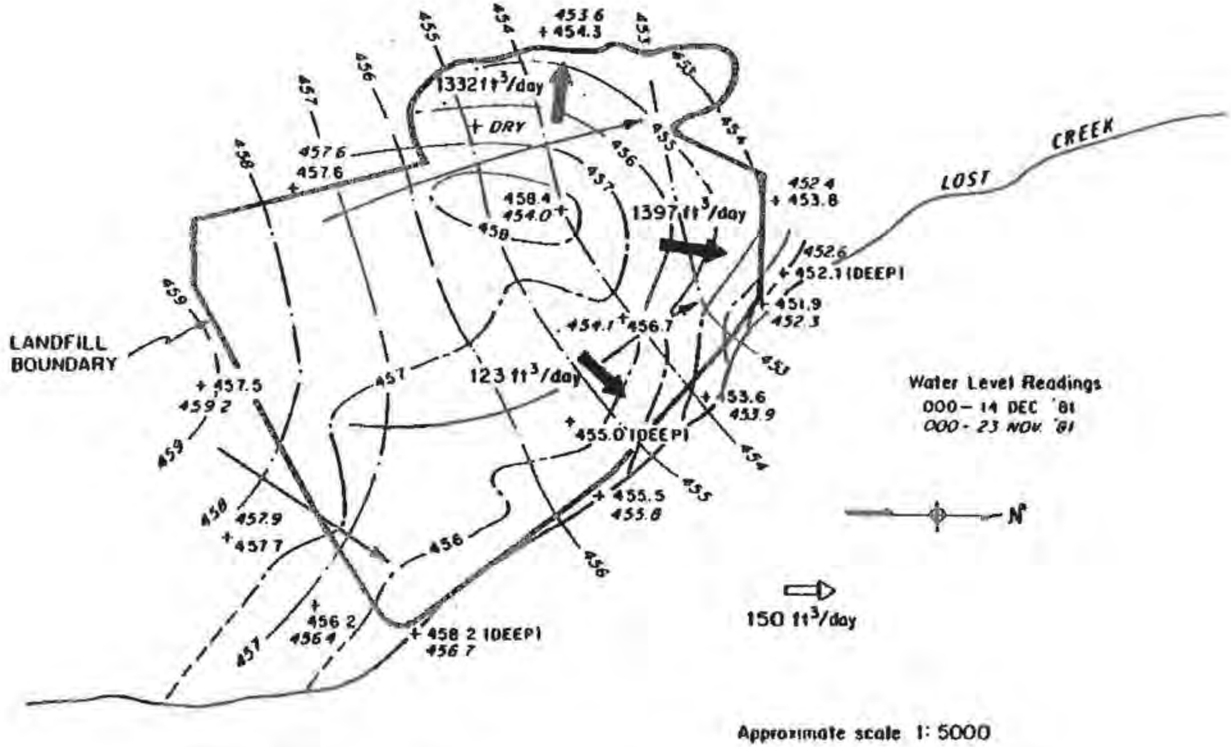
Symbol representing location of groundwater monitoring instrumentation (observation well, piezometer)

—?— Symbol representing an infered contact, not confirmed by subsurface information.

———— Infered top of original ground, prior to landfill construction.

Note: Not all contacts represent conditions as they may exist in the field. Contacts are infered and do not compensate for offsets from the profile line

FIGURE 5.40 SUBSURFACE GEOLOGICAL PROFILES - POWERTON SITE
COMMONWEALTH EDISON COMPANY - TAZEWELL COUNTY, IL.



POWERTON PLANT – APPROXIMATE MAGNITUDE AND DIRECTION OF GROUNDWATER FLOW AWAY FROM GROUNDWATER MOUND BENEATH NORTHERN PORTION OF LANDFILL.

FIGURE 5.41

- There was no evidence of Poz-O-Pac® liner material in four of the five borings that extended fully through the retired landfill into underlying soil. Liner material was visible in the active landfill [where the liner was to be about 1.5 m (4.5 ft) thick], although no borings were undertaken in that area.

- Chemical concentrations measured on different dates at the same sampling locations are similar and in accordance with the cause and effect hypotheses discussed in the following section. Some values were consistently higher at individual locations during the dry season and consistently lower at the same locations during the wetter periods.

- Nitrate values (7 to 77 mg/l) consistently exceeded the EPA Interim Primary Drinking Water Standard (10 mg/l) in groundwaters obtained from background wells in fertilized corn fields, the well within the waste, the downgradient well located in a corn fields and all of the Lost Creek sampling stations. Nitrate levels were well below the same standard (less than 0.6 to 2.5 mg/l) in the downgradient wells which were not located in corn fields.

- Groundwater samples from all wells placed within the waste and downgradient of the disposal site showed concentrations of several expected waste-related chemical tracers, including sulfate, boron, sodium, strontium and calcium, which were consistently higher than background levels. Comparative ranges were shown in Table 5.35.

- Several sulfate concentration values exceeded the proposed EPA Secondary Drinking Water Standard of 250 mg/l. Calcium values were generally higher in the downgradient wells (109 to 247 mg/l, with a mean of 181 mg/l) compared to the in-waste values (96 to 126 mg/l, with a mean of 116 mg/l), and background (82 to 104 mg/l, with a mean of 95.7 mg/l).

- Lost Creek surface water samples from the two drier sampling periods (December and August) consistently showed slightly higher downgradient concentrations of all of the above potential chemical tracers as compared to background levels. Respective ranges of background versus downgradient concentrations during these two sampling periods were:

  Sulfate: 63 to 84 mg/l background versus 75 to 96 mg/l downgradient concentration;

  Boron: 0.09 to 0.23 mg/l background versus 0.44 to 0.74 mg/l downgradient concentration;

Sodium: 11 to 13 mg/l background versus 14 to 15 mg/l downgradient concentration;

Calcium: 77 to 97 mg/l background versus 90 to 104 mg/l downgradient concentration; and

Strontium: 0.081 to 0.106 mg/l background versus 0.083 to 0.106 mg/l downgradient concentration.

- During the April high-flow sampling, values for all the above parameters in Lost Creek, except boron (0.04 mg/l background versus 0.11 mg/l downgradient), overlapped and were virtually identical at the background versus downgradient locations. The only surface water sample to exceed potentially applicable federal water quality criteria for the noted waste-related tracers was one dry-season downgradient sample for which boron slightly exceeded the non-binding criterion for protection of sensitive crops value of 0.75 mg/l.

- As shown in Table 5.35, analysis of waste solids indicated areas of consistently higher concentrations of four trace metals: copper, chromium, lead and zinc. None of the above metals were consistently measured at higher than background levels in the downgradient wells or surface water; copper and zinc were detectable in the in-waste well in the dry season sample.

- Arsenic and selenium groundwater concentrations were generally well below drinking water standards and at or near the detection limits, with the exception of a recurring arsenic concentration elevation at one downgradient well. The observed elevations were less than half the value of the Interim Primary Drinking Water Standard for arsenic.

5.6.5.4 Cause and Effect Relationships--

The Powerton site results are consistent with the following hypotheses:

- The groundwater concentrations of the major waste tracer species indicate that leachate migration from the retired landfill has reached approximate steady-state conditions with respect to the concentrations of these species in the waste and downgradient wells.

- The chemical testing results are consistent on the overall scale with the preliminary site water balance; on the smaller scale the changes in concentration that were measured would be expected due to seasonal variations in background (dilution water) flows and the observed general absence of artificial liner material under the retired landfill.

- The observed general absence of liner material under the retired landfill is consistent with the anticipated difficulty of achieving uniform placement of a relatively thin layer [i.e., less than 0.25 m (10 in)] of soil-like material over a large area using conventional engineering practices. It appears that a minimum thickness of 0.45 to 0.60 m (1.5 to 2.0 ft) of liner placed using current engineering practice would be desired to ensure full effectiveness.

- The analytical results for Lost Creek surface water are also consistent with the water balance observations; these indicate that the stream has adequate assimilative/dilution capacity to render the present levels of waste contributions relatively insignificant.

- The results also suggest that the extent of further downgradient groundwater contamination by the waste plume may be limited if a stream acts as an effective groundwater flow divide.

- The levels of trace metal concentrations in groundwater suggest that a combination of dilution and chemical attentuation (which is in the intermediate range for the site soils tested as shown in Table 5.36) is preventing the buildup of significant concentrations at downgradient locations.

- Elevated nitrate concentrations in groundwater from various sampling locations can be attributed to local agricultural and urban non-point source activities and not to the coal ash landfills.

5.6.5.5 Environmental Effects Implications--

The program findings for the Powerton site support conclusions 1,2,3, and 5 given in Section 5.1 and have the following broader environmental effects implications for the disposal of coal ash in managed landfills:

- Landfill disposal of western coal ash in an eastern interior setting of modest-to-high precipitation, relatively pervious underlying soils, and near-surface groundwater with relatively low background concentrations of contaminants can have a measurable (but not necessarily significant) impact on groundwater quality. Major dissolved species, notably sulfate, can be leached in exceedance of the Secondary Drinking Water Standard of 250 mg/l and may remain unattenuated. However, in all but direct, upgradient hydrogeologic proximity to a drinking water supply, such major species leaching would be expected to have no environmental significance because of the relatively small area in which concentration elevations would prevail and the general absence of ecological significance of these species at the prevailing concentrations.

- Release of most trace metals from landfills similar to those at Powerton appears to be held well within acceptable limits as a result of the combined effects of dilution typically available at most interior sites and the relative chemical immobility of most of waste species. The potential exception appears to be arsenic, which showed isolated concentration elevation and off-site mobility at this location and would require a case-by-case basis evaluation for analogous wastes.

- The apparent ability of even the relatively small stream bordering the Powerton landfill to assimilate and dilute the waste contributions suggests that:

  - the vast majority of flowing surface waters would be immune to significant impact from adjacent landfill disposal of coal ash similar to that produced at Powerton, and

  - location of a managed coal ash landfill disposal area so as to rely on a flowing surface water body for dilution and assimilation of non-toxic major species (like sulfate) may be a technically effective mitigative practice to avoid groundwater supply contamination. The hydrology, water quality and other sources of contamination would need to be evaluated on a site-specific basis to validate this conclusion.

5.6.6 Engineering Cost Assessment

5.6.6.1 Engineering Assessment--

The Powerton Plant is a baseload facility with a current nameplate generating capacity of 1,786 MW. Six units have been in service throughout the life of the plant, although the four older units were retired in October 1974. The operating cyclone-fired units, Units 5 and 6, started up in 1972 and 1975, respectively; each has a nameplate generating capacity of 893 MW. In 1978 and 1979, the annual capacity factors for these units were 46.8 and 54.6 percent, respectively.

Air Pollution Control--Fly ash is collected in dry form by cold-side electrostatic precipitators. This equipment has a design particulate removal efficiency of 99.5 percent and operates at 99.6 percent efficiency.

Coal Consumption--Coal used at the Powerton Plant has been obtained from Montana and Illinois. Coal consumption during the period 1974 through 1979 ranged from 2.3 to 3.4 million metric tons/yr (2.5 to 3.8 million tons/yr). The coal originally used at this plant had an ash content of approximately 12.0 to 14.0 percent by weight; the coal in current use contains about 10.0 percent ash. Although the sulfur content of coal previously used was 3.5 weight percent, a much lower coal sulfur content of 0.6 weight percent is characteristic of the coal currently in use. The annual average heat content of coal used at the Powerton Plant during the period 1974 through 1978 has ranged from 23.5 to 24.9 million joules/kg (10,100 to 10,700 Btu/lb).

Waste and Water Management--Wastes generated as a result of coal combustion at the Powerton Plant include fly ash and slag. In 1978 nearly 450,000 metric tons/yr (500,000 tons/yr) of ash was generated.

Fly ash is pneumatically conveyed to two silos for interim storage prior to disposal. A rotary mixer is employed to wet the fly ash at the silo discharge. This facilitates truck transport and placement of the waste. Process flow diagram F-500, Figure 5.42 depicts the fly ash handling system and presents a material balance for the system.

Economizer ash is collected in wet hoppers and discharged through jet pumps to the slag handling system.

Slag is collected from the wet bottom boilers and sluiced with the economizer ash to hydrobins for dewatering. Following dewatering, the slag and economizer ash are transported by truck to the landfill disposal site. Aqueous effluent from the dewatering bins is directed to settling ponds for clarification prior to discharge to the cooling lake and ultimate reuse. Process Flow diagram F-501, Figure 5.43 illustrates the slag and economizer ash handling and processing system.

Miscellaneous plant wastes are directed to the settling ponds. Process flow diagram F-502, Figure 5.44 provides information on this system.

Disposal Operation--An abandoned gravel pit was in use for ash disposal at the time of this study. It had been used for ash disposal since 1977 and was expected to be retired in 1982. This landfill is 6.5 hectares (16.0 acres) in surface area and is designed to contain a maximum waste placement depth of 9 m (30 ft). Wastes consisting of 25 percent fly ash and 75 percent slag in a partially saturated state were spread in the gravel pit by dozers and front-end loaders. Although mixing of ash has been attempted, there was no systematic method of mixing fly ash and slag. Although some degree of ash compaction was afforded by the spreading operation, no other compacting operations have been used. The bottom and sides of the landfill are lined with Poz-O-Pac®, a lime/ash mixture. The liner thickness ranges from 1.5 m (5 ft) on the bottom to 3 m (10 ft) on the sides.

A second landfill was previously employed for disposal of Powerton Plant wastes. This landfill was retired, reclaimed and revegetated.

A list of area accounts assigned to the Powerton Plant waste handling and disposal operation was developed and is provided in Appendix G, Table G-5. Additionally, a detailed equipment list for each area account is presented in the same appendix as Table G-11.

5.6.6.2 Cost Assessment--

The engineering assessment information presented herein was the basis for the capital and annualized cost estimates for the waste handling and disposal operation at the Powerton Plant. It should be noted that a number of engineering specifications were assumed to be the same for all study sites (e.g., plant service life, load factor and heat rate), in order to provide consistency among the cost estimates for the six sites. The design premises which relate to the Powerton cost estimates are listed in Table 5.37.

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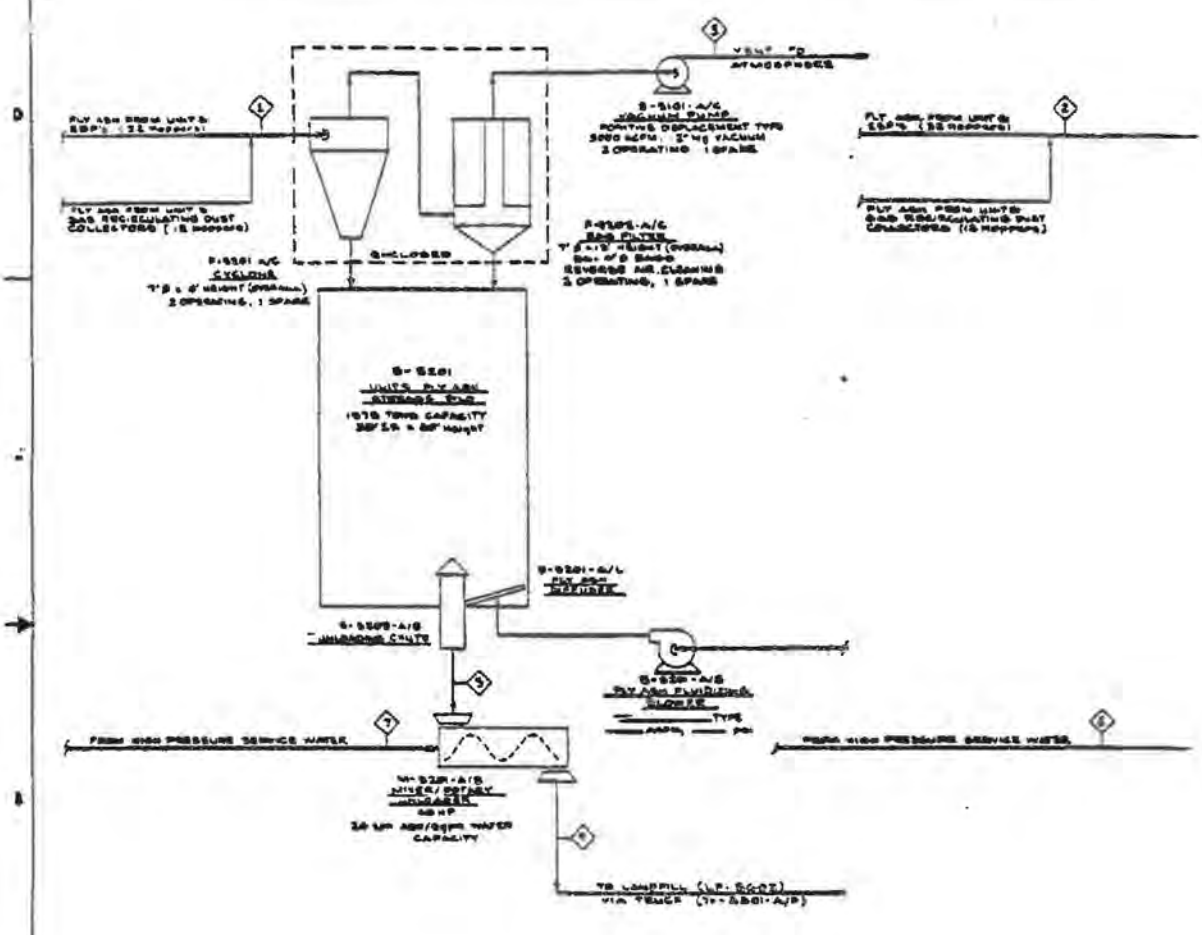


DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY, FULL LOAD

DETAIL \ STREAM NO.	1	2	3	4	5	6	7	8	9	10
TONS FLY ASH / DAY	612	612	—	—	612	612	—	—	612	612
K TONS AIR / DAY	110	110	10	110	—	—	—	—	—	—
TONS WATER/DAY	—	—	—	—	—	—	58	58	58	58

FIGURE 5.42

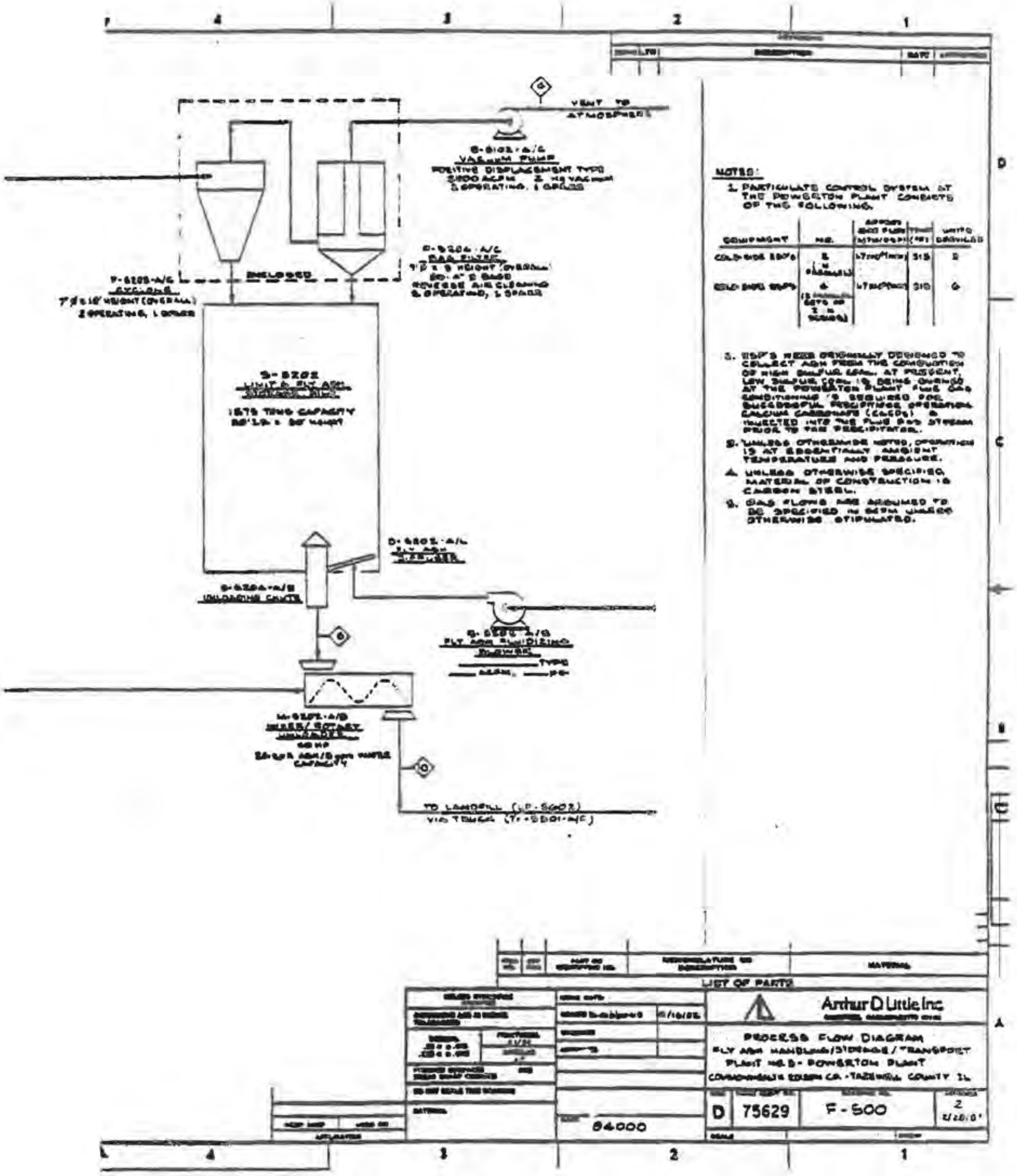
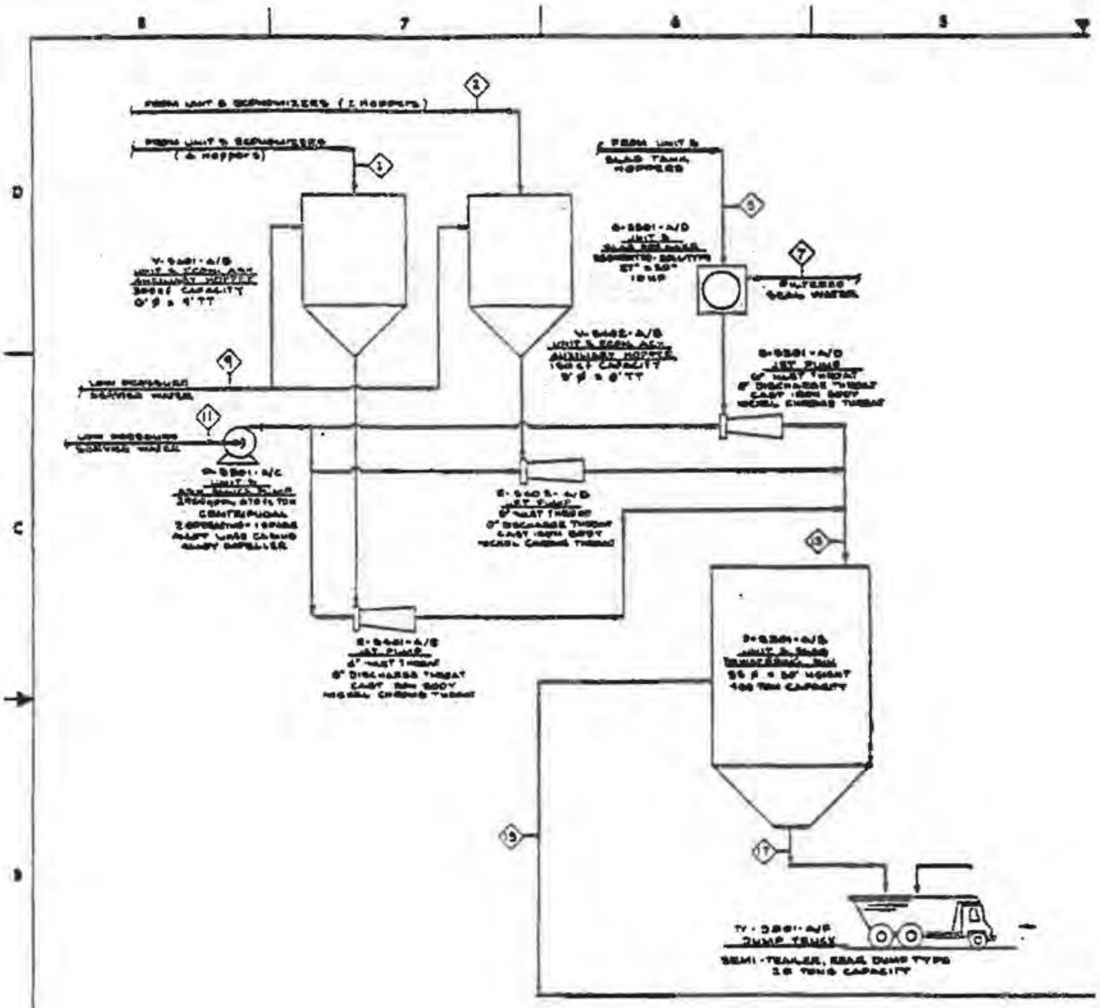

NOTES:
LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
D
75629
F-500
84000

FIGURE 5.42



DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY FULL LOAD

DETAIL \ STREAM NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TONS ASH/DAY	47	23	47	23	1050	1050	—	—	—	—	—	—	1090	1090	10	10	980	980	1980	220
TONS WATER/DAY	—	—	—	—	4050	4050	80	80	850	850	8000	[illegible]	10,700	8760	10,850	10,[illegible]	0	110	220	21,300
GPM	—	—	—	—	1.062	1.062	0.019	0.019	0.206	0.206	1.391	1.391	2.862	2.862	2.555	2.555	—	—	—	5.10
% SOLIDS	100	100	80	100	20	20	0	0	0	0	0	0	9	9	1		90	90	90	
SPECIFIC GRAVITY	—	—	—	—	1.14	1.14	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.06	1.01	1.01	—	—	—	1.0

FIGURE 5.43

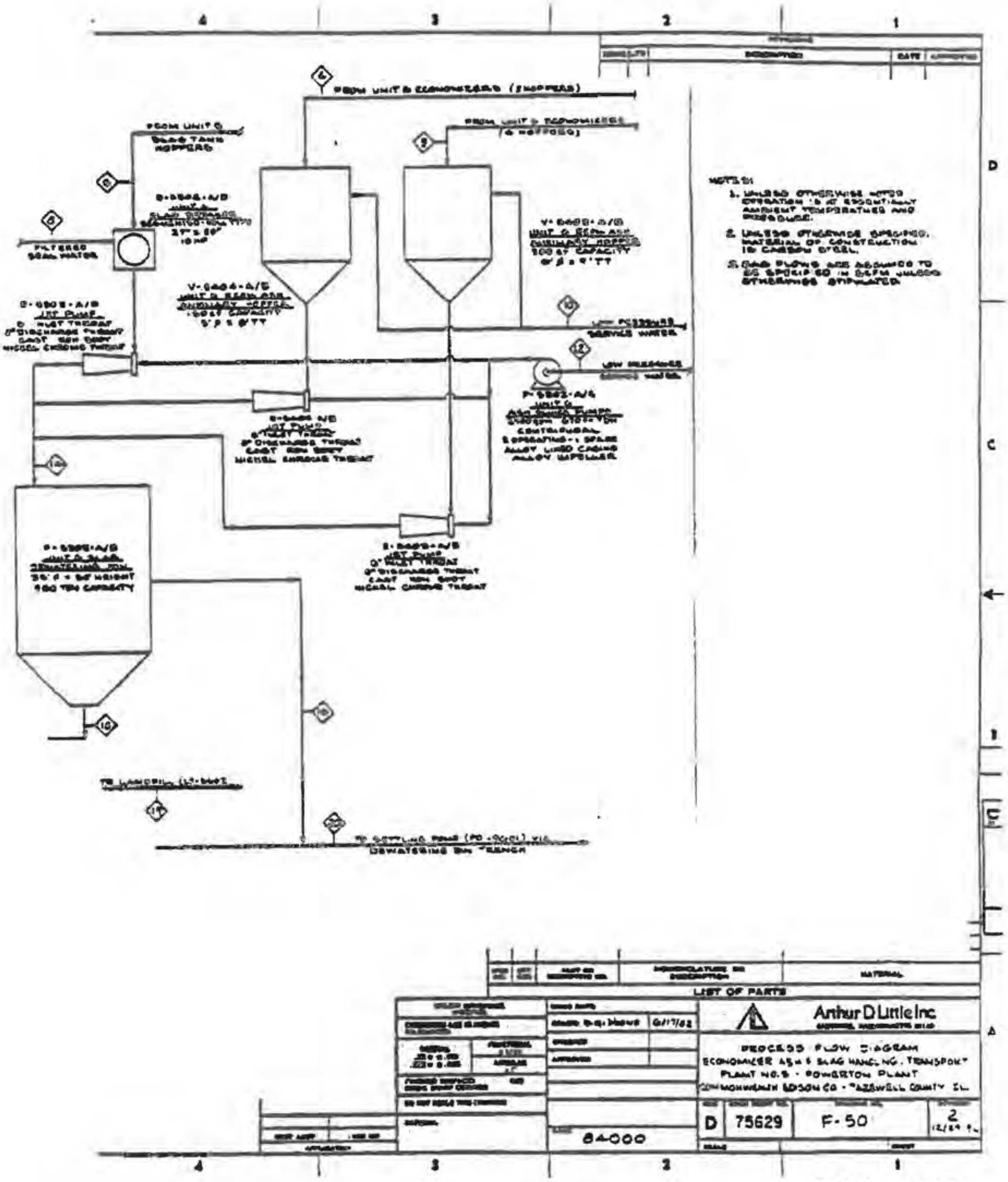
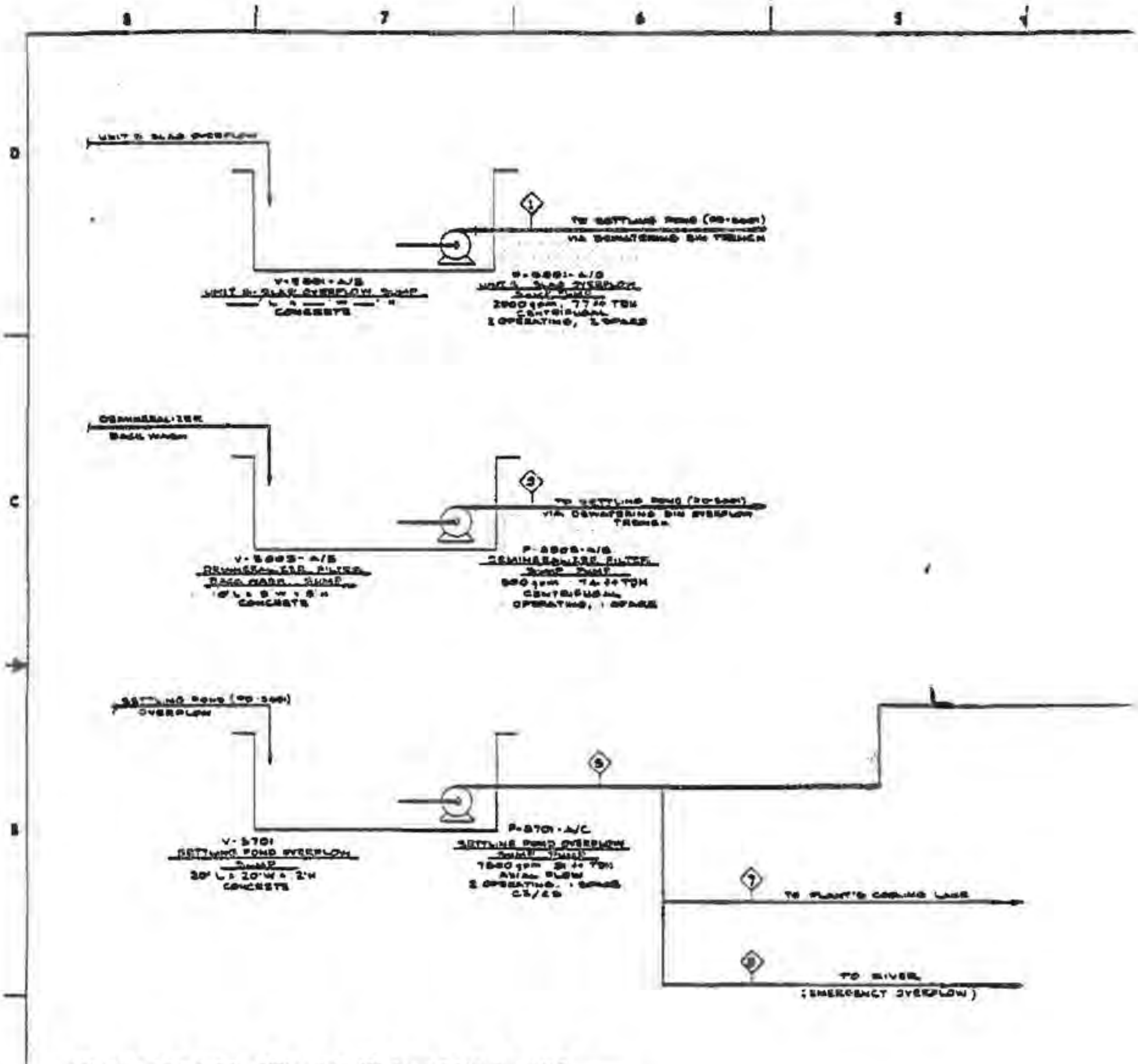

LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
ECONOMIZER ASH & SLAG HANDLING, TRANSPORT
PLANT NO. 5 · POWERTON PLANT
COMMONWEALTH EDISON CO · TAZEWELL COUNTY IL
D
75629
F-50
2
84000

FIGURE 5.43



DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY, FULL LOAD

DETAIL / STREAM NO.	1	2	3	4	5	6	7	8	9
TONS WATER/DAY	50	[illegible]	136	—	21,823	—	21,823	—	—
x 200	12	12	30	—	3,162	—	3,162	—	—

FIGURE 5.44

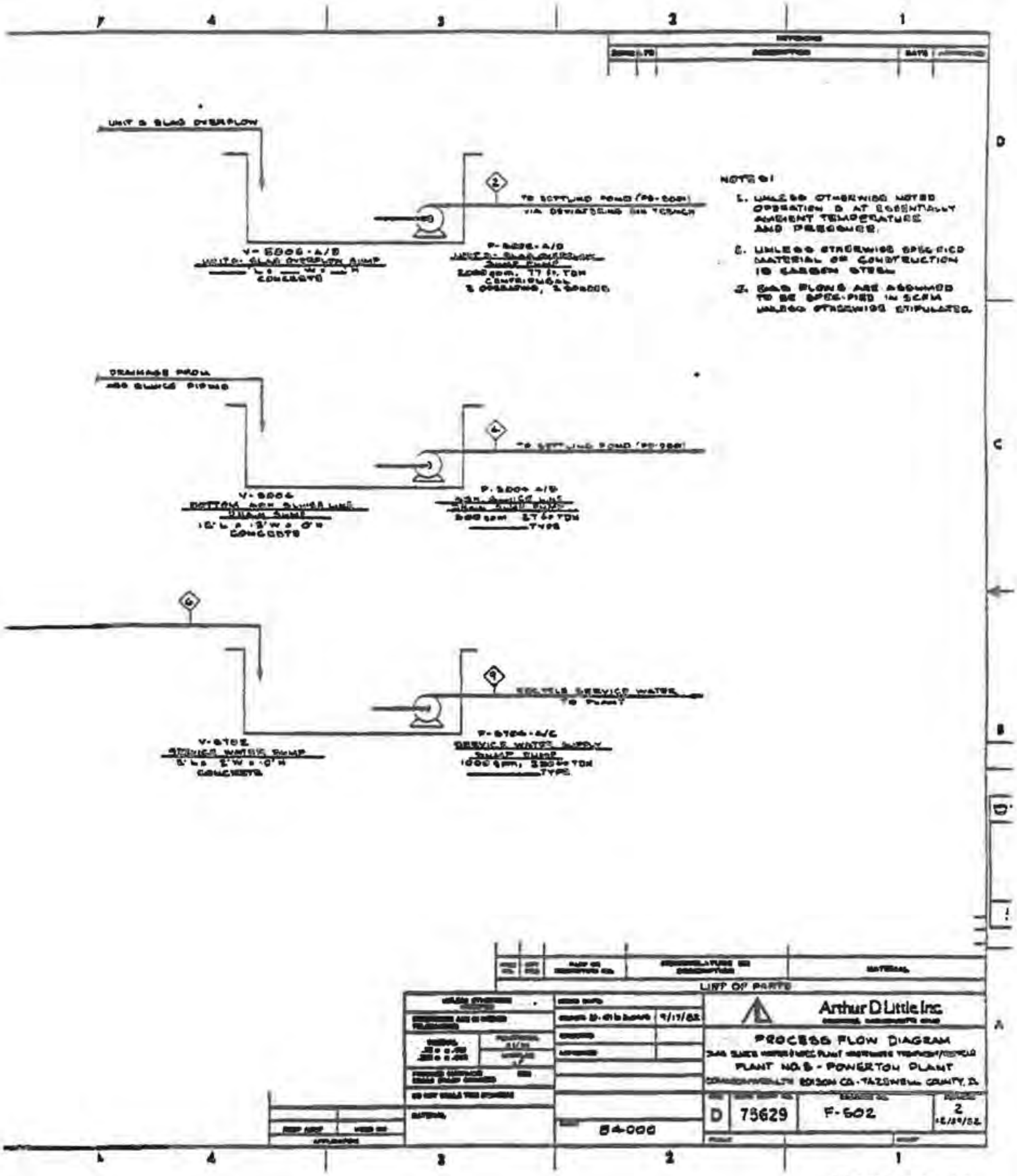

LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
PLANT NO. 5 - POWERTON PLANT
D
75629
F-502
2
84-000

FIGURE 5.44

TABLE 5.37

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR
POWERTON PLANT
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES	
Power Plant	
Plant Size (MW)	1786
Boiler Type	Cyclone-Fired
Heat Rate (M joules/kWh; Btu/kWh)	12; 11,400
Location	Illinois
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Waste Generated (dry basis)	
Fly Ash/Bottom Ash Ratio	40/60
Fly Ash Generation (metric tons/yr; tons/yr)	300,000; 330,500
Bottom Ash Generation (metric tons/yr; tons/yr)	472,300; 521,300
FGD Waste Generation (metric tons/yr; tons/yr)	--
Ash Utilization	None
Coal Properties	
Coal Type	Subbituminous
Sulfur Content (Percent)	0.6
Ash Content (Percent)	14.0
Heating Value (M joules/kg; Btu/lb)	23.5; 10,[illegible]
Air Pollution Control	
Particulate Control	Cold-Side ESP's
Particulate Removal (Percent)	99
Sulfur Oxides Control	None
Disposal Site	
Type	Landfill (gravel pits)
Design Life (yr)	30
Land Area (m^2; acre)	1,800,900; 445
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner (type; m; ft)	Poz-O-Pac; 3 to 4.5; 10 to 15
Distance from Plant (km; mile)	1.6; 1.0

Detailed capital cost estimates for the waste handling and disposal system at the Powerton Plant are presented in Appendix G, Table G-17. A condensed summary of these capital costs is presented in Table 5.38. The air pollution control system costs for this plant ($18/kW) comprise a significantly smaller fraction (only 25 percent) of the total capital costs of the combined air pollution control and waste handling and disposal systems than it does for the remaining five study plants (where it comprises 65 to 75 percent). This is due to two factors: (1) The Powerton Plant cyclone-fired boilers which produce proportionately less fly ash than bottom ash (40:60 fly ash to bottom ash ratio) than the pulverized coal-fired boilers in use at the other study plants (approximately 80:20 fly ash to bottom ash ratio). Thus, proportionately smaller, less expensive electrostatic precipitators are required; (2) No flue gas desulfurization is practiced at Powerton, unlike the case at two of the other study sites.

Another cost element of importance is the disposal facility. At Powerton, the waste placement and disposal module constitutes nearly 80% ($45/kW) of the total capital cost of $56/kW (excluding related air pollution control system costs). This is because all landfill area anticipated for the remaining life of the plant was assumed to be lined with Poz-O-Pac® [3 m (10 ft) thick on the sides and 1.5 m (5 ft) thick on the bottom], as was the case in the most recent landfill. The cost for this liner, in addition to its considerable thickness, results in very significant landfill costs. This situation is somewhat atypical; in considering the other study sites that practice landfill disposal, the major capital cost element (module) was waste handling and processing. At the Dave Johnston Plant, this is because an expensive pressure conveying system is used. As a result, the waste handling/processing module constitutes nearly 50 percent of the total waste handling/disposal system capital cost. At the Elrama Plant the waste handling/processing module is expensive because it is relatively complex, consisting of thickeners, vacuum filters, and pug mills for the fixation of FGD waste.

Annual costs for waste handling and disposal at the Powerton Plant are presented in Appendix G, Table G-23. These costs are summarized in Table 5.39. Annual costs for landfill disposal at the three plants evaluated range from $25/dry metric ton at Dave Johnston to nearly $33/dry metric ton at Elrama. The Powerton annual cost for waste handling and disposal is $27.30/dry metric ton, somewhat larger than would be anticipated due to the large plant size and corresponding economies of scale. However, the capital charges which result from the expensive Poz-O-Pac® landfill liner tend to result in relatively high annualized costs.

5.7 LANSING SMITH PLANT

5.7.1 Plant Description

5.7.1.1 Background--

The Lansing Smith Plant of Gulf Power Company is located in Bay County, Florida, on a Gulf Coast peninsula separating North Bay and West Bay

TABLE 5.38

CAPITAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Powerton
Plant Location: Tazewell County, Illinois
Utility Name: Commonwealth Edison Company
Nameplate Generating Capacity (MW): 1786

WASTES	CAPITAL COSTS ($1000) Fly Ash	Slag	Misc. Plant Wastes	Total
MODULES				
• Waste Handling and Processing				
Dry Wastes	$1,850	-	-	$1,850
- Wet Wastes (Exclusive of Recycle Water System)	238	$6,133	-	6,371
- Recycle Water System		1,635		1,635
• Waste Storage	6,027		-	6,027
• Waste Transport	392	612		1,004
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	31,229	48,846	-	80,075
SUBTOTAL MODULAR COSTS	$39,736	$57,226	$ -	$96,962($54/KW)
RELATED ENVIRONMENTAL SYSTEMS				
• Miscellaneous Plant Wastes Handling and Transport	-	-	$2,384	2,384
• Air Pollution Control	31,168	-	-	31,168
TOTAL CAPITAL COSTS	$70,904	$57,226	$2,384	$130,514($73/KW)

[a] ENR Cost Index 3931.11 (1913=100)
365.97 (1967=100)

Source: Arthur D. Little, Inc. estimates.

TABLE 5.39

ANNUAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Powerton
Plant Location: Tazewell County, Illinois
Utility Name: Commonwealth Edison Company

Operating Load Factor (percent): 70
Nameplate Generating Capacity (MW): 1786
Waste Generation (dry metric tons/yr):
Fly Ash - 100,000
Slag - 472,800

WASTES	Fly Ash	Slag	Misc. Plant Wastes	Total
	ANNUAL COSTS ($1000)			
MODULE				
• Waste Handling and Processing				
Dry System	$ 605.9	$ -	-	$ 605.9
- Wet System Exclusive of Recycle Water System	79.8	1,689.4	-	1,769.2
Recycle Water System		375.3		375.3
• Waste Storage	1,328.9	-	-	1,328.9
• Waste Transport	490.3	767.0	-	1,257.3
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	6,153.3	9,624.6	-	15,777.9
SUBTOTAL MODULAR COSTS	$8,658.2	$12,456.3	$ -	$21,114.5 ($27.30/dry metric ton)
RELATED ENVIRONMENTAL SYSTEMS				
• Miscellaneous Plant Waste Handling and Transport	$ -	$	$ 522.6	$ 522.6
• Air Pollution Control	NA[b]			NA[b]
TOTAL ANNUAL COSTS	$8,658.2 +NA[b]	$12,456.3	$ 522.6	$21,637.1 +NA[b]

[a] ENR Cost Index 3931.11 (1913=100)
365.97 (1967=100)

[b] NA = Information not available.

Source: Arthur D. Little, Inc., estimates.

(Alligator Bayou) within the St. Andrew Bay System. It is approximately 13 km (8 miles) north of Panama City, Florida, as shown in Figure 5.45.

Unit 1 of the Lansing Smith facility began operation in 1965; a second unit was added in 1967. Both units are equipped with hot-side electrostatic precipitators, and fly ash collected by these is sluiced to a disposal pond. Bottom ash, mill rejects and coal pile runoff are also directed to the same disposal pond by separate pipelines.

The Lansing Smith ash disposal pond, which consists of a 810,000 m^2 (200 acre) aboveground facility, was constructed by excavating on-site surficial sands into a low containment dike system. The pond capacity has been increased by raising the dikes on three separate occasions. Soil and ash, dredged from within the pond complex, was used to raise the pre-existing dike system. The dikes, now approximately 6.0 to 7.5 m (20 to 25 ft) in height were not designed as water retention structures. In fact, seepage through the exterior slopes has been observed. Very little standing water is maintained within the pond, as all excess water is channelled through a recycling canal and pumped back to the plant facility for reuse as sluicing water.

A number of factors were important in the selection of the Lansing Smith Plant for inclusion in this program. These are discussed below.

The disposal practice at the Smith Plant is combined disposal of fly ash and bottom ash in an unlined pond. It is the single most prevalent utility waste disposal practice in the Atlantic and Gulf Coastal Plain regions, the latter of which is the location of this plant. It was also the single most prevalent nationwide disposal practice at the time of site selection.

The disposal operation at the Smith Plant had been in existance for more than 15 years at the time of site selection, allowing sufficient time for measurable leachate to exit the pond and reach the surrounding environment. In addition, the hydrogeology of the site environment was judged to be relatively uncomplicated and amenable to understandable monitoring efforts over a period of a year.

The Smith Plant is a true coastal site (located within the zone of tidal influence). The site occupies the estuarine interface between the saline waters of adjacent St. Andrews Bay and Alligator Bayou and the acidic freshwater swamp environment which is adjacent to the north. The site has other characteristics that typify many tidally-influenced coastal plain locations, including the presence of a near-surface aquifer with relatively high dissolved solids concentrations and an underlying deep aquifer (the Floridan) which is a principal drinking water supply. The aquatic setting allows the study of the special situation where ash pond leachate and seawater would admix. The seawater would contribute its unique chemistry and buffering capacity.

The site experiences extremely heavy precipitation in a setting of pervious, coastal soils and was expected to illustrate the potential maximum extent of leachate formation and transport in a pond disposal setting. The

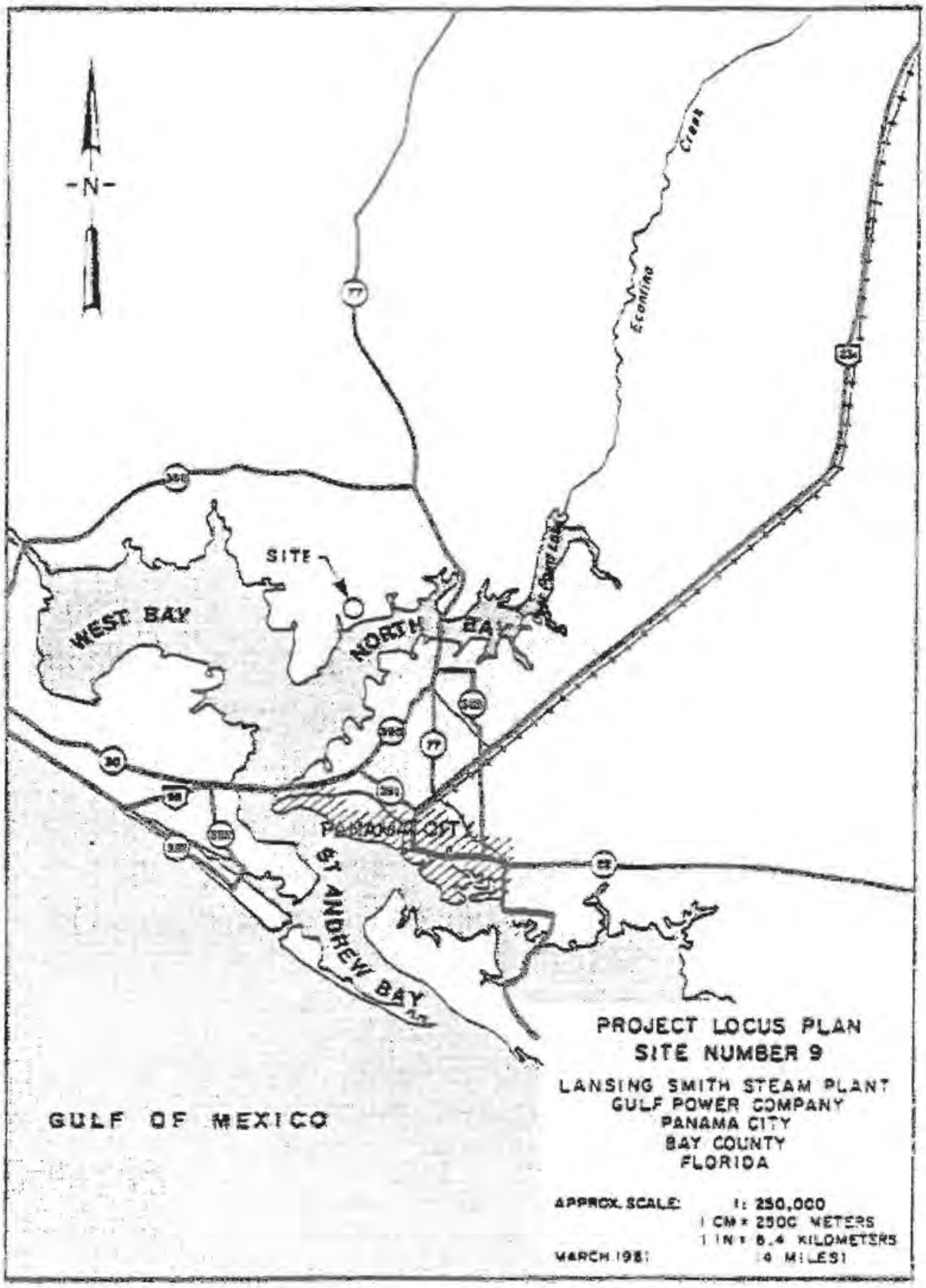

-N-
SITE
WEST BAY
NORTH BAY
ST ANDREW BAY
Econfina Creek
GULF OF MEXICO
77
PROJECT LOCUS PLAN
SITE NUMBER 9
LANSING SMITH STEAM PLANT
GULF POWER COMPANY
PANAMA CITY
BAY COUNTY
FLORIDA
APPROX. SCALE: 1: 250,000
1 CM = 2500 METERS
1 IN = 6.4 KILOMETERS
MARCH 1981 (4 MILES)

FIGURE 5.45

use of bay water for plant make-up water is a site feature that could prevail in other coastal plain locations and, thus, was also of interest. The coastal location of the Smith Plant was also considered a positive site selection factor because of anticipated increases in coal conversion of coastal oil-fired power plants. Additionally, the general paucity of literature data and previous studies of coastal disposal operations were of importance in selecting this site for study. Finally, it was possible that major storm events (i.e., tropical storms) might be experienced during the monitoring period. (During its operating lifetime, the plant has experienced a hurricane.) Such events could possibly provide a chance to observe the effect of a frequently recurring "abnormal event" that could change contaminant transport and distribution from a pond disposal operation. However, no such storm events took place during the time frame of the monitoring program.

5.7.1.2 Geologic Conditions--

The Lansing Smith Plant is located within the Flatwood Forest Division of the East Gulf Coastal Plain Physiographic Province. The area is characterized by low-lying [0 to 3 m (0 to 10 ft) mean sea level], nearly flat-lying, ancient marine terraces with intervening swamps and bayous.

The bedrock that underlies the site area at an approximate depth of 30 m (100 ft) consists of highly permeable limestones and constitutes the principal aquifer of the County and the largest fresh water aquifer in the United States. However, due to a very thick aquiclude of Miocene clay overlying the Floridan Formation, very slight hydraulic communication exists between the aquifer, which is under artesian pressures, and the overlying Pleistocene granular sediments. Overlying Miocene clays form another semi-confining layer of calcareous silts and sands with varying amounts of clay and shells. This formation is referred to as the Intracoastal Formation and is overlain in turn by loose permeable terrace silts and sands, approximately 7.6 m (25 ft) in thickness. These deposits are referred to as the Citronelle Formation and are overlain by thin topsoil and shallow organic deposits, which for the most part were not removed during construction of the ash basin complex.

Figure 5.46 summarizes the site area surficial geologic conditions and Figure 5.47 presents diagrammatic subsurface geologic profiles in the site area.

5.7.1.3 Hydrologic Conditions--

The Lansing Smith Plant site is located within the Gulf Coastal Plain Groundwater Province on the west shore of North Bay, a branch of St. Andrews Bay, and lies within the Econfina Creek drainage basin. Groundwater occurs in two separate hydrologic environments; the deep and confined Floridan bedrock aquifer and the shallow, unconfined Citronelle Formation. The groundwater within the Citronelle Formation is not potable in the plant vicinity, with very high chloride and iron contents. Fresh water for plant use is obtained from several deep wells within the underlying Floridan aquifer.

Annual precipitation in the site area is approximately 1.467 m(58 in) with an average annual potential evaporation of 1.219 m (48 in). The average annual runoff is between 0.508 m (20 in) and 0.635 m (25 in). High flow rates

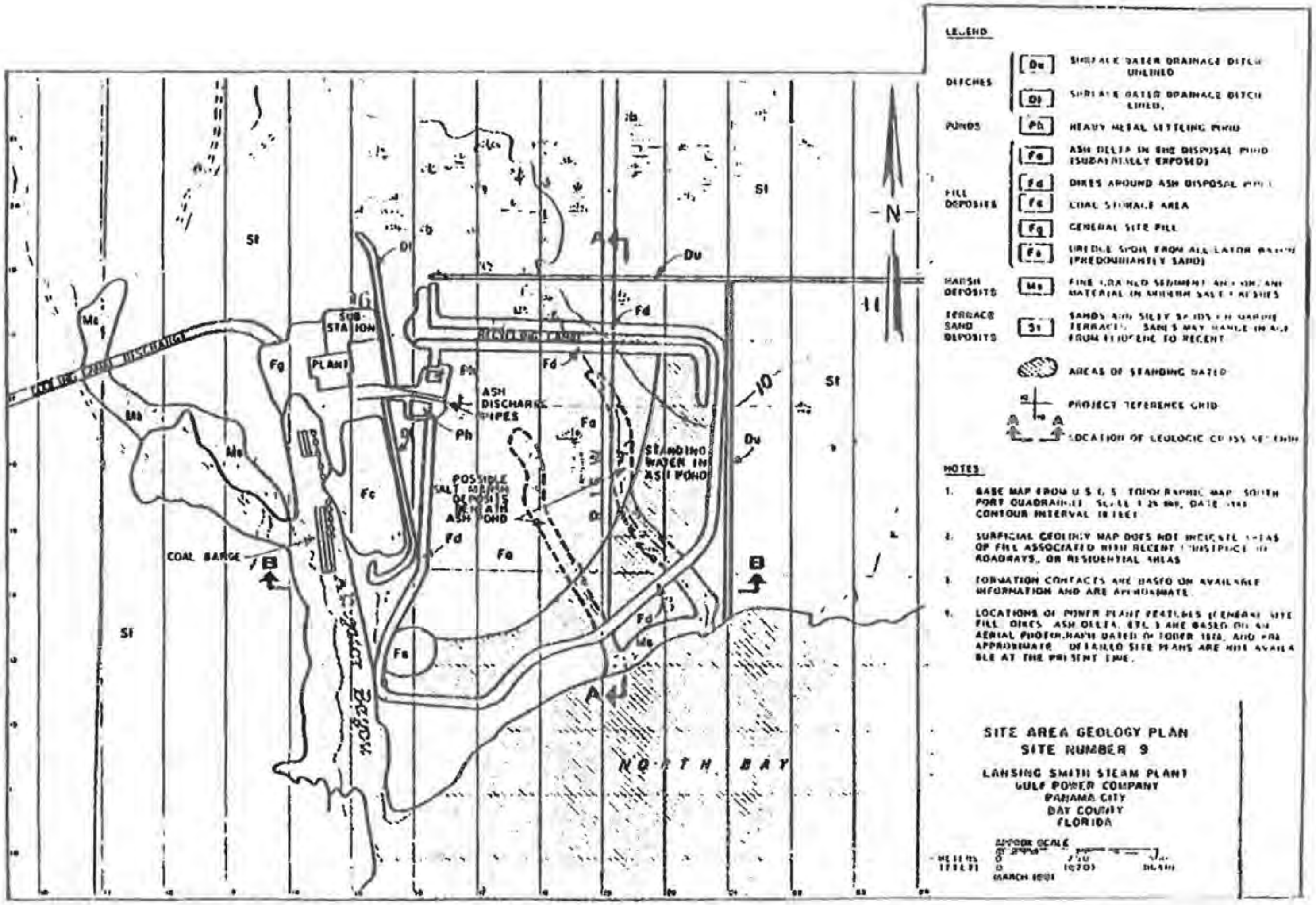

LEGEND
DITCHES
PONDS
FILL DEPOSITS
MARSH DEPOSITS
TERRACE SAND DEPOSITS
HEAVY METAL SETTLING POND
DIKES AROUND ASH DISPOSAL
GENERAL SITE FILL
AREAS OF STANDING
PROJECT REFERENCE GRID
NOTES
SITE AREA GEOLOGY PLAN
SITE NUMBER 9
LANSING SMITH STEAM PLANT
GULF POWER COMPANY
PANAMA CITY
BAY COUNTY
FLORIDA
SUB-STATION
PLANT
ASH DISCHARGE PIPES
STANDING WATER IN ASH POND
POSSIBLE SALT MARSH DEPOSITS BENEATH ASH POND
COAL BARGE
NORTH BAY
N

FIGURE 5.46

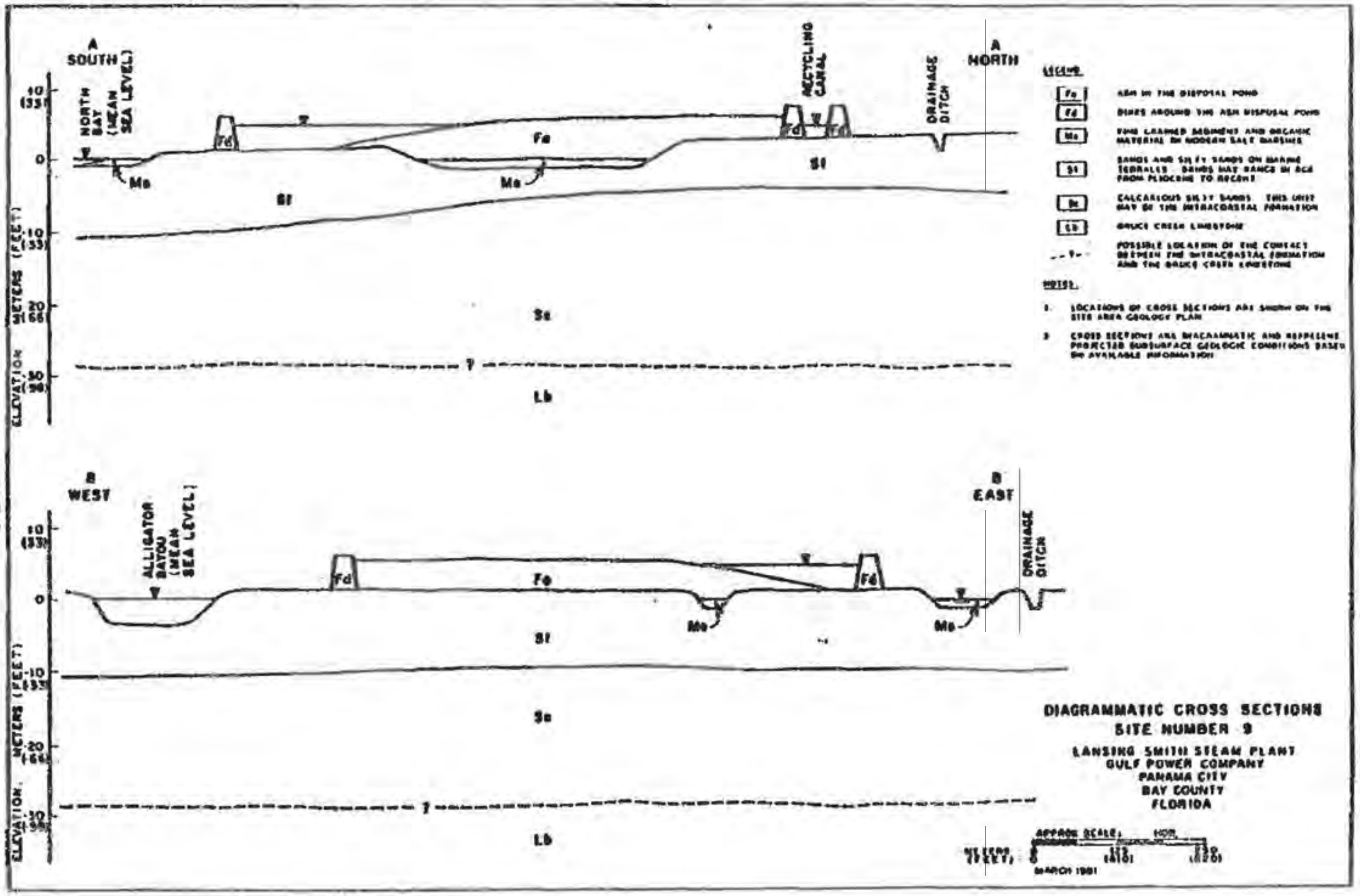

A
SOUTH
NORTH BAY (MEAN SEA LEVEL)
RECYCLING CANAL
DRAINAGE DITCH
A
NORTH
Fa
Fd
Me
Sf
Sa
Lb
ELEVATION METERS (FEET)
B
WEST
ALLIGATOR BAYOU (MEAN SEA LEVEL)
B
EAST
DIAGRAMMATIC CROSS SECTIONS
SITE NUMBER 9
LANSING SMITH STEAM PLANT
GULF POWER COMPANY
PANAMA CITY
BAY COUNTY
FLORIDA
MARCH 1981

FIGURE 5.47

in Econfina Creek are maintained by groundwater from a confined aquifer which is discharging through springs into the creek bed. Northwestern Florida experiences numerous flooding and drainage problems. The low elevations of the site area have experienced flooding from both river basin inundation and coastal storms.

The regional groundwater flow is southeasterly towards North Bay. However, due to the hydrologic influence of the ash pond, local site filling and the proximity of North Bay and Alligator Bayou, flow patterns are multi-directional in the plant vicinity. The unconfined groundwater level is at, or very close to, ground surface throughout the majority of the site area. Groundwater mounding has occurred beneath the disposal pond area and is in contact with the disposed ash materials.

5.7.2 Site Evaluation Plan and Site Development

Preliminary subsurface information was obtained from plant foundation boring logs supplied by Gulf Power. There were no pre-existing monitoring wells at the Smith Plant disposal site area.

Due to the hydrogeologic complexities at the project site area, the detailed program included the installation of 24 multi-purpose monitoring wells and piezometers throughout the site area. Two upgradient observation wells (9-4 and 9-5) were installed approximately 0.4 km (1/4 mile) and 1.2 km (3/4 mile) north of the disposal facility for background monitoring purposes. As the hydrologic effects of the aboveground disposal basin were not known at the time of site development, it was considered necessary to install a backup system some distance from the disposal area. Eleven "downgradient" wells and piezometers were installed around the ash disposal pond at varying locations and elevations. Eight monitoring devices were installed in and through the dike. Three wells were installed directly through the disposed ash within the basin complex.

At the completion of all monitoring installations, the wells were flushed, bailed and an initial sample obtained for chemical evaluation purposes.

The location of all explorations and monitoring/sampling installations are indicated on Figure 5.48 and a summary of all field results, sample locations, depths, types and tests are indicated on Table 5.40.

5.7.3 Physical Testing Results

The results of tests performed on samples recovered from the Smith site are included as Figure 5.49. The physical testing program for the Smith site was not as comprehensive as that for the other sites because of the detailed study which was performed earlier for the ash ponds at the Allen site. In a manner similar to that observed at the Allen ash pond, the waste at the Smith site segregated into lenses of coarser and finer grained ash. Generally, the coarser ash has a coefficient of permeability of approximately 9×10^{-4} cm/sec, while the fly ash has a coefficient of permeability of approximately 3

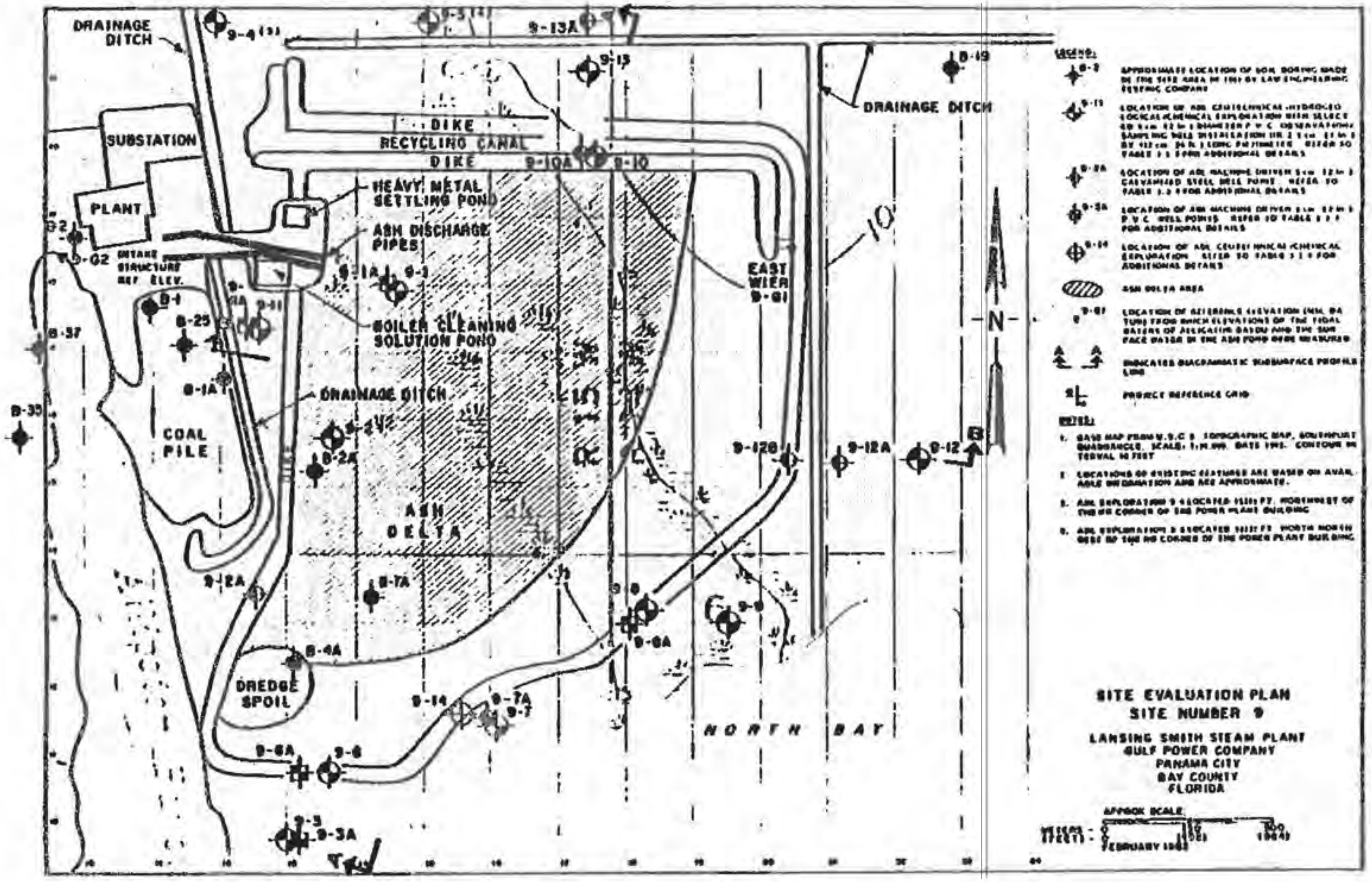

DRAINAGE DITCH
SUBSTATION
PLANT
DIKE
RECYCLING CANAL
DIKE
HEAVY METAL SETTLING POND
ASH DISCHARGE PIPES
BOILER CLEANING SOLUTION POND
DRAINAGE DITCH
COAL PILE
ASH DELTA
DREDGE SPOIL
NORTH BAY
EAST WIER
DRAINAGE DITCH
N
SITE EVALUATION PLAN
SITE NUMBER 9
LANSING SMITH STEAM PLANT
GULF POWER COMPANY
PANAMA CITY
BAY COUNTY
FLORIDA
APPROX SCALE

FIGURE 5.48

TABLE 5.40

SITE DEVELOPMENT SUMMARY

SITE: LANSING SMITH STEAM PLANT
BAY COUNTY, FLORIDA

DATES: December 1, 1981 - December 22, 1981

FILE NO. 453509

TOTAL NO. EXPLORATIONS ON THIS SITE: 25

Boring #	9-1	9-1A	9-2	9-2A
Soils Classification [depth (m): class]	0-3.8: Fly Ash 3.8-5.5: Ash/Sand 5.5-6.6: Sand	0-2.8: Fly Ash	0-3.2: Fly Ash 3.2-3.4: Sand 3.4-3.5: Sand	0-4.3: Ash Fill
Number of Samples Obtained	5	No Samples Obtained	3	No Samples Obtained
Field Permeability Tests [depth (m); results (m)/sec)]	No Tests	No Tests	RHT 1.6-3.0 5.66 to 31.2 x 10^{-6}	No Tests
Well Installation [wellpoint type; diameter (in); location (m)]	0.010" slot; 2.0 ID; 4.4'-5.9'	0.010" slot; 2.0 ID; 1.4'-2.8'	0.010" slot; 2.0 ID; 1.6'-3.0'	Steel 0.020" slot; 2.0 ID; 2.9'-4.3'
Boring #	**9-3**	**9-3A**	**9-4**	**9-5**
Soils Classification [depth (m): class]	0-6.7: Silty Find Sand 6.7-8.2: Fine Sand 8.2-10.1: Silty Fine Sand 10.1-12.6: Calcereous Salty Fine Sand	0-3.9: Silty Fine Sand	0-0.8: Topsoil 0.8-5.2: Silty Fine Sand 5.2-9.0: Fine Sand 9.0-12.6: Calcereous Silty Fine Sand	0-4.7: Fine Sand 4.7-5.9: Silty Fine Sand 5.9-7.5: Calcereous Silty Fine Sand
Number of Samples Obtained	10	No Samples Obtained	9	8
Field Permeability Tests [depth (m); results (m/sec)]	No Tests	No Tests	No Tests	RHT 4.6-7.5 1.758 x 10^{-6}
Well Installation [wellpoint type; diameter (in); location (m)]	0.010" slot; 2.0 ID; 9.9-11.3	0.010" slot; 2.0 ID; 2.5-3.9	0.010" slot; 2.0 ID; 9.1-11.9	0.010" slot; 2.0 ID; 4.6-7.5

RHT = rising head test

(continued)

TABLE 5.40

SITE DEVELOPMENT SUMMARY

SITE: LANSING SMITH STEAM PLANT

Boring #	9-6	9-6A	9-7	9-7A
Soils Classification [depth (m): class]	0-3.5: Dike Fill 3.5-6.4: Silty Fine Sand	0-3.5: Dike Fill	0-1.2: Organic Silty Sand 1.2-2.9: Fine Sand 2.9-3.2: Organic Silt 3.2-5.8: Organic Silty Sand 5.8-7.9: Fine Sand 7.9-8.1: Calcereous Silty Fine Sand	0-1.2: Organic Silty Sand 1.2-2.9: Fine Sand 2.9-3.2: Organic Silt 2.9-4.1: Organic Silty Sand
Number of Samples Obtained	7	1	6	No Samples Obtained
Field Permeability Tests [depth (m); results (m/sec)]	No Tests	No Tests	RHT 5.6-7.0; 1.06578×10^{6}	No Tests
Well Installation [wellpoint type; diameter (in); location (m)]	0.010" slot; 2.0 ID; 3.7'-5.2'	0.010" slot; 2.0 ID; 2.1'-3.5'	0.010" slot; 2.0 ID; 5.6'-7.0'	steel 0.020" slot; 2.0 ID; 2.7'-4.1'

Boring #	9-8	9.8A	9-9	9-10
Soils Classification [depth (m): class]	0-4.3: Dike Fills 4.3-6.6: Silty Fine Sand	0-4.1: Dike Fills	0-1.2: Organic Silt 1.2-4.0: Organic Fine Sand 4.0-5.0: Fine Sand	0-4.4: Dike Fills 4.4-6.2: Fine Sand
Number of Samples Obtained	7	1	4	8
Field Permeability Tests	No Tests	No Tests	No Tests	No Tests
Well Installation [wellpoint type; diameter (in); location (m)]	0.010" slot; 2.0 ID; 4.4-5.9	0.010" slot; 2.0 ID; 2.8-4.2	0.010" slot; 2.0 ID; 2.7-4.1	0.010" slot; 2.0 ID; 4.3-5.8

RHT = rising head test

(continued)

TABLE 5.40

SITE DEVELOPMENT SUMMARY
(continued)

SITE: LANSING SMITH STEAM PLANT

Boring #	9-10A	9-11	9-11A	9-12
Soils Classification [depth (m): Class]	0-4.3: Dike Fills	0-2.0: Fill 2.0-2.5: Organic Silt 2.5-6.9: Silty Fine Sand 6.9-7.8: Silty Fine Sand 7.8-9.3: Fine Sand 9.3-9.9: Fine Sandy Clay 9.9-12.8: Fine Sandy Silt 12.8-25.0: Calcereous Silty Fine Sand 25.0-30.2: Calcereous Silty Sand 30.2-30.3: Residual Soil	0-2.0: Fill 2.0-2.5: Organic Silt 2.5-4.4: Silty Fine Sand	0-0.3: Topsoil 0.3-3.0: Fine Sand 3.0-6.1: Silty Fine Sand 6.1-7.3: Silty Fine Sand 7.3-7.9: Calcereous Silty Fine Sand
Number of Samples Obtained	No Samples Obtained	15	1	6
Field Permeability Tests [depth (m); results (m/sec)]	No Tests	No Tests	RHT 3.0-4.4 4.30×10^{-6}	RHT 4.3-7.1 1.5524×10^{-6}
Well Installation [wellpoint type; diameter (in); location (m)]	steel 0.020" slot; 2.0 ID; 2.9'-4.3'	Porous tip; 1.0 ID; 27.8' 29.3'	0.010" slot; 2.0 ID; 3.0'-4.4'	0.010" slot; 2.0 ID; 4.3' 7.1'

Boring #	9-12A	9-12B	9-13	9-13A
Soils Classification [depth (m): class]	0-0.3: Topsoil 0.3-3.0: Fine Sand 3.0-4.1: Silty Fine Sand	0-4.1: Dike Fills	0-1.2: Fine Sand 1.2-3.7: Silty Fine Sand 3.7-4.7: Fine Sand 4.7-5.8: Silty Fine Sand 5.8-7.9: Silty Fine Sand 7.9-9.6: Calcereous Silty Fine Sand	0-1.2: Fine Sand 1.2-3.7: Silty Fine Sand 3.7-4.7: Fine Sand 4.7-5.8: Silty Fine Sand 5.8-7.3: Silty Fine Sand
Number of Samples Obtained	No Samples Obtained	No Samples Obtained	8	No Samples Obtained
Field Permeability Tests [depth (m); results (m/sec)]	No Tests	No Tests	RHT 6.2-9.1 2.314×10^{-6}	No Tests
Well Installation [wellpoint type; diameter (in); location (m)]	steel 0.020" slot; 2.0 ID; 2.7-4.1	steel 0.020" slot; 2.0 ID; 2.7-4.1	0.010" slot; 2.0 ID, 6.2-9.1	steel 0.020" slot; 2.0 ID; 5.9-7.3

RHT - rising head test

(continued)

TABLE 5.40

SITE DEVELOPMENT SUMMARY

SITE: LANSING SMITH STEAM PLANT

Boring #	9-14
Soils Classification [depth (m): Class]	0-3.5: Dike Fill 3.5-5.0: Fine Sand
Number of Samples Obtained	4
Field Permeability Tests	No Test
Well Installation	No Well

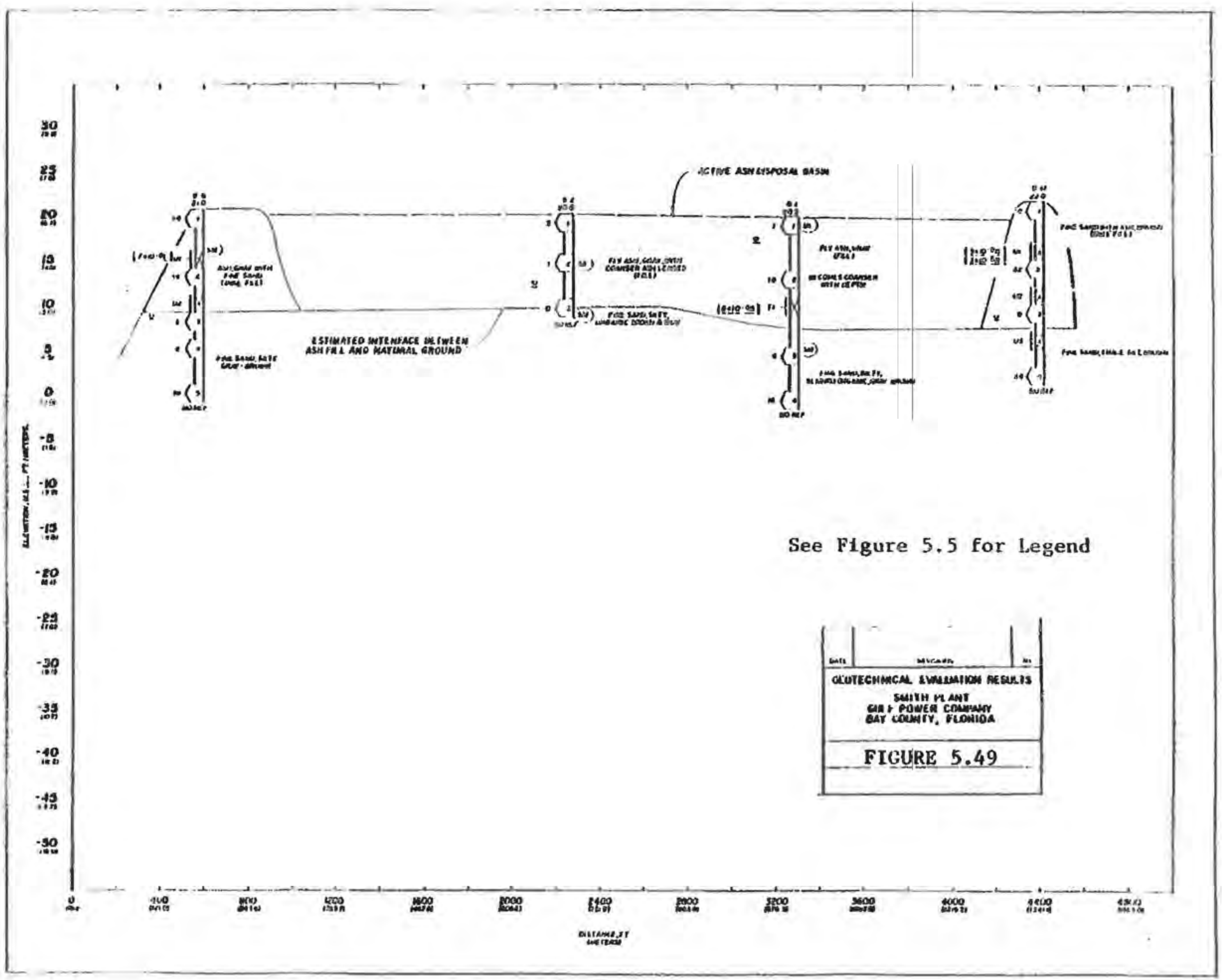

ACTIVE ASH DISPOSAL BASIN
ESTIMATED INTERFACE BETWEEN ASH FILL AND NATURAL GROUND
See Figure 5.5 for Legend
GEOTECHNICAL EVALUATION RESULTS
SMITH PLANT
GULF POWER COMPANY
BAY COUNTY, FLORIDA

FIGURE 5.49

x 10^{-5} cm/sec. Moreover, the vertical ash deposit permeability will be controlled by the coefficient of permeability of fly ash, while the horizontal permeability will be more influenced by the coefficient of permeability of the coarse ash (bottom ash).

Table 5.41 provides a brief summary of selected physical testing results for the Lansing Smith Plant. A more detailed compilation is provided in Appendix E.

5.7.4 Chemical Testing Results

The monitoring infrastructure for this program was developed in December 1981. At that time, solid and liquid samples were taken for analysis. Groundwater and surface water samples were subsequently obtained in February, March, and August 1982. Precipitation had been unseasonably low (even for the dry season) at the period of the first two sampling occasions, but returned to a more normal pattern at the time of the March sampling trip. Precipitation was typical of the wet season at the time of the August 1982 sampling. Freshwater inputs resulted in the seasonally typical depression of background salinities in Alligator Bayou and St. Andrews Bay, resulting in major dissolved species concentrations roughly one-half as high as those during the earlier sampling visits.

Table 5.42 provides a summary of selected chemical testing results. Table 5.43 presents selected results of chemical attenuation studies performed with soils from the Smith site. A more detailed presentation of these results is provided in Appendix F.

5.7.5 Environmental Assessment

5.7.5.1 Approach for the Lansing Smith Site--
The environmental assessment of the Smith site results focused on the following issues:

- effects of the ash pond leachate on downgradient groundwater quality; and
- effects of the ash pond leachate on downgradient surface water quality.

A third anticipated area for focus was the relative importance of major storm events with respect to contaminate transport. This issue was not fully pursued because such events did not occur during the course of the study. However, the study results provided some insight into this issue as well. (See Section 5.7.5.4.)

The steps employed in the environemntal assesment at this site were as follows:

- Site subsurface geological profiles and a site water balance were prepared.

TABLE 5.41

SELECTED PHYSICAL TESTING RESULTS

LANSING SMITH PLANT[a]

Permeability (cm/sec)	2.6×10^{-7} - 7.08×10^{-5}
Specific Gravity	2.21 - 2.72
Grain Size Distribution (Weight Percent)	
• > 74 um	28 - 97
• 2-74 µm	6 - 59
• < 2 µm	0 - 8
Moisture Content (Weight Percent)	4.3 - saturated

[a] See Appendix E for detailed results.

Source: Arthur D. Little, Inc., and Bowser-Morner Testing Laboratories, Inc.

TABLE 5.42

SELECTED DATA FOR REPRESENTATIVE SAMPLING LOCATIONS AT THE SMITH PLANT[a]

	CONCENTRATION			
Location	Ca (mg/ℓ)	Sr (mg/ℓ)	As (μg/ℓ)	Se (μg/ℓ)
Surface Water (9-15) (Seawater Background)	93-252	1.49-3.75	.6-1.2	<.26
Ash Interstitial Waters	498-1710	18.9-62.9	5-11	.3-4.5
Well 9-2 (Under Pond)	1210-1830	33.6-61.9	6.3-8	.6-4.0
Seep 9-16 (Western)	831-931	12.1-14.8	1-1.4	<.1
Well 9-6A (South Dike)	453-510	3.02-3.67	13	.2
Well 9-10 (North Dike)	420-501	9.43-11.3	--	--
Well 9-3A (Downgradient)	479-533	2.97-3.6	<.1-.5	<.1
Well 9-9 (Downgradient)	349-490	4.61-5.41	<.15	<.26
Seep 9-20 (South)	397-543	5.91-6.21	--	--
Well 9-5 (Freshwater Background)	7-10	.04-.06	1.2	<.26

[a]See Appendix F for detailed results from individual samples.

TABLE 5.43

SELECTED RESULTS OF SOIL ATTENUATION STUDIES
SMITH SITE[a]

Element	Solution Concentration (ppb)	Soil Capacity (µg/gm)	Soil Capacity ÷ Solution Concentration
Arsenic	2-240 5-338	1.0-335 1.0-215	450-1396 200-635
Selenium	2-12 4-28	0.2-12.3 0.26-11.1	100-1025 65-393
Cadmium	130-140	3-22	23-157
Chromium	0.210	6.8 ± 2.5	32
Copper	0.47-0.91 8	35-308 <1.78	745-3385 <220
Calcium	419-429 ppm	60-82	0.14-0.20

[a] Soil sample for these tests was from boring 9-5, upgradient background location. See Appendix E for details.

- The values and trends in chemical sampling and analysis results were compared for the various site areas. Regression analyses were used to attempt to identify waste-related "tracer" parameters.

- The water balance, geological profiles, and chemical and physical testing results were considered together to structure and evaluate hypotheses concerning the nature of leachate generation and movement at the site. The importance of the periodic use of seawater for ash sluice water makeup and the seasonal fluctuations in the local salinity of the estuary were explicitly considered in this step.

- The broader implications of the Smith site results were considered in terms of their applicability to similar combinations of waste types, disposal methods, and environmental settings. This step can be considered particularly important for the Smith site because of the lack of other data on such disposal activities in tidally-influenced coastal settings.

5.7.5.2 Geological Profiles and Water Balance--
Figure 5.50 illustrates the subsurface geological profiles for several areas of the Smith waste disposal site. These profiles were prepared on the basis of site development results for this program along with the available site background information.

The water balance for the Smith site was based on the data from the site development activities, and is briefly summarized below:

- Estimated seepage through the pond dike = 72.5 m^3/day,

- Estimated incident precipitation = 3113 m^3/day,

- Inputs = precipitation + ash sluice (variable),

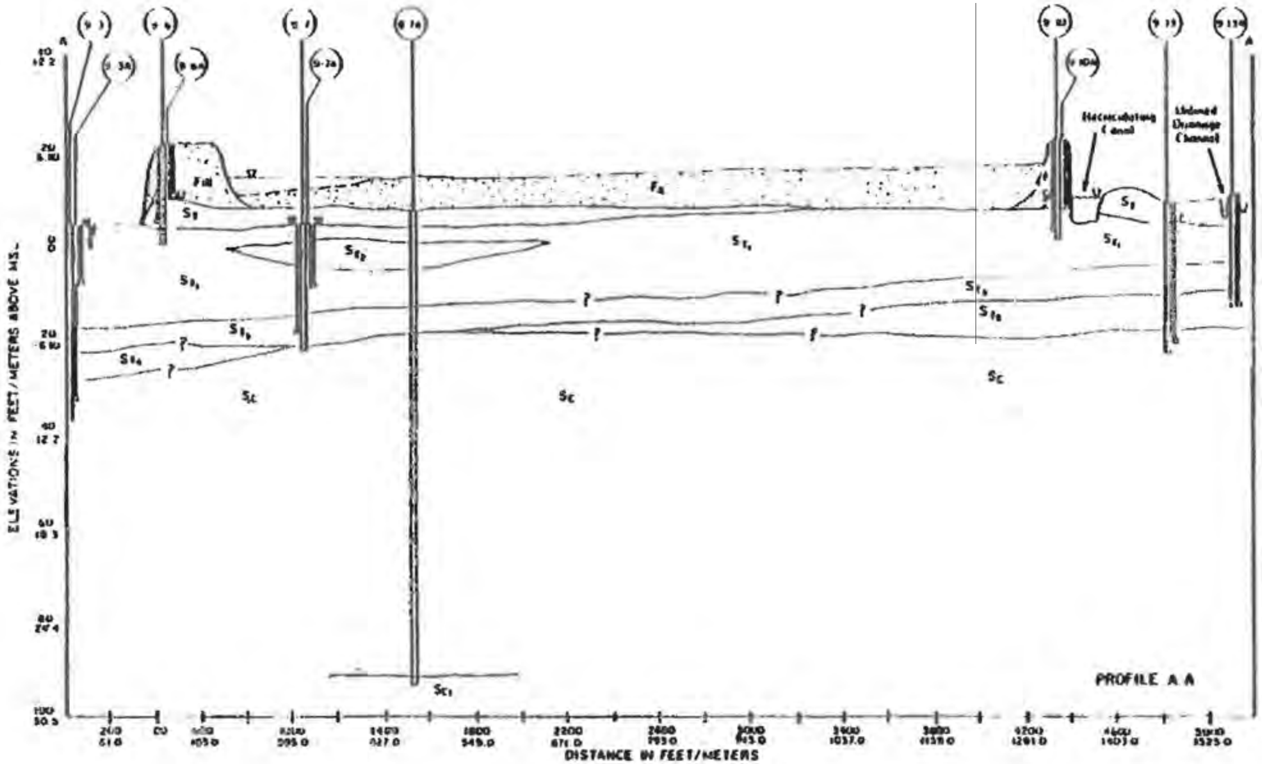
- Outputs = evaporation and bottom seepage and dike seepage and recycle discharge.

Therefore,

3113 m^3/day and ash sluice =

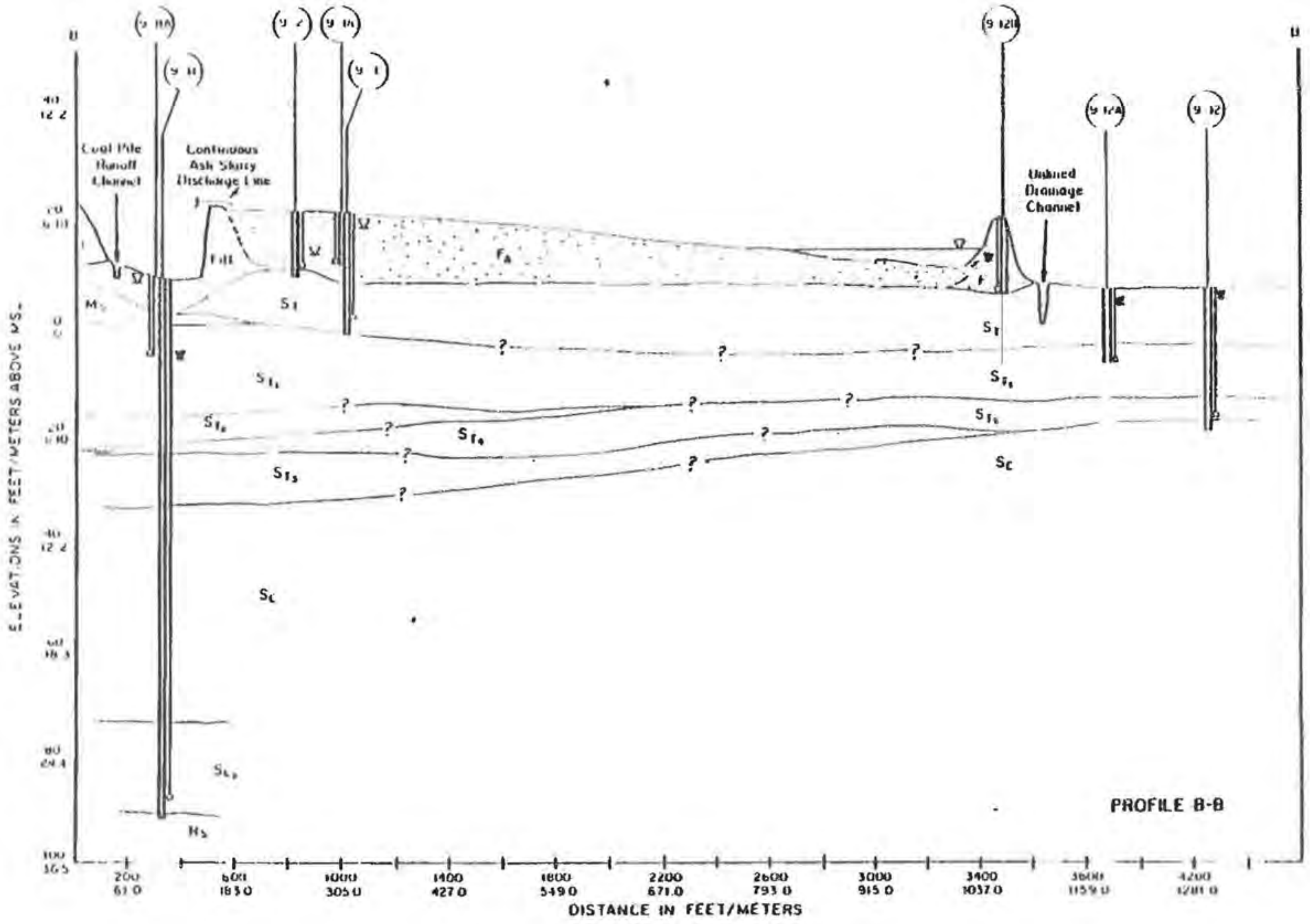
2579 m^3/day and 377 m^3/day + 72.5 m^3/day + recycle discharge;
and
Recycle discharge = 86 m^3/day + ash sluice.

5.7.5.3 Evaluation of Testing Results--
The analytical results obtained from the various sampling trips are generally consistent; one can readily see the effects of the use of bay water for make-up purposes on pond liquor composition. Such was in effect at the time of the February and August sampling trips, but not during the March 1982 sampling. Additionally, concentration values for all seawater-related species varied in the background sampling locations in accordance with the seasonal



SUBSURFACE GEOLOGICAL PROFILES - SMITH SITE
GULF POWER COMPANY - BAY COUNTY, FL.

FIGURE 5.50



SUBSURFACE GEOLOGICAL PROFILES - SMITH SITE
GULF POWER COMPANY - BAY COUNTY, FL.

FIGURE 5.50 (Continued)

variation in freshwater input. On the whole, chemical values measured on different dates at the same sample locations are similar and in accordance with seasonal phenomena expected at the site.

Calcium and, to a lesser degree, strontium appear to be reliable tracers of the ash pond-related leachate and seepage at the Smith site. As illustrated by Table 5.42, there is a distinct concentration gradient with increasing distance from the pond for these two species in both groundwater and surface water. This concentration gradient can be compared with seawater background concentrations to indicate the concentration elevations (in some cases as much as an order of magnitude) resulting from ash pond leachate. Note also these tracer concentrations are even more elevated in the ash waters when compared with freshwater background from wells to the north of the pond (e.g., well 9-5).

Selenium and arsenic could also be considered possible tracers of pond leachate on the basis of observations of somewhat elevated concentrations in the ash interstitial waters in comparison to site background concentrations. However, the degree of elevation is far less than that observed for calcium and strontium, and the difference is not sufficient to allow for consistently reliable comparisons.

The calcium concentrations are comparable between the interstitial waters obtained from within the ash and two locations external to the pond (well 9-2, located in the soil underneath the ash, and seep 9-16, along the western dike). At these locations, calcium values are at least five to ten times higher than those observed in background seawater and are even more significantly elevated compared to background freshwater.

At a second set of locations, represented by dike wells [well 9-6A (in the south dike) and well 9-10 (in the north dike)], shallow downgradient wells to the south of the pond (represented by wells 9-3A and 9-9), the other seeps along the south dike (e.g., well 9-20), and in the seepage discharge to North Bay (well 9-24), the tracer species concentrations are generally about 1.5 to 2 times as high as the background seawater, and even greater than the background freshwater.

The sampling and analysis results obtained in the aftermath of the rainy season showed up to a 50 percent reduction of major seawater species concentrations in the background waters, but showed less than a 10 percent reduction in similar and tracer species concentrations at the locations apparently more affected by pond seepage and leachate.

Sampling of the deep underlying aquifer (well 9-11) throughout the program showed no evidence of contamination by ash pond leachate or the seawater, as was the case in the near-surface aquifer.

5.7.5.4 Cause Effect and Relationships--

The chemical and physical testing results from the Smith site are consistent with the site water balance, which suggests that pond seepage and leachate dominate water flows in the immediately adjacent downgradient areas on all sides of the pond, and is especially significant to the west, where the seepage was estimated to be roughly twice that experienced on other dike faces.

Steady-state appears to have been achieved between the species leaching from the pond to the immediately adjacent downgradient areas (as exhibited by the quality of water at well 9-2).

Consistent with the attenuation test results (Table 5.43), the field data indicate little or no chemical attenuation of the major tracer species such as calcium and strontium; a progressive reduction in concentrations is observed downgradient. This is consistent with admixing of leachate with greater amounts of dilution water. This would adequately explain the concentration gradient observed in the downgradient locations (e.g., wells 9-3A and 9-9, seeps 9-20 and 9-24, and similar locations). This further suggests that long-term leaching, rather than individual events (e.g., tropical storms), are largely responsible for the concentration gradients in the area.

Insufficient samples were obtained from the downgradient tidal creek surface waters to describe the concentration gradients and admixing that prevail therein.

The use of bay water as sluice water make-up and its presence in adjacent downgradient areas masks and assimilates the potential for significant impact from such typical ash pond tracer species as sulfates, chlorides and boron, which are already elevated into a comparable concentration range in the Bay.

The levels of trace metal concentrations can be attributed to several factors:

- The levels may be inherently low due to the absence of significant trace metal concentrations in the coal and resulting ash. This is suggested by the relatively low concentrations measured for potentially good tracers (i.e., arsenic and selenium) in alkaline environments; these were observed at other sites in far greater concentrations.

- The use of bay water for ash sluice water make-up may tend to both dilute and reduce the availability of trace metals that might otherwise be readily leachable from the surface layers of the ash.

- Once diluted by the tidally influenced receiving waters and attenuated by surrounding soils, even those metals with somewhat higher concentrations in the ash (e.g., arsenic and selenium, as shown in Table 5.42) are observed only at background or near-background levels in locations where the other tracers (calcium and strontium) are evident. The attenuation capacities of the organically-enriched soils surrounding the Smith disposal pond are relatively high in comparison with those of the other sites in this program.

5.7.5.5 Environmental Effects Implications--

The major environmental effects implication of the Smith site findings is that different considerations apply to ash disposal operations in typical tidally-influenced estuarine settings. This includes the fact that traditional drinking water standards are often not meaningful for assessment of phenomena in the shallow aquifers already affected by salt water intrusions and not used for drinking water. Further, the composition of seawater renders most of the major species contributions from the ash insignificant counteracting the tendency for these settings to transmit contaminants rapidly by a combination of extremely high precipitation and extremely pervious surrounding soils.

5.7.6 Engineering Cost Assessment

5.7.6.1 Engineering Assessment--

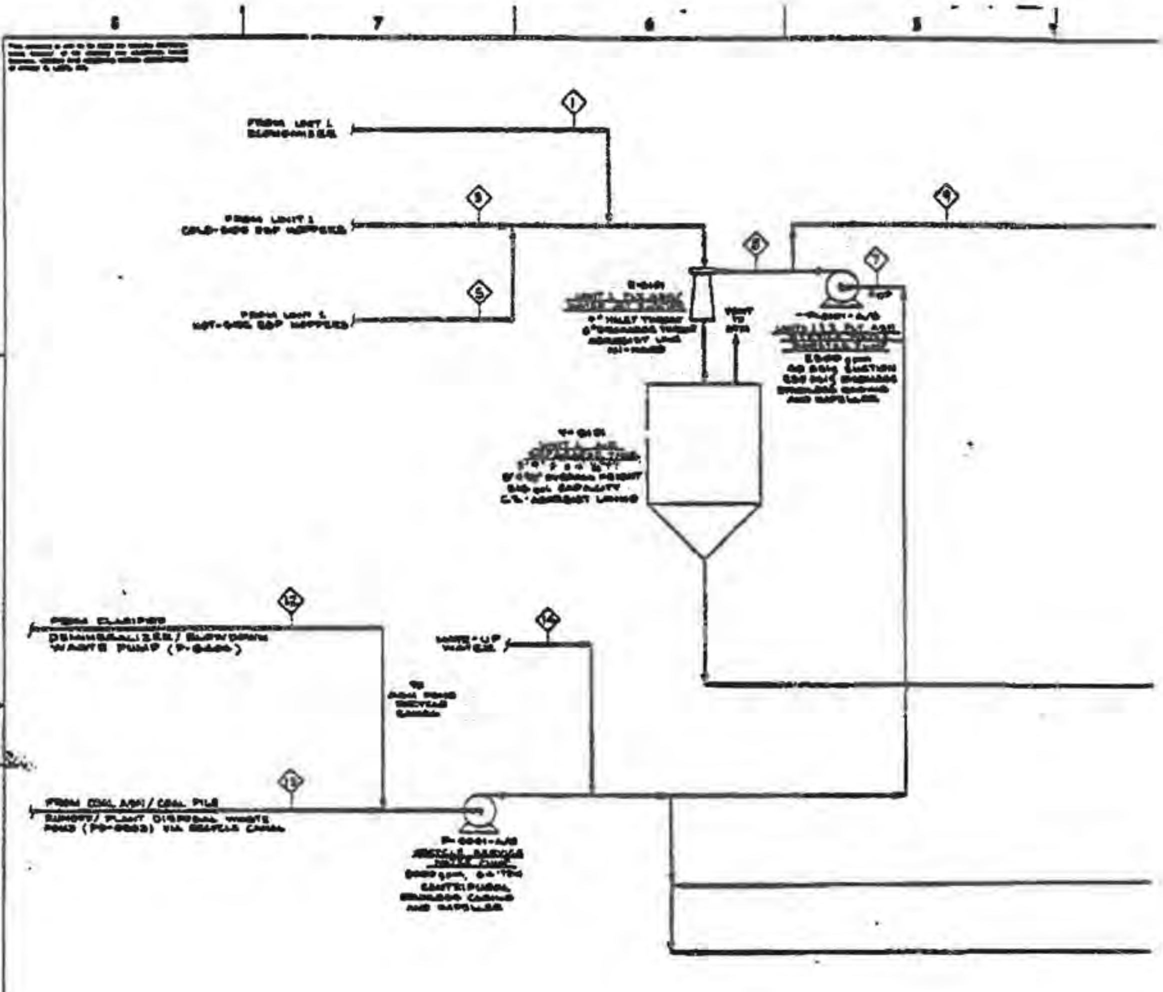
The Lansing Smith Plant, a baseload facility, is comprised of two tangentially-fired, pulverized coal-fired boilers with a total nameplate generating capacity of 340 MW. Unit 1, a 150 MW nameplate generating capacity boiler, started up in 1965. A second 190 MW boiler, Unit 2, started up in 1967. In addition, the plant uses a 42 MW gas turbine, fired by number two fuel oil. No significant quantity of ash results from the gasturbine operation.

Air Pollution Control--Units 1 and 2 were originally equipped with cold-side electrostatic precipitators to collect dry fly ash. The design particulate removal efficiency of this equipment is 98 percent. In 1977, both units were retrofitted with hot-side electrostatic precipitators to facilitate the removal of fly ash generated as a result of burning coal with a lower sulfur content.

Coal Consumption--Bituminous coal used by the Smith Plant is presently obtained from South Africa and Kentucky, with the former source providing the bulk of the coal currently consumed. The domestic coal, which has a somewhat higher sulfur content, is employed to enhance particulate collection and to avoid the need for sodium sulfate conditioning of flue gas. The sulfur content of South African coal, 0.7 weight percent, is much lower than that of the coals for which the original particulate collection system (cold-side electrostatic precipitator) was designed, 2.8 weight percent. The ash content of the coal in use at the Lansing Smith Plant has remained relatively constant at 13.0 weight percent. The heat contents of coals employed have ranged from 27.0 to 27.6 million joules/kg (11,615 to 11,880 Btu/lb). In 1978, coal consumption at the Smith Plant was 815,000 metric tons (900,000 tons).

Waste and Water Management--Wastes generated at the Smith Plant as a result of coal combustion include fly ash and bottom ash; ash wastes produced at this plant presently consist of 98 percent fly ash and 2 percent bottom ash. Fly ash is conveyed by a vacuum pneumatic system, slurried in water and sluiced to the disposal area via two pipelines. Process flow diagram F-600, Figure 5.51, depicts the fly ash handling and transport system.

Bottom ash is also handled as a wet slurry which is transported to the disposal site by way of two pipelines. Other solid wastes generated at this

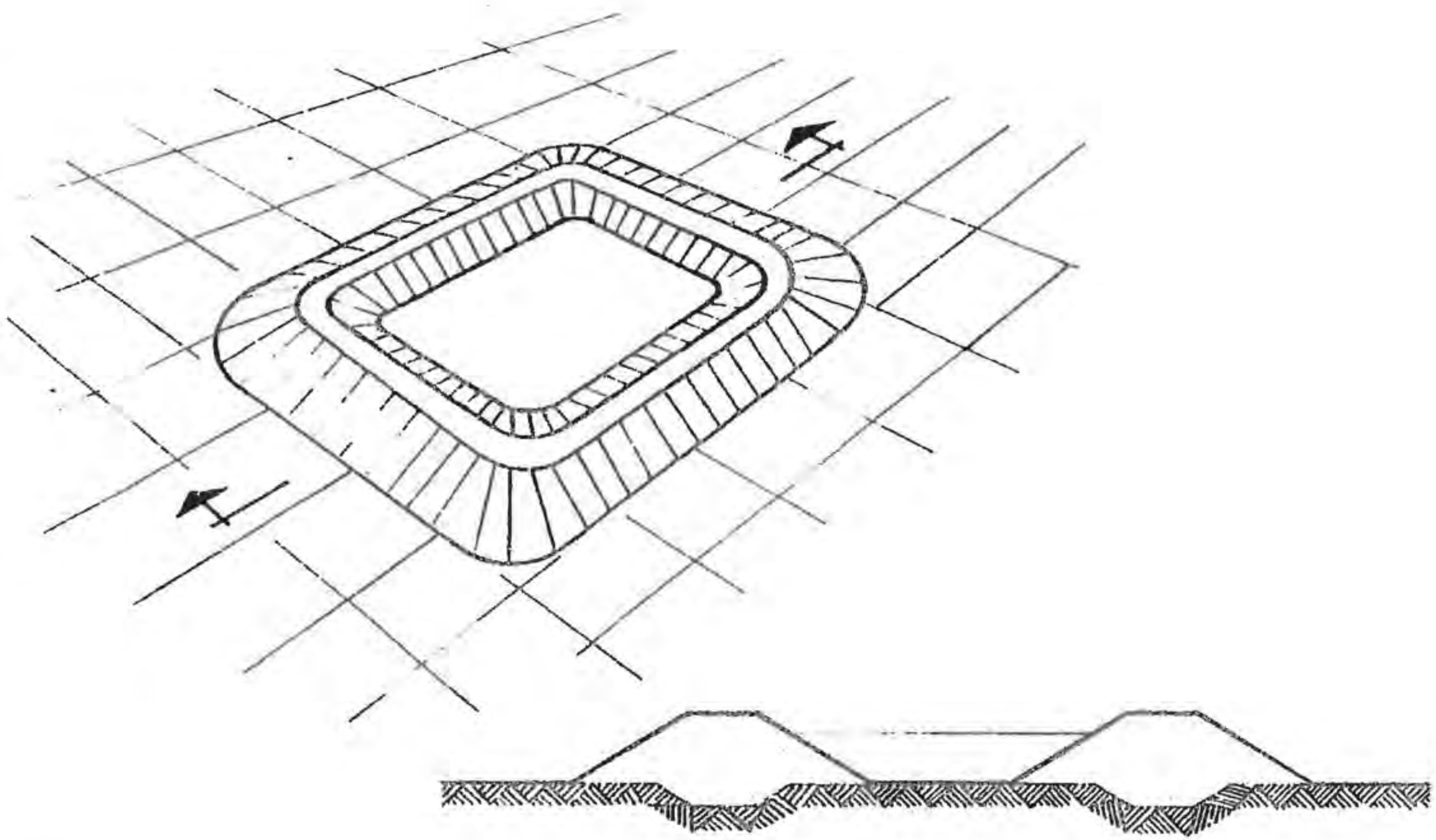


DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY, FULL LOAD

DETAIL / STREAM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TONS SOLIDS/DAY	2	3	9	11	175	250	—	—	—	250	264	—	—	—	—	—
TONS WATER/DAY	—	—	—	—	—	—	15,000	7,000	7,000	7,000	7,000	25	17,745	400	900	2,700
TONS AIR/DAY	N/A	N/A	N/A	N/A	N/A	N/A	—	—	—	—	—	—	—	—	—	—
SCFD	N/A	N/A	N/A	N/A	N/A	N/A	—	—	—	—	—	—	—	—	—	—
MGPD	—	—	—	—	—	—	3.60	1.80	1.80	1.82	1.88	[illegible]	4.27	0.10	0.12	0.66
% SOLIDS	100	100	100	100	100	100	0	0	0	3.7	3.5	0	0	0	0	0
SPECIFIC GRAVITY	2.2	2.2	2.2	2.2	2.2	2.2	1.6	1.0	1.0	1.01	1.02	1.0	1.0	1.0	1.0	1.0

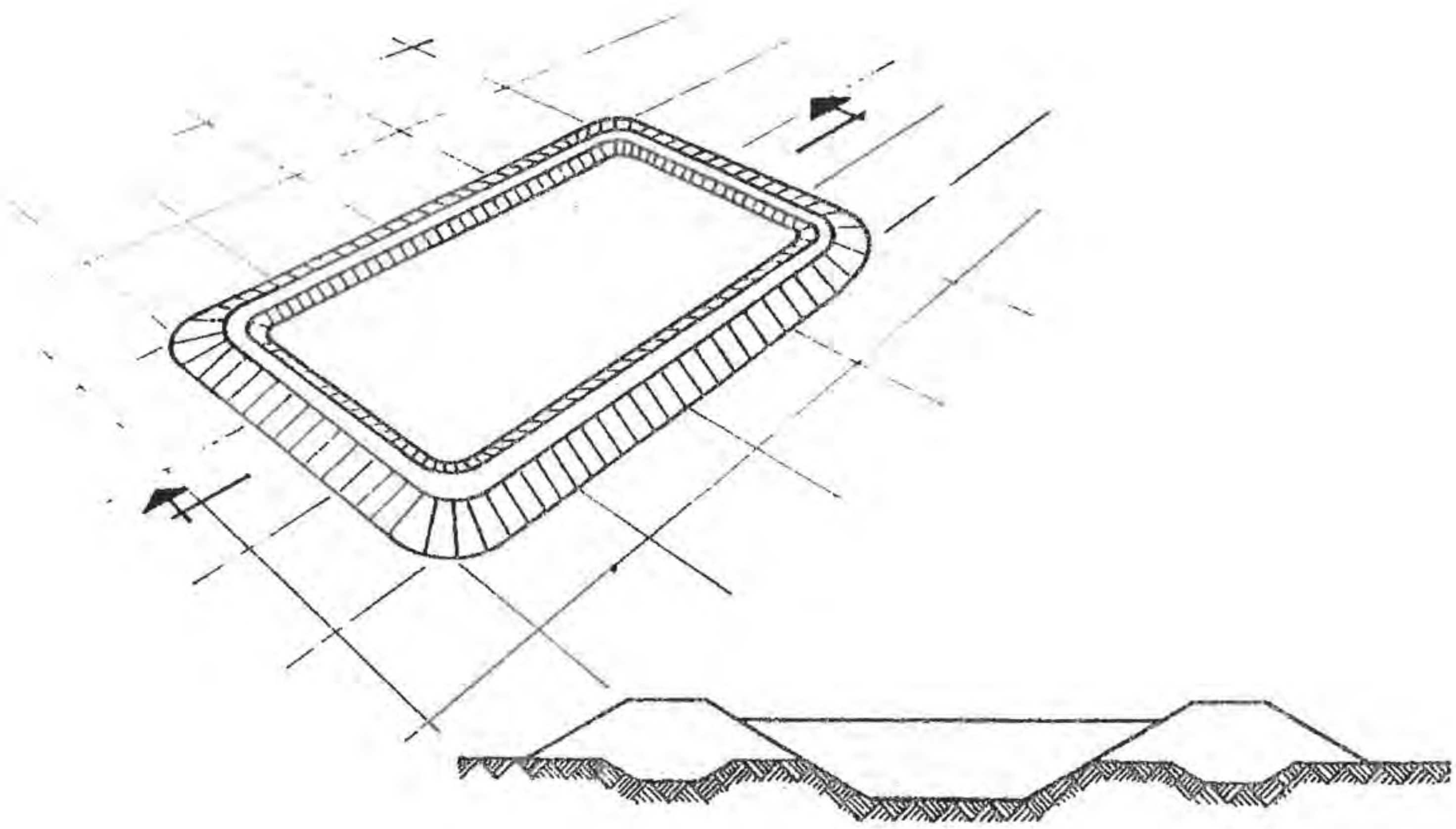
N/A - INFORMATION NOT AVAILABLE

FIGURE 5.51



Source: Reference 17

FIGURE 6.19 DIKED POND CONSTRUCTED ABOVE-GRADE.



Source: Reference 17

FIGURE 6.18 DIKED POND PARTIALLY EXCAVATED BELOW-GRADE.

Proper disposal site selection is often the most effective way to reduce the environmental consequences associated with land disposal of FGC wastes. There is no question that proper site selection can, by itself, eliminate most potential disposal impacts. A disposal site located near existing or potential groundwater users may require mitigative measures. But the same design scheme at a site which is relatively isolated from existing or potential groundwater users could be environmentally acceptable.

6.1.7.2 Pond Disposal of Coal-Fired Utility Solid Wastes--

At present, most coal-fired utility plants dispose of coal ash and/or FGD wastes by ponding. However, pond disposal is anticipated to be less widely practiced in the future. This is primarily due to the relatively high cost of this disposal option. Excavation and construction of ponds is quite expensive. Thus, future ponding operations will likely be limited to sites which can be converted to ponds with relatively little excavation or dike construction.

A number of pond configurations are used for disposal of coal-fired utility wastes. The most common wet disposal configuration is the diked pond. Here the pond is contained within a perimeter embankment or dike. Figures 6.18 and 6.19 illustrate two types of diked ponds. A level or nearly level site is required for these two pond types. Dikes are constructed of materials excavated from below the existing grade at the pond site, or they may be constructed above-grade from borrow material. Above-grade construction is necessary if excavation below the existing grade is difficult due to the shallow depth of groundwater or bedrock.

Incised ponds are contained within an excavation entirely below the existing ground surface area. This pond configuration is used where there is limited space for dike construction and where groundwater and bedrock will not be encountered in excavation. This type of pond is also attractive when excavated materials are either unsuitable for dike construction or valuable for other purposes. An incised pond design is shown in Figure 6.20.

A third pond configuration is the side-hill pond. This pond design lends itself to hilly terrain where a level site is not available for construction of incised or diked ponds. In this case, the local terrain provides one or two sides of the pond. The side-hill pond design is shown in Figure 6.21.

Other pond configurations are also in use. Existing basins, such as abandoned surface mines and quarries, may be used for pond disposal sites. Cross-valley ponds, created by constructing a dam across an existing natural valley between the two valley walls, have been employed.

Dike stability is a critical design consideration. Designs are generally conservative and incorporate many factors which enhance stability:

- flat dike slopes;
- staged, controlled rate of construction;

TABLE 6.3

MATRIX OF WASTE TYPES AND DISPOSAL OPTIONS

	Disposal Option				
	Pond Disposal	Landfill Disposal	Mine Disposal	Ocean Disposal	Utilization
Coal Ash					
• Dry Fly Ash	–	✓	✓	P	✓
• Dewatered Fly Ash	–	✓	✓	P	✓
• Fly Ash Slurries	✓	–	–	–	–
• Dewatered Bottom Ash	–	✓	✓	P	✓
• Bottom Ash Slurries	✓	–	–	–	–
FGD Waste					
• Dry FGD Waste	–	✓	✓	P	✓
• Stabilized/Fixated FGD Waste	✓	✓	✓	P	✓
• Primary/Secondary Dewatered FGD Waste	–	✓	✓	P	P
• Primary Dewatered FGD Waste	✓	–	–	P	–
• FGD Waste Slurries	✓	–	–	–	–

✓ = Disposal option in current use for waste type of comparable waste.

P = Potential disposal option.

Source: Arthur D. Little, Inc.

plant, a return pipeline (part of the waste handling and processing system) must also be provided. The waste transport pipeline may be used for this purpose if wastes are not transported through the line continuously. Provision must also be made for periodic pipeline flushing and cleaning.

Conventional steel piping and pumping equipment may be suitable for transporting utility wastes. However, when the slurry pH deviates from neutral or the slurry is highly abrasive, corrosion and erosion may be problems. In these cases, rubber-lined steel or plastic piping may be used. Steel pipe is easy to install, easy to support due to the pipe's rigidity, and has good wear resistance. Only when the slurry is highly abrasive or corrosive should one consider the use of alternatives to steel. In severely cold climates, line freezing may also be a problem that might very well decrease the potential for pipeline transport or necessitate the use of some type of steam tracing.

Ash/water slurries can be transported by centrifugal pumps or jet pumps. Slurries of about 20 weight percent ash can be moved. Considerable dilution is required at the suction end of the pump to enable slurry pumping. Centrifugal pumps are approximately 40 percent more efficient than jet pumps. This does not account for the efficiency of the auxiliary pumping equipment that supplies the ejector nozzle. However, use of jet pumps is advantageous because of the relative ease of servicing such pumps, although they must be serviced more frequently than centrifugal pumps. When system heads exceed 30.5 m (100 ft), jet pumps are impractical. Although jet pumps are not effective when operated in series, centrifugal pumps are commonly placed in series for high-head requirements.

Pumps for ash/water slurry transport are constructed of hard metals, especially in areas where abrasion is most severe. Since abrasive wear increases as velocities increase, velocities are kept sufficiently low to reduce such wear without impairing pump efficiency.

6.1.7 Coal-Fired Utility Waste Placement and Disposal

6.1.7.1 Overview--
Three modes of utility solid waste disposal are currently practiced:

- ponding of coal ash, FGD wastes and/or fixated FGD wastes;
- impoundment of dry or dewatered coal ash, FGD wastes and/or stabilized/fixated wastes in landfills; and
- mine disposal of coal ash and/or FGD wastes.

This discussion of placement and disposal practices is not specific to different waste types, but rather focuses on disposal practices as they are dictated by the physical form (i.e., aqueous waste slurries or dry wastes) of the waste. Table 6.3 summarizes the applicability of the various waste disposal options for specific wastes.

of transport from interim ponds to landfills which are of close proximity, self-loading scrapers may be used for both excavation and transport.

Rail transport of utility wastes is an option for long or short transport distances. It is possible to use empty coal cars to haul FGC wastes to mines for disposal, thus avoiding dead-heading costs. Today rail transport is not commonly utilized, except at a few utilities.

A major consideration with trains and trucks is the need to load the vehicles. Both vehicle types can usually be loaded with front-end loaders, belt-conveyors, or chutes. The front-end loader loads the vehicle from a surge pile by dumping directly into the car. Chutes and belt-conveyors can load directly from the outlet of processing equipment or from storage silos. However, the use of front-end loaders is preferred, since processing is usually a continuous process, whereas transportation is an intermittent process normally carried out on a 144,000 sec (40 hour) week basis.

6.1.6.3 Transport Systems for Wet Wastes--

Wet disposal is practiced for coal ash and FGD wastes which exhibit fluid properties. It is theoretically possible to use all methods of transport previously described, except belt-conveyors, to transport wet wastes. However, pipeline transport of these wastes is the most practical method and, to date, the only method which has been used.

The four principal factors that must be considered in the design of pipeline systems are:

- solids settling;
- erosion/abrasion potential;
- corrosion potential; and
- freeze protection.

Of these, avoidance of solids settling in pipelines is usually the overriding factor in design. To prevent settling, conveying velocities usually range between 1.5 and 3.7 m/sec (5-12 ft/sec), depending on material density, particle size and pipeline configuration. In long pipelines handling coarse materials, velocities must be increased above those used for shorter lines. In addition, some device to create turbulence may be required to maintain a homogeneous slurry mix, particularly when conveying bottom ash or mill rejects. Fly ash and FGD waste slurries with finer particles can be pumped at the lower range of velocities.

Typically, a single pumping station is required to transport the ash and/or FGD waste slurry to the disposal pond. More pumping stations may be required for long transport distances and/or uphill transverses. At least two full-sized pipelines are required for redundancy. The need for such redundancy may be eliminated by providing emergency storage for the slurry in the event of pipeline outages. If supernatant is to be recycled to the

6.1.6.2 Transport Systems for Dry Wastes--

Dry disposal is practiced for coal-fired utility wastes which do not exhibit fluid properties. All but one (i.e., pipelines) of the utility solid waste transportation methods previously identified can be used to transport dry wastes.

Conveyors are suitable for dry waste transport but are used only for short transportation distances. To date, no belt conveyor has been used to carry coal-fired utility solid wastes from a plant to the final disposal site. This is because long belt conveyors (of several hundred meters or more) have high maintenance costs and are inflexible, permanent fixtures requiring fixed starting and ending points. A high capital investment is required for conveyor systems, although they have long service lives. For the given life of many plants, this trade-off is uneconomical.

Trucks are by far the most common and flexible means of transporting dry utility wastes over both short and relatively long distances. The availability of trucks from private contractors in varied numbers for varying time periods provides a number of solid waste transportation alternatives. All truck hauling may be contracted, or the use of a captive fleet of trucks may be supplemented by contracting additional trucks as the need arises. Three types of trucks are commonly used to transport dry FGC wastes:

- conventional rear-dump;
- semi-trailer rear-dump; and
- semi-trailer bottom-dump.

In colder areas, many trucks may be equipped with exhaust gas-heated bodies to prevent moist wastes from freezing.

The primary advantage of truck transportation for utility wastes is its flexibility. This transport method can readily accommodate changes in the quantity of solid waste produced. Additionally, transport routes may be conveniently altered in response to relocation of the disposal site. Maintenance and standby vehicles provide inherent transportation system availability; idle vehicles may be used for other hauling purposes. Contract hauling is cost-accountable as an operating expense and requires little or no capital investment.

An important disadvantage of truck transport is that this operation is labor-intensive. Thus, operating costs (due to inflation) can be expected to increase over the life of the disposal operation. Additionally, this operation has high public visibility which may result in public opposition to increased truck traffic, dust, and noise.

Transport of dry, dewatered, or processed waste is usually accomplished by open, on-highway rear-dump trucks with capacities of 7 to 18 metric tons (8 to 20 tons) or by off-highway trucks with typical capacities of 32 to 77 metric tons (35 to 85 tons). The selection of the appropriate vehicle depends on the required capacity and location of the disposal area. In cases

TABLE 6.2

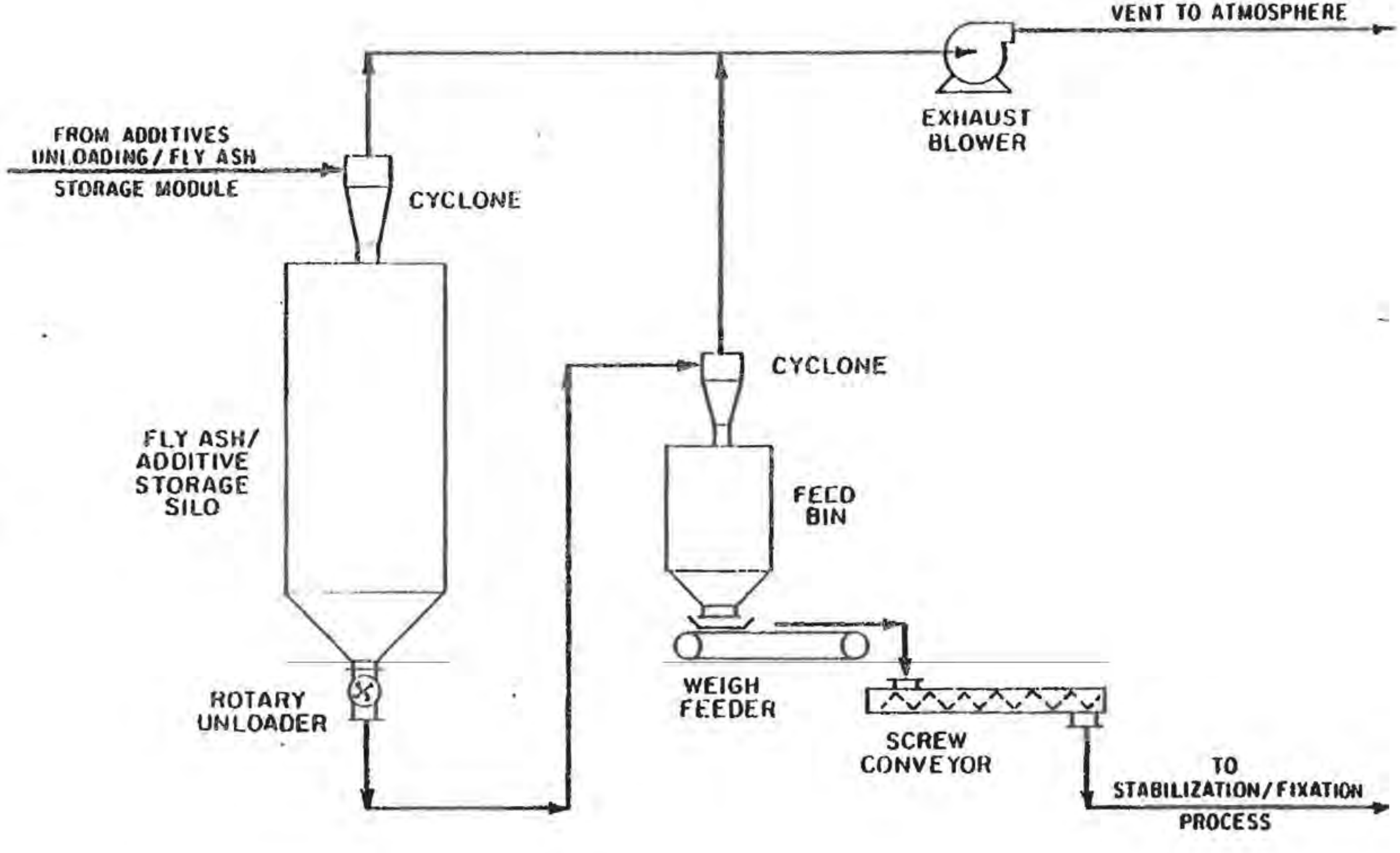
MATRIX OF WASTE TYPES AND TRANSPORT OPTIONS

Waste Type	Dry Transport Options				Wet Transport Option
	Belt Conveyor	Truck	Barge	Railroad	Pipeline
Coal Ash					
• Dry	P	✓	P	✓	–
• Aqueous Slurry	–	–	–	–	✓
FGD Waste					
• Dry	P	✓	P	✓	–
• Aqueous Slurry	–	–	–	–	✓
• Primary Dewatered Waste From Wet Scrubber	–	–	–	–	✓
• Secondary Dewatered Waste From Wet Scrubber	P	✓	P	✓	–
• Stabilized/Fixated FGD Waste	P	✓	P	✓	–

✓ = Transport method currently in use on waste type or comparable waste.

P = Potential transport option.

Source: Arthur D. Little, Inc.



Source: Arthur D. Little, Inc.

FIGURE 6.17 RAW MATERIALS HANDLING AND STORAGE MODULE feed the silo must be provided. The receiver can consist of a cyclone-type collector with dust filter above, which feeds the air lock discharge. The air lock may be either a rotary driven gate or a gate lock type of feeder.

Mechanical systems are also available for handling lime and Calcilox®. With mechanical handling, the additive is usually discharged from the transport vehicle into a hopper, then transferred by a screw, pan, or drag conveyor to a bucket elevator and finally elevated to storage. Pan and drag conveyors are preferred for larger-sized additives.

Several designs are available to facilitate unloading of raw materials from storage silos. The raw materials of interest exhibit some inherent problems with flowability, necessitating the use of flow-enhancing unloading systems. The simplest device for improving flowability is the electro-magnetic vibrator attached to the outside of the hopper face. Air jets or pulsating air pads are also used on hoppers to facilitate flow. When using air jets or pads, the silo must be vented. Proper sloping of the silo bottom is another means of improving flowability.

Feeders are typically located beneath the silos, with the raw material simply flowing by gravity to the feeder. The feeding system is usually adjustable to give different rates of feed. The feed may be by volume or, more commonly, by weight. Gravimetric feeders take numerous forms but are generally classified as pivot belts, rigid belts and loss-in-weight hoppers. Most feeders for use in power plants will be of the rigid belt type. Figure 6.17 illustrates a typical additive storage and handling system.

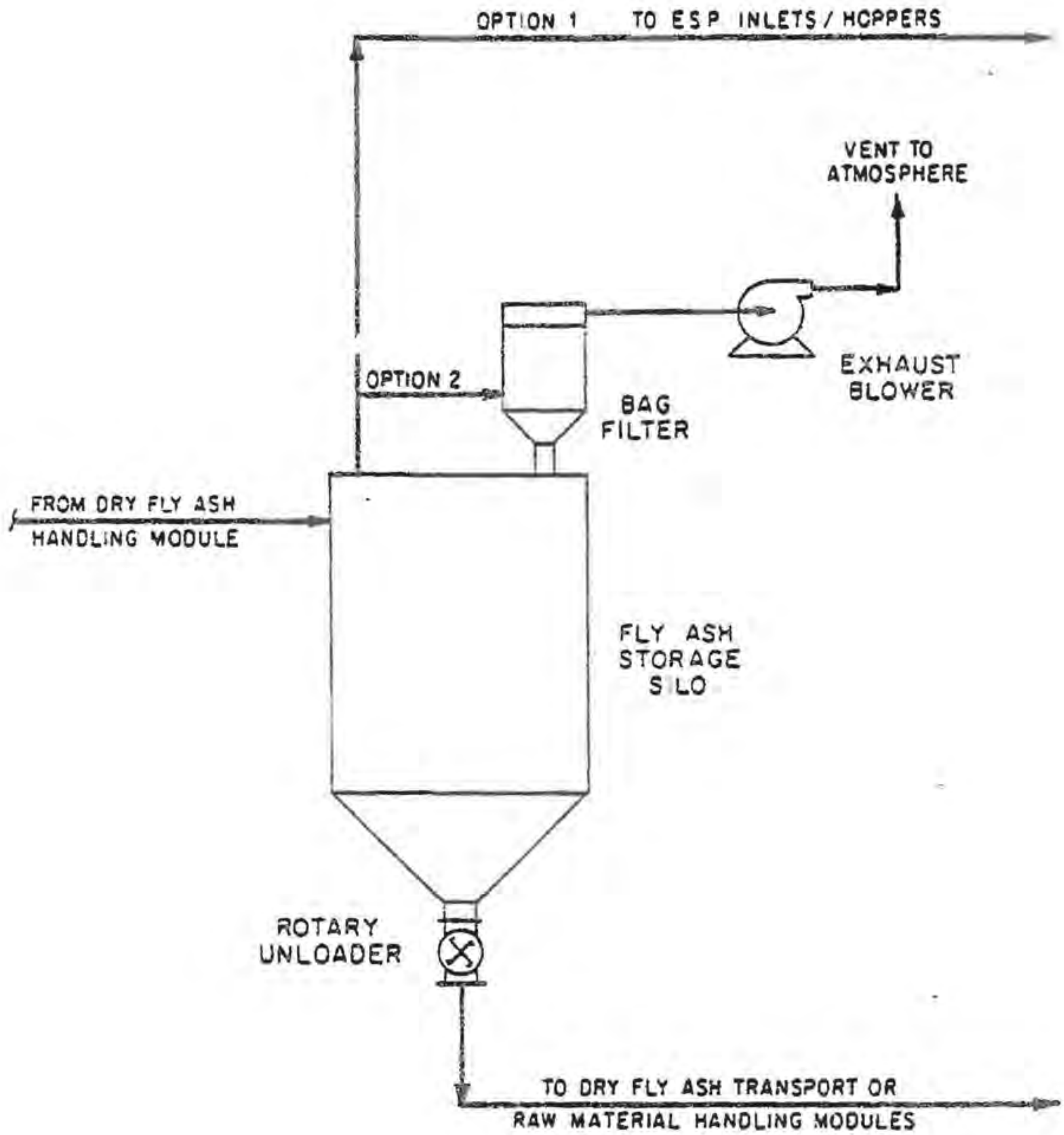
6.1.6 Coal-Fired Utility Solid Waste Transport

6.1.6.1 Overview--

The coal-fired utility solid waste transport system is an essential component of the waste handling and disposal operation. Conceptually, five transportation methods can be used for coal-fired utility wastes:

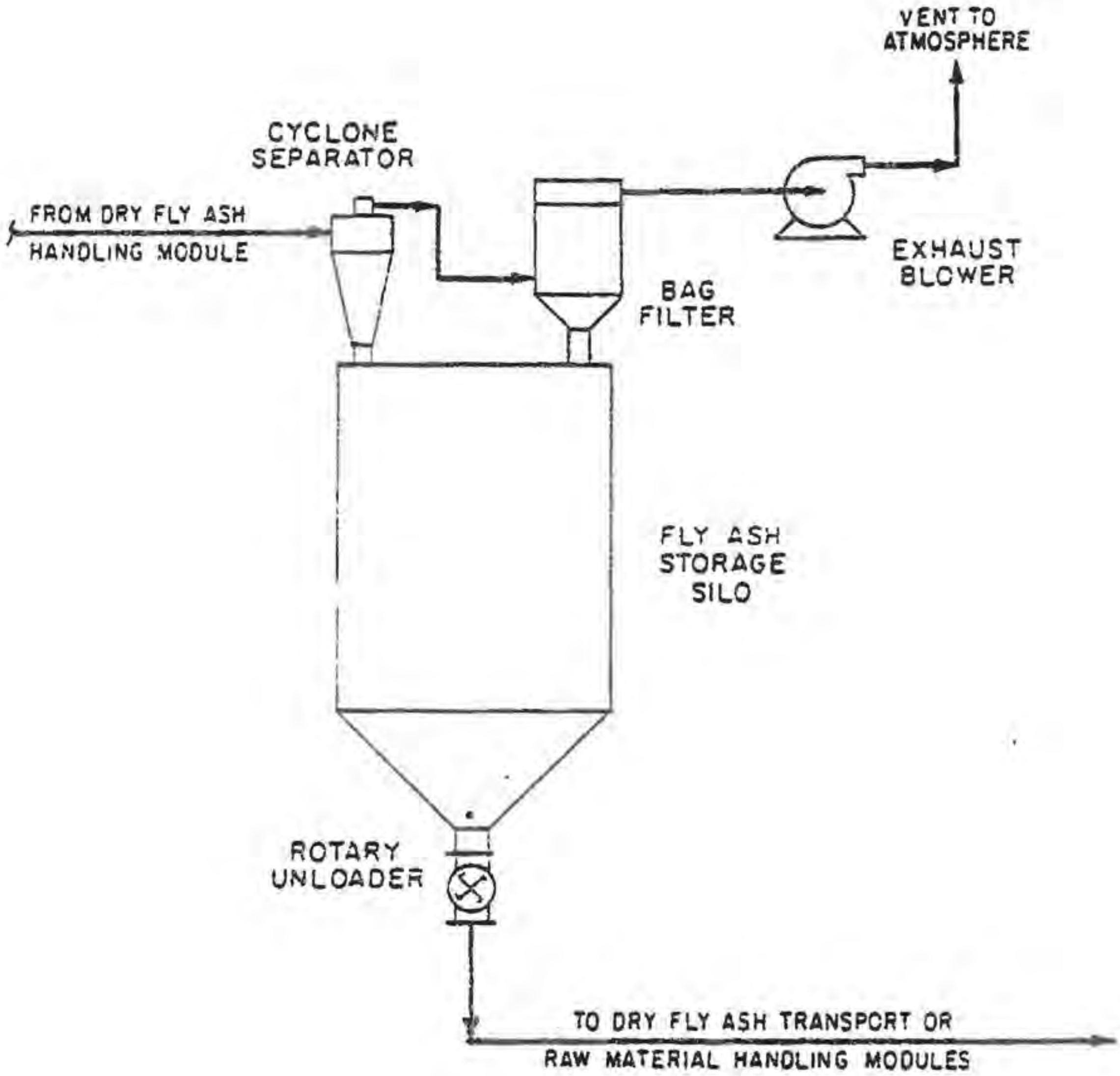
- belt conveyors;
- trucks;
- railroads;
- barges; and
- pipelines.

The ultimate choice of a transportation scheme depends on many factors, including waste type, distance of transport, cost, and availability of transport options. However, the form of the waste (i.e., wet or dry) ultimately limits transport options. Table 6.2 summarizes waste types and appropriate transport options.



Source: Arthur D. Little, Inc.

FIGURE 6.16 FLY ASH STORAGE MODULE



Source: Arthur D. Little, Inc.

FIGURE 6.15 FLY ASH STORAGE MODULE

Before truck or rail transport, fly ash must be wetted to prevent dust problems during transport. This is accomplished by conditioners, which may be of the horizontal rotary pugmill type or of the vertical type. The horizontal conditioner is capable of conditioning a maximum of 45 kg/sec (180 tons/hr) of fly ash with up to 20 weight percent water addition. The vertical type can process as much as 63 kg/sec (250 tons/hr) at similar water addition rates. Figures 6.15 and 6.16 illustrate two typical fly ash storage systems.

Storage systems for dry FGD wastes will be similar to those used for fly ash.

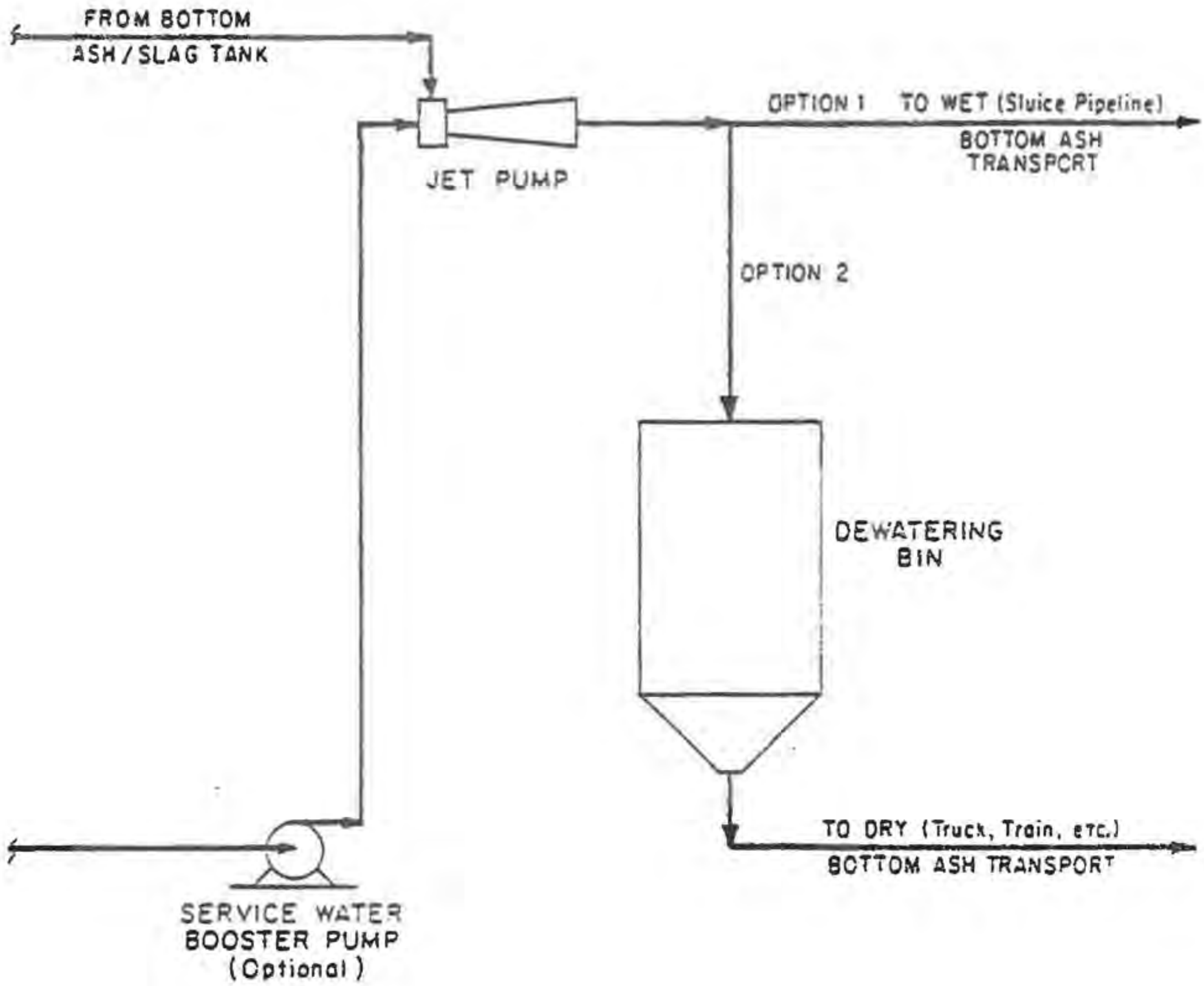
6.1.5 Raw Materials Handling and Storage

In cases where FGD waste processing is achieved by stabilization or chemical fixation, cementious additives and/or fly ash are typically added to the FGD waste. Fly ash would be considered to be a raw material in stabilization (i.e., blending) processes and in the CSI chemical fixation process. Cementious additives include lime, which is used in the CSI and Dravo chemical fixation processes, and Calcilox®, a proprietary fixation additive in the Dravo process. Handling and storage facilities are required for all these raw materials.

These materials are commonly stored in storage bins or silos. The decision to install one or more large handling/storage units versus several small ones will be site-specific and should be based on such factors as daily additive requirements, type of demand (steady or intermittent), type of delivery, future needs, etc. In any case, the total storage capacity for purchased additives is generally at least 50 percent greater than the minimum delivery in order to guarantee adequate supply. Since lime and many fly ashes are not corrosive, storage bins or silos can in many cases be constructed from conventional steel or concrete. Lime storage units, however, must be water and air tight, since lime can absorb moisture and carbon dioxide. At present, most raw materials storage units are silos with conical bottoms. This bottom type assists in discharaging the material from the silo.

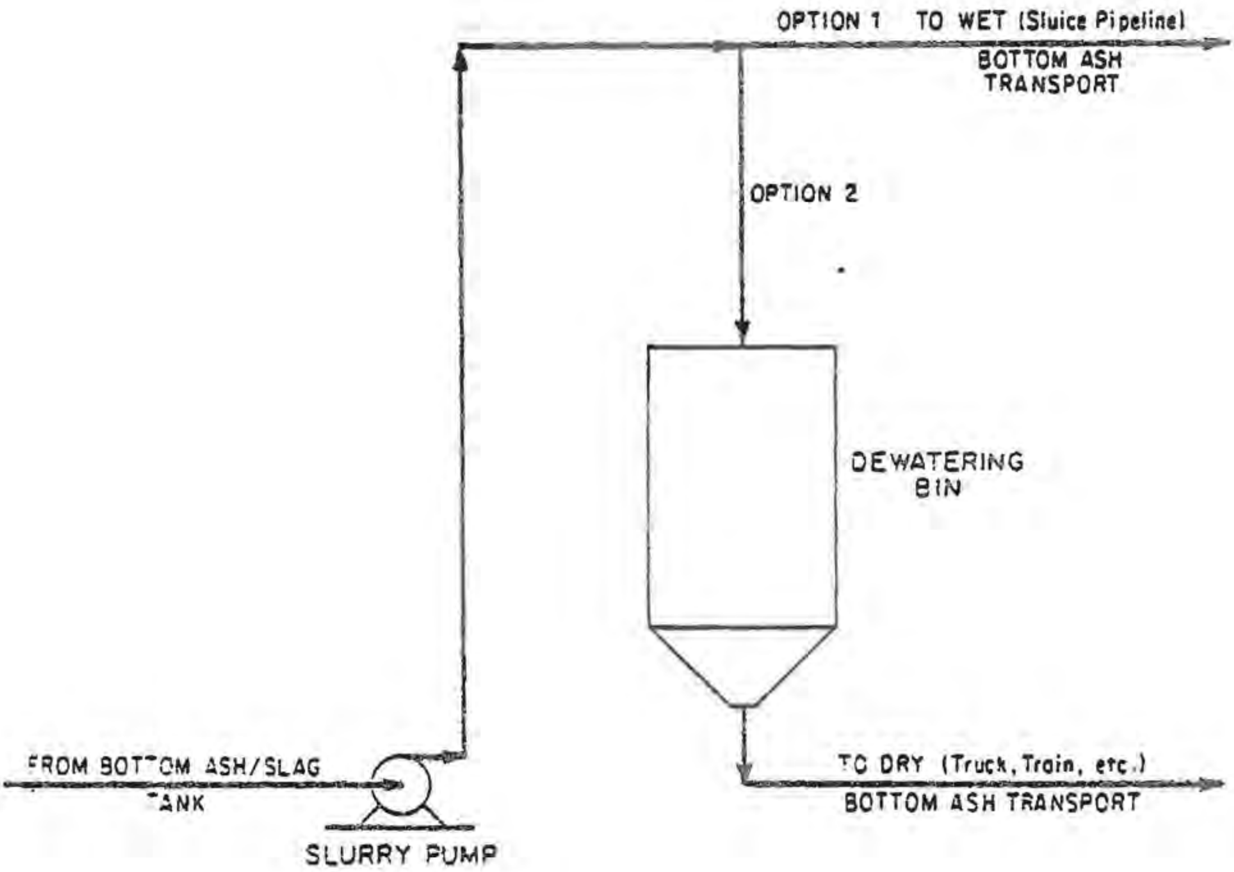
Raw material handling systems vary according to the source of the material. Fly ash is delivered to the raw material storage area from the fly ash handling or storage equipment at the power plant by pneumatic transport. The silo arrangement is like that described in Section 6.1.5 for conventional fly ash storage.

Lime and Calcilox additives are typically delivered to the raw materials handling unit in truck or rail cars. The additives can be pneumatically transported from the delivery vehicle with pressure or vacuum systems. In pressure systems, motive force is supplied by a positive displacement rotary blower mounted on the delivery vehicle. A particulate collection device must be provided to clean air vented from the silo. With the vacuum handling system, the raw material is pulled into the silo by vacuum. A lobe-type suction pump, filter receiver, and discharge air lock to



Source: Arthur D. Little, Inc.

FIGURE 6.14 BOTTOM ASH / SLAG HANDLING AND PROCESSING MODULE
Wet Handling Options



Source: Arthur D. Little, Inc.

FIGURE 6.13 BOTTOM ASH / SLAG HANDLING AND PROCESSING MODULE
Wet Handling Options

floating decanter. Water is drained from the body of the ash through stationary decanters on the sidewalls of the bin. Normally, about 28,800 sec (eight hours) are required for the total dewatering process, if a product satisfactory for truck or rail transport is desired. Ash is discharged through the bottom of the bin by means of a hydraulically operated gate.

Various bottom ash handling and processing options are shown in Figures 6.13 and 6.14.

6.1.4 Coal-Fired Utility Solid Waste Storage

Until recently, dry fly ash was the only coal-fired utility waste which required provisions for its storage. With the advent of dry FGD scrubbing, the need arose for storage of wastes from this process also. Fly ash can be stored for intermittent removal for sale, for use in FGD waste stabilization/fixation, or for disposal. Dry FGD wastes will typically be stored prior to disposal.

Dry fly ash is conveyed pneumatically (see Section 6.1.3.1) from the air pollution control device to the storage area. Fly ash can be separated from the conveying air by means of cyclone separators or fabric filters located on top of the storage silo. Collected fly ash is discharged through the bottom of these devices into the storage silo. Cyclone separators are inertial separators which remove particles from the carrying gas by transforming the velocity of inlet stream into a confined double vortex. The gas moves downward in spiral fashion at the outside of the cyclone and upward at the center to discharge at the top. The particles, due to their inertia, move toward the cyclone wall and are collected at the bottom of the cyclone.

Fabric filters provide higher efficiency than cyclones. The fly ash laden air is passed through a fabric bag which filters the ash from the gas. A number of these fabric filters are housed in a single baghouse. Fly ash is removed from the bags by shaking, pulsing a jet of air through the bags, or reversing the air flow through the bags.

Alternately, fly ash and the accompanying conveying air may be discharged directly into the storage silo. These silos are provided with vent filters (typically fabric filters) to prevent the discharge of dust along with displaced air as the silo is being filled. Venting can also be provided by a duct from the silo roof back to the precipitator inlet or hoppers. 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 dropout of fly ash in the duct.

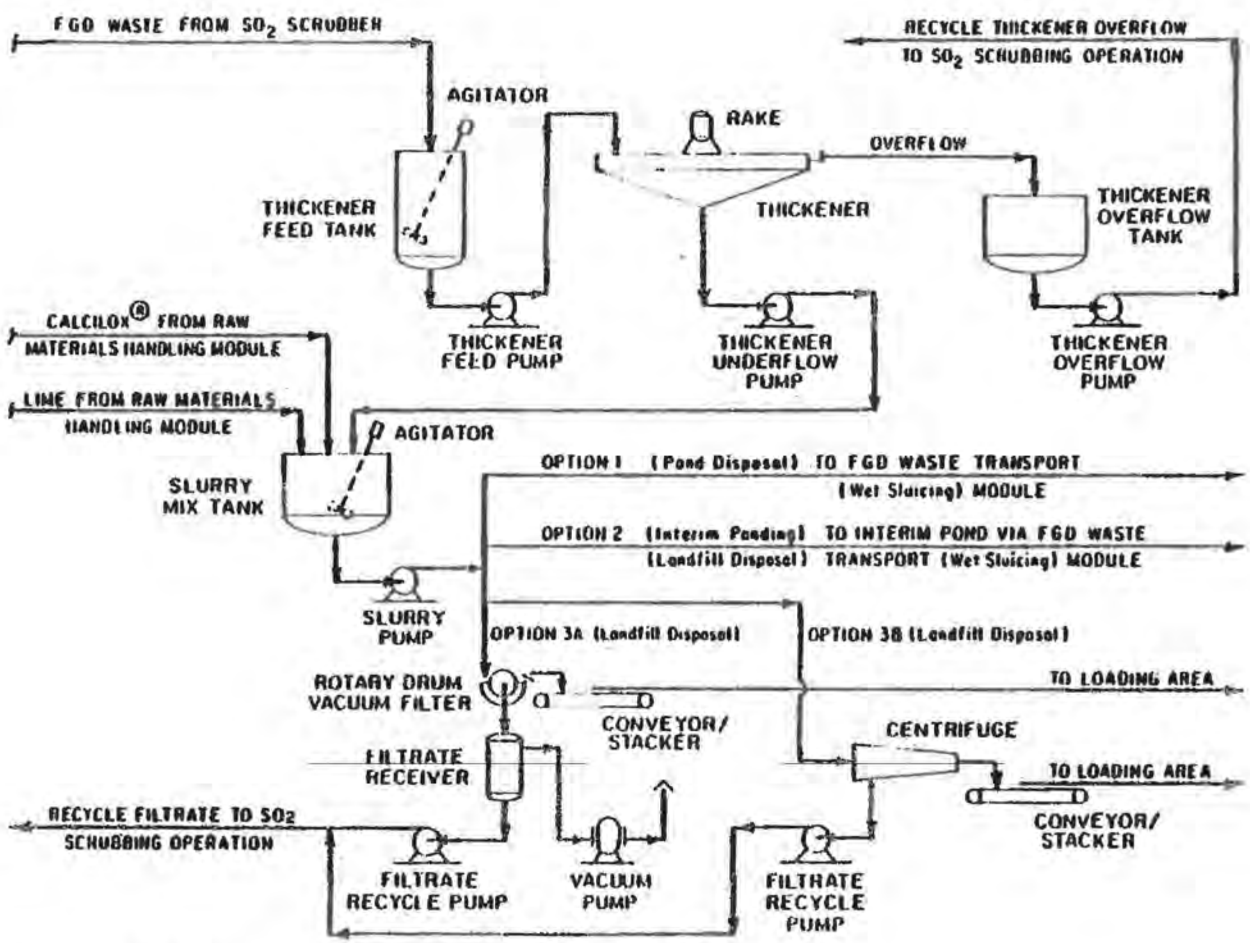
Storage silos may be of carbon steel or hollow concrete stave construction. Flat bottom silos are equipped with aeration stones or slides to fluidize dust and induce flow to the discharge outlets. Motor driven blowers supply the fluidizing air. Heaters may be required to prevent moisture from accumulating in the silo.

Bottom ash produced by dry bottom boilers is collected in hoppers. Different types of hoppers are used, depending upon the capacity of the boilers which they service. For smaller boilers, with steam generating capacities in the 126 kg/sec (1.0 million lb/hr) or smaller range, ash feeding is not a consideration, and flat-bottom ash hoppers with a single end or center outlet are used. Such ash hoppers provide maximum storage with limited headroom. Ash must be fed from the flat bottoms by means of operator-controlled nozzles. Larger boilers require hoppers with large storage capacities, steep self-feeding slopes, and water containment to quench ash and to provide delivery at a high rate to the conveying system. The bottom ash hopper will be equipped with refractory-lined ash gates, which may be water cooled if high temperatures are anticipated. These ash gates may be either manually operated or equipped with an air-operated cylinder.

For continuously slagging, wet-bottom boilers, slag tanks are employed. Ash leaves the boiler in a molten state. Slag is quenched in a water-filled hopper. The quenching medium may, in some instances, be used as the transport fluid for sluicing the quenched ash. The slag hopper design is similar for wet bottom pulverized coal-fired boilers and for cyclone boilers. However, larger hoppers will be required for the latter system, since the percentage of bottom ash recovered in cyclone furnaces is higher than in the pulverized coal-fired type of boiler.

Bottom ash and slag handling and processing requirements are dictated primarily by the disposal method. Handling and processing options include sluicing for bottom ash or slag disposed by wet ponding and dewatering for dry disposal. In either case, the bottom ash is generally passed through a grinder before it is handled or processed. Double and single roll clinker grinders are used. This crushing is sufficient to produce particles which will pass through ejectors, pumps, and conveying lines.

Bottom ash and slag are typically sluiced with jet pumps, although slurry pumps have been employed. With jet pumps, water provides the motive force. The waste may be sluiced to the disposal area for wet disposal or to a hydrobin for dewatering when dry disposal is called for. Hydrobins are available in a range of capacities to meet the requirements of plants of varying sizes. These capacities range from 23 to 900 metric tons (25 to 1000 tons), based on a dry coal ash density of 720 kg/m^3 (45 lb/ft^3). In most cases, at least two hydrobins are employed. One bin is available to receive ash, while the second contains ash which is being dewatered and unloaded. Ash is pumped into the bin over a bar screen, which permits the finer material to drop directly into the center while the coarser particles are diverted toward the sides of the bin to form a filter to trap fines before they reach the decanting elements. Aqueous overflow enters a serrated weir around the bin periphery and subsequently flows into a trough to a drain or settling system. The flow over the weirs is reasonably steady and undisturbed due to the presence of an underflow baffle. All material entering the bin must pass under this baffle before reaching the weirs. In this manner, turbulence caused by the inlet discharge does not reach the weirs. Once a bin is full, it is allowed to stand for about 3600 sec (one hour) until most ash has settled. The standing water is drained by a



Source: Arthur D. Little, Inc.

FIGURE 6.12 FGD WASTE HANDLING AND PROCESSING MODULE
Dravo Fixation Process

6-27

A second chemical fixation process of interest is the Dravo process. The Dravo Lime Company patented a method of FGD waste fixation through the use of hydrated lime and Calcilox®, a cementitious product derived from basic blast furnace slag. Dravo offers three distinct variations of its process:

- direct ponding;
- interim ponding followed by landfilling; and
- direct landfilling.

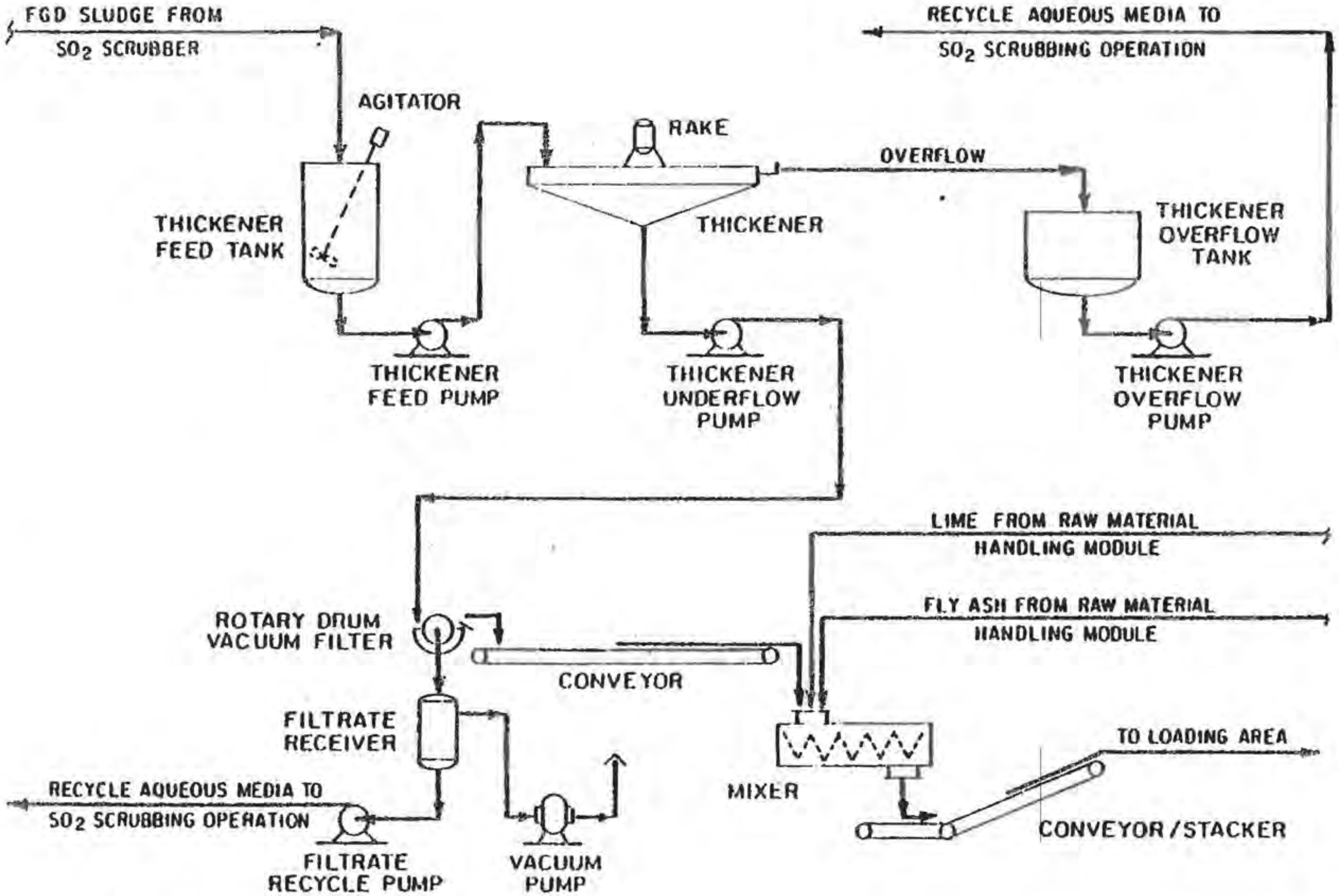
In the Dravo ponding process, FGD waste is dewatered in a thickener to 25 to 30 weight percent solids. The dewatered waste is mixed in a tank for 1,200 sec (20 minutes) with the lime and Calcilox fixation agents. Normally 5 to 10 percent of Calcilox is added in terms of dry slu ge solids weight. The lime is added in sufficient quantity to raise the pH of the mixture to between 10.5 and 11.0. After mixing, the treated waste slurry is pumped to the disposal pond. It is in the pond that the fixated waste solidifies to form an earth-like substance called Synearth . The pond supernatant is usually returned to the scrubbing system, since the highly alkaline liquor cannot be discharged to local surface water streams without costly acid treatment.

The remaining two Dravo processes employ much of the same FGD waste processing methods that are used by Dravo to treat wastes for pond disposal. With the interim pond option, the major difference is that the treated waste is dewatered in the pond and is dredged and ultimately disposed in a landfill. The direct landfilling option calls for dewatering of the treated waste slurry from the mixing tank by the secondary methods (e.g., filtration and centrifugation) previously described. Figure 6.12 illustrates the various Dravo options for FGD waste handling and processing.

Forced oxidation is a waste processing step which is incorporated as part of the scrubber cycle. Here sulfite species are intentionally oxidized to sulfate so that gypsum (which is more readily dewatered) is the primary FGD sludge component. Forced oxidation involves addition of air to the scrubbing liquid or recycle loop bleed stream by means of compressors or an eductor. The control of pH is essential, since the oxidation rate increases as pH decreases. The pH can be controlled by employing a two-stage scrubbing process, in which the first stage is maintained at low pH for oxidation purposes and the second stage at a higher pH for sulfur dioxide removal. The ultimate value of forced oxidation system is with respect to the nature of the waste generated. Gypsum is readily dewatered, unlike calcium sulfite wastes; thus, forced oxidation systems reduce FGD waste processing costs as well as those for transport and disposal.

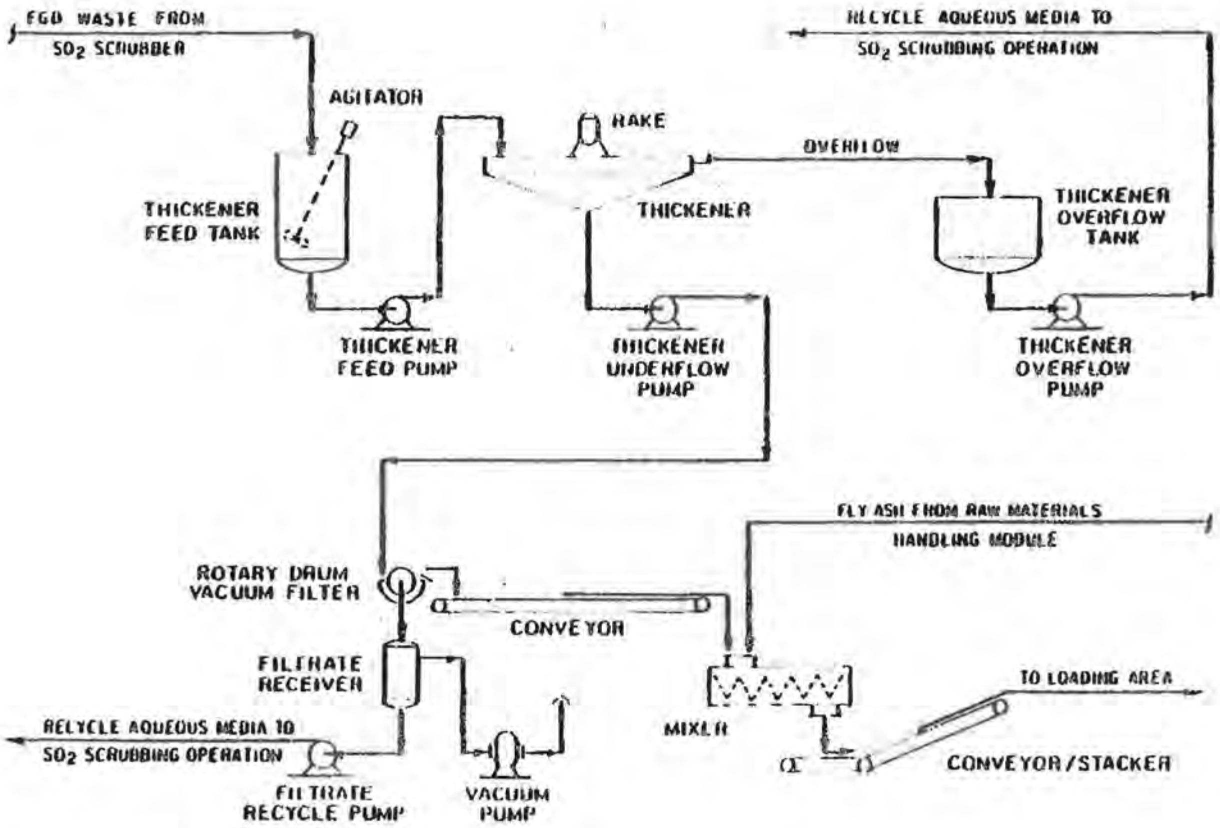
6.1.3.3 Bottom Ash and Slag Handling and Processing--

Bottom ash and slag collection systems differ, depending upon the form of the waste; bottom ash may be collected in dry form from dry bottom boilers, while slag is collected when a wet bottom boiler is employed.



Source: Arthur D Little, Inc.

FIGURE 6.11 FGD WASTE HANDLING AND PROCESSING MODULE
CSI Fixation Process



Source: Arthur D. Little, Inc.

FIGURE 6.10 FGD WASTE HANDLING AND PROCESSING MODULE
FGD Waste/Fly Ash Blending System

(in which solids discharge from the end opposite the slurry inlet). These centrifuges differ significantly. Concurrent centrifuges are large in size and operate at low centrifugal force, while countercurrent centrifuges are smaller in size but employ high centrifugal force. To date, the advantage of one type over the other for this application has not been proven.

Dry blending of FGD waste and fly ash (i.e., stabilization of FGD waste with fly ash) results in a third FGD handling and processing variation. In blending applications, FGD wastes are dewatered in primary and secondary operations, and the resulting waste is mixed in a pug mill with dry fly ash to produce a mixture with a lower moisture content than the FGD waste alone. Figure 6.10 is a process flow diagram of FGD waste/fly ash blending. A variation on this process is to mix the fly ash with the FGD sludge at the landfill site with earth moving equipment. Control of moisture content to obtain the optimum compaction in the landfill is essential to this process. Fly ash reactivity is a second parameter of importance, since use of alkaline fly ash containing significant quantities of calcium oxide can cause the co-disposed waste to undergo a pozzolanic reaction, thereby generating a fixated waste. This type of reaction can be desirable; in fact, processes based on other additives have been designed to produce fixated wastes, as described below.

The fourth FGD waste handling and processing option is chemical fixation. In this process, fly ash and lime or other additives are added to dewatered FGD wastes prior to disposal. In the fixation process, the FGD wastes and cementitious additives undergo pozzolanic reactions that produce increased structural integrity of the resulting wastes. This chemical process continues even after placement of the process waste.

The most common FGD waste fixation process in use today is the Conversion Systems, Inc. (CSI) process. In it, the FGD wastes undergo primary and secondary dewatering to a high solids content (50 to 60 percent). A thickener and filter are typically employed. Subsequently, the waste is blended with fly ash and lime in a pug mill, where the pozzolanic reaction yields a material with cementitious properties. [The raw materials (i.e., fly ash and lime) storage and delivery system is described in Section 6.1.5.] The fixated waste that leaves the mixer is transported by belt conveyors to temporary surge piles for storage until it is reclaimed for ultimate disposal. Single stationary stacking conveyors are satisfactory for delivering dry sludge to surge piles of moderate size. However, only conical piles can be built with a stationary conveyor and because of the height limitations of such piles, it is often necessary to distribute the surge pile over a larger area than is possible with a stationary conveyor. Therefore, many utilities use inclined conveyors pivoted at the tail end on the loading point centerline (i.e., radial stackers). The conveyor structure is supported near the midpoint by a tower. The radial stacker design allows for movement of the conveyor discharge point, thereby permitting the formation of large capacity arc-shaped piles. Figure 6.11 is a process flow diagram of the CSI fixation process.

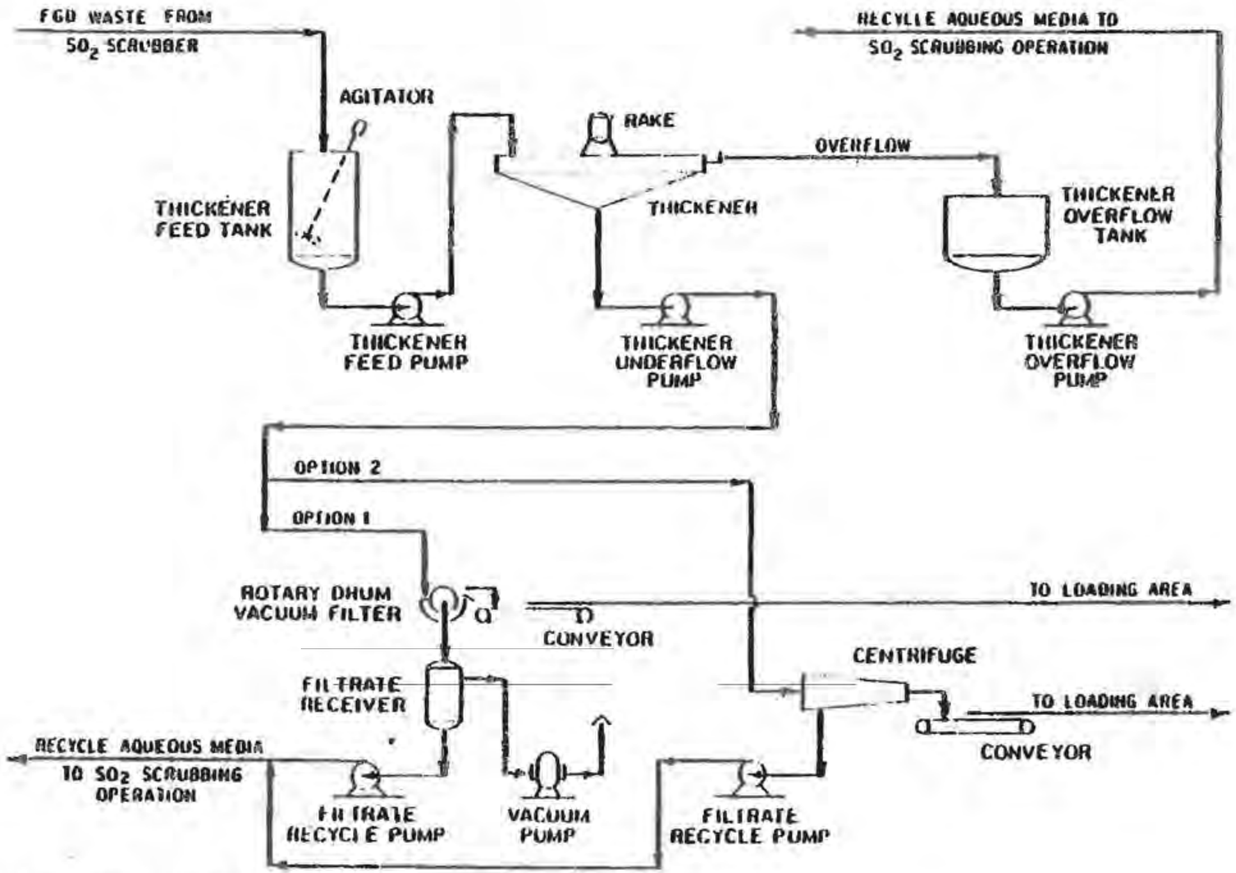


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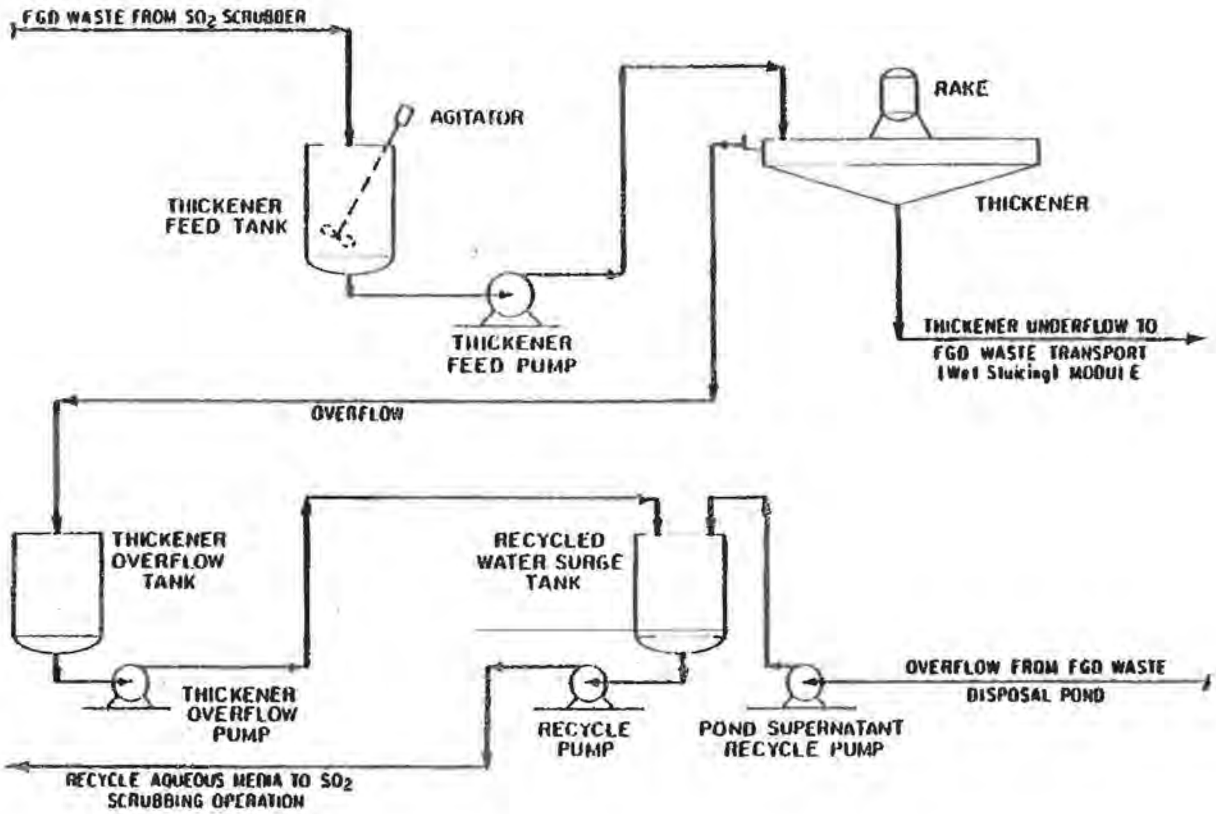
FIGURE 6.9 FGD WASTE HANDLING AND PROCESSING MODULE
Primary and Secondary Dewatering Options



Source Arthur D Little, Inc.

FIGURE 6.8 FGD WASTE HANDLING AND PROCESSING MODULE
Primary Dewatoring System

- dewatering of the FGD waste and subsequent chemical fixation prior to disposal.

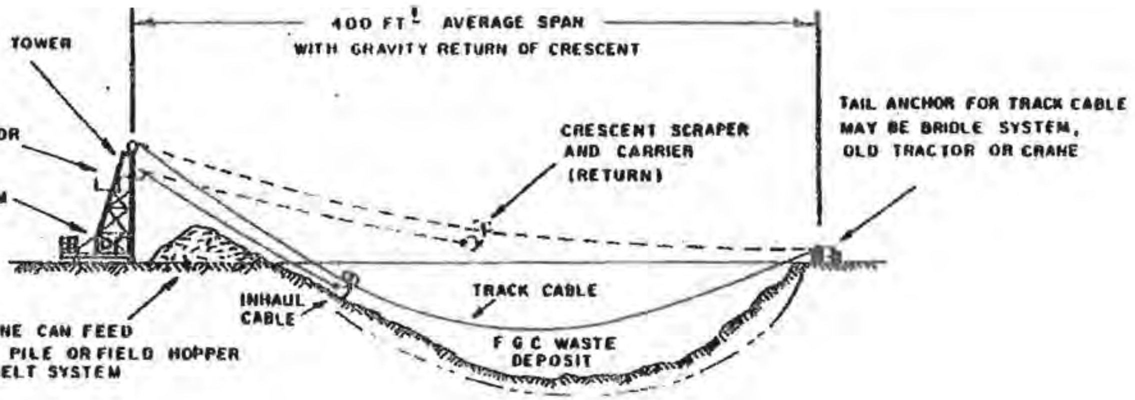
In cases where FGD wastes are directly ponded, the supernatant is generally returned to the process. This practice may also be employed when FGD wastes are dewatered prior to disposal. However, not all ponding systems incorporate water recycle, and many which do include this feature practice only partial recycle. As a rule, water management and conservation dictate water reuse. For new systems, recycle and optimum water management are anticipated to be mored widely practiced.

Most unthickened slurry wastes produced by FGC systems contain on the order of 5 to 15 weight percent suspended solids. In order to avoid the unnecessary discharge of large amounts of process liquor, these wastes are frequently mechanically dewatered prior to being disposed. Dewatering decreases the volume of waste for transport and disposal, thereby reducing the costs of these operations. Additionally, wastes dewatered to an optimum moisture content exhibit a maximum strength; thus, dewatering to reach that moisture content is a useful engineering technique. Primary dewatering is usually accomplished with thickeners or interim ponds. Primary dewatering is virtually universally practiced to reduce sludge volume and conserve water. Figure 6.8 illustrates a typical primary thickening operation for pond disposal of FGD waste. Interim ponding of FGD wastes is practiced in the same way as interim fly ash ponding (Section 6.1.3.1). Secondary methods of dewatering are also sometimes used. These include vacuum filtration and centrifugation. Secondary dewatering is only practiced as a precursor to dry impoundment to improve the handling properties of the wastes prior to truck transport, stabilization or fixation. Figure 6.9 shows typical primary and secondary dewatering options.

Conventional gravity thickeners operate similarly to settling tanks. Feed solutions enter at the center and are distributed radially. A circulating rake is used to gently push settled solids toward the discharge point. Sludge solids are collected as underflow in a sump and then directed to disposal or secondary dewatering operations (i.e., vacuum filtration or centrifugation). Clarified aqueous effluent is discharged over a weir and is generally recycled to the scrubber system.

Two types of vacuum filters have been used to dewater FGD sludges, rotary-drum filters and belt filters. These filters are similar in operation, although a scraper is required to remove solids from the rotary drum filter cloth, while none is needed for the belt filter. From a maintenance standpoint, this scraping results in costly wear of the rotary drum filter cloth. However, the installed capital cost of belt filters can be up to 30 percent higher than that of drum filters. Both filters require auxiliary equipment such as a vacuum receiver, vacuum pump, and filtrate pump.

Two types of centrifuges are applicable to dewatering FGD scrubber sludges. These are the countercurrent centrifuge (in which solids are discharged at the slurry inlet end of the bowl) and the concurrent centrifuge



SOURCE Arthur D Little, Inc

FIGURE 6.7 SKID-MOUNTED DRAGLINE MACHINE

If the waste is not sufficiently dewatered to permit this type of excavation or if the pond is too large to be excavated by shovels, a cable powered dragline may be employed. Draglines have been in use for more than 50 years for long range digging and hauling, with scraper sizes ranging from 0.4 to 15 m^3 (0.5 to 20 yd^3) and on spans of up to 305 m (1,000 ft). Skid-mounted units are available in sizes up to 2.3 m^3 (3 yd^3). These machines offer high production and portability where the line of operation must be frequently shifted (Figure 6.7).

Draglines work equally well on high banks [measuring as high as 73 m (240 ft)], level ground, and under water. Hauls from the deposit can be made to a surge pile or hopper. Dragline machines are built in sizes to match all tonnage requirements. Both the size of the dragline and the length of haul are the chief factors in determining handling capacity.

The drag line consists of a bottomless scraper, operating cables, a two- or three-drum hoist, and guide blocks. The blocks may be mounted on a mast, skid frame, or mobile towers located at the head and tail ends of the installation. The cables are spooled in the drums, reeved through the guide blocks, and drag the scraper through its operating cycle. Scrapers can discharge their load at the head end support into a surge pile, or into a hopper, truck or rail car. With larger size scrapers, 4 m^3 (5 yd^3) and larger, a track cable is used to lift the scraper off the surface on the return cycle and to lower the scraper to contact the waste material during the digging and waste hauling cycle.

In some interim ponding or disposal ponding operations, supernatant recycle may be practiced. This operation is similar to that discussed in the following section on FGD waste processing and handling.

6.1.3.2 FGD Waste Processing and Handling--

FGD wastes, like fly ash, can be collected in either wet or dry form by currently available sulfur oxides control devices. Dry FGD waste technologies are relatively new and, therefore, most FGD waste handling and processing options in use are based on wet wastes. However, the use of dry sulfur oxide scrubbing technologies is growing at a rapid pace, and the handling and processing systems for wastes from these technologies warrant attention. In general, handling systems for dry FGD wastes would be similar to the dry fly ash handling systems discussed in Section 6.1.3.1.

There are four basic approaches to processing and handling wet FGD wastes:

- pumping the wet scrubber effluent directly to a disposal pond with no processing;
- dewatering scrubber sludge prior to pumping it to a disposal pond;
- dewatering scrubber sludge prior to stabilization of the dewatered waste by mixing with fly ash; and

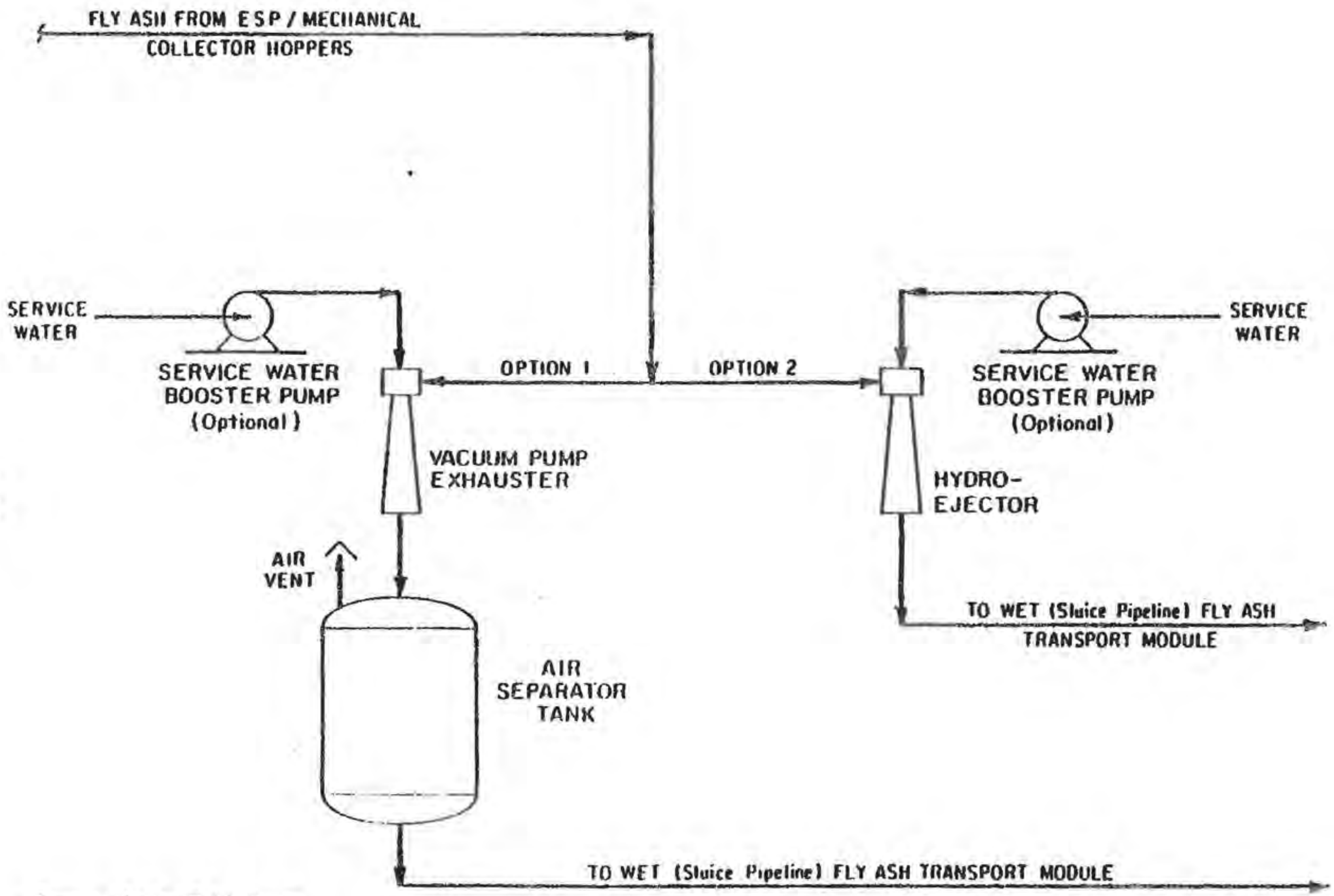


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FIGURE 6.6 FLY ASH HANDLING AND PROCESSING MODULE
Combination Vacuum Pneumatic Conveying – Wet Sluicing System

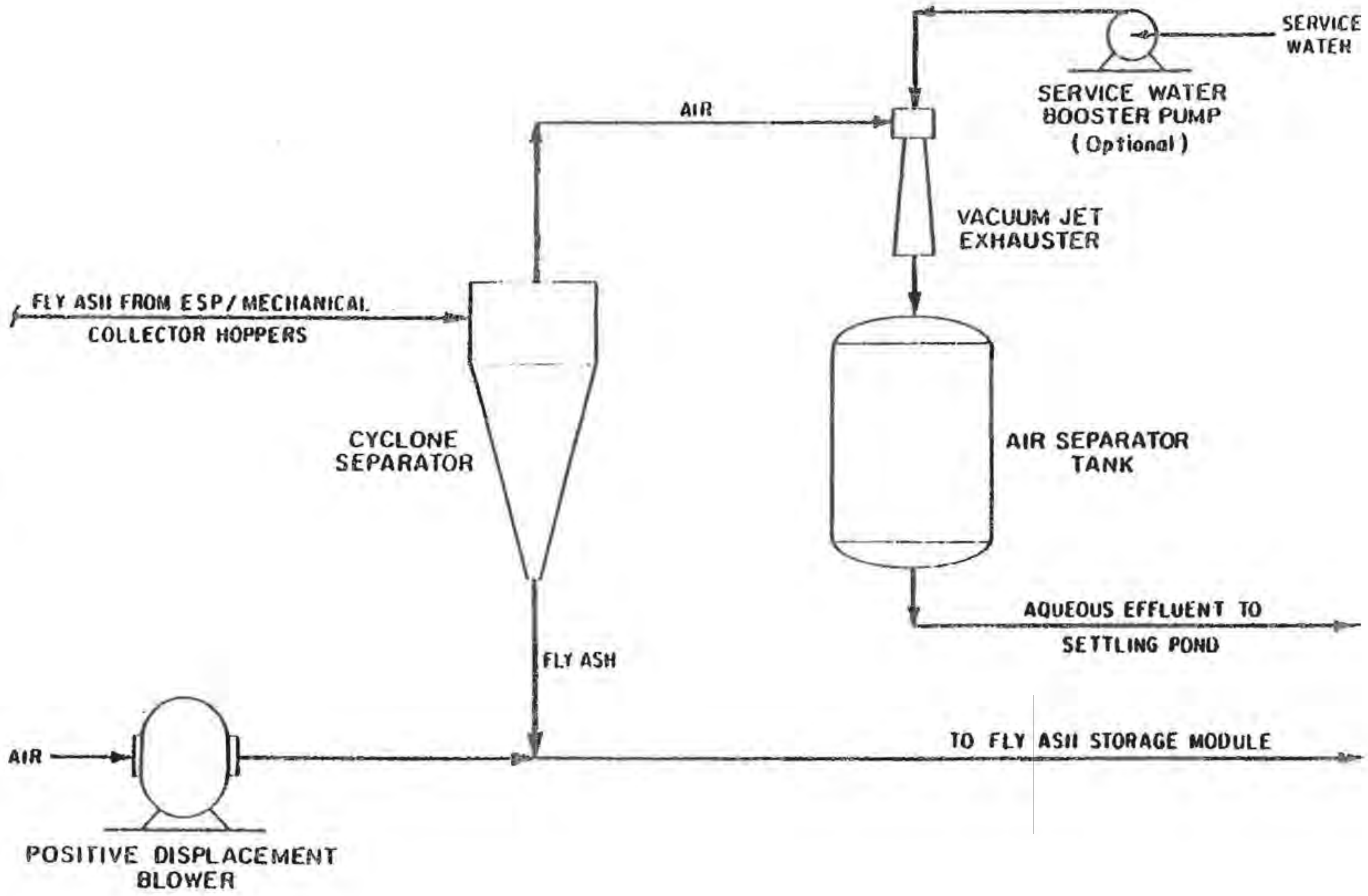

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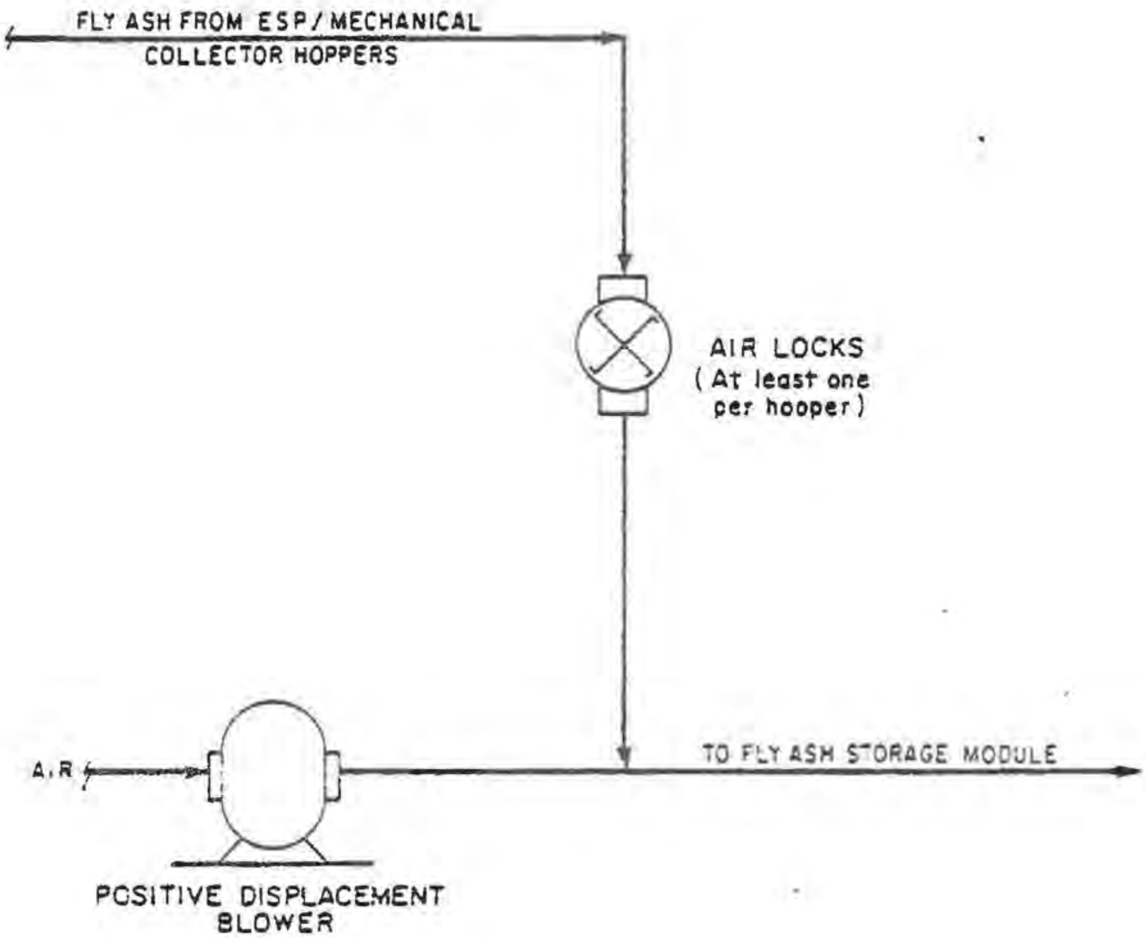
FIGURE 6.5 FLY ASH HANDLING AND PROCESSING MODULE
Combination Vacuum/Pressure Pneumatic Conveying System



Source: Arthur D. Little, Inc.

FIGURE 6.4 FLY ASH HANDLING AND PROCESSING MODULE
Pressure Pneumatic Conveying System

For longer conveying distances, pressure conveying is the most economical method. Air locks are used to transfer fly ash from the hoppers of the air pollution control devices to the transport lines. A positive displacement blower is used to create the motive force. This system is shown schematically in Figure 6.4.

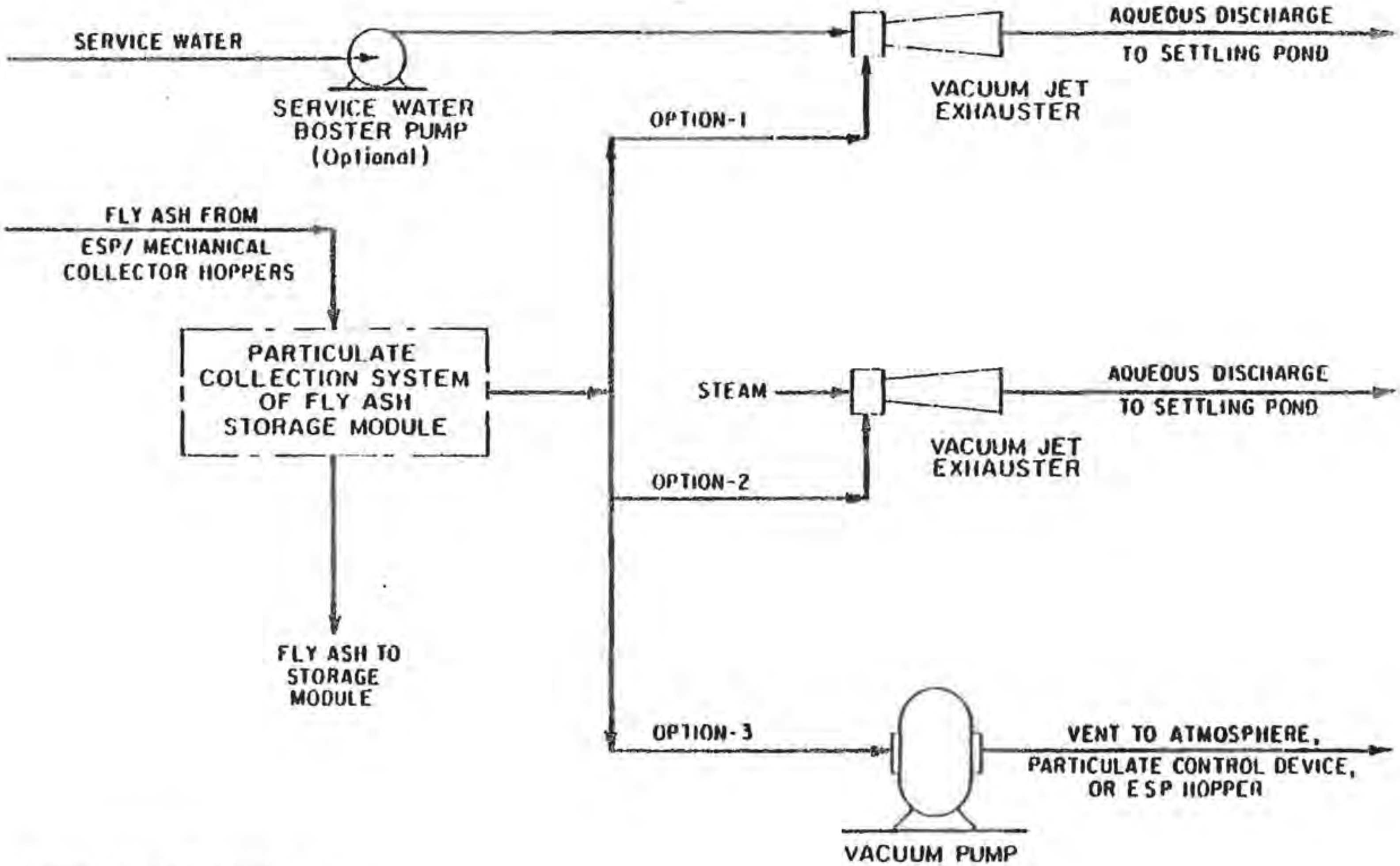
It is sometimes economical to employ a combination of vacuum and pressure conveying of fly ash where distances rule out the use of vacuum conveying alone. In this manner, the advantages of both systems are utilized. The vacuum system, with its simplified controls, removes the fly ash from the collection device hoppers at an optimum rate and transports it to a single transfer point. From this point, the pressure system economically delivers the fly ash to the terminal destination. The combination vacuum/pressure pneumatic fly ash handling system is shown in Figure 6.5.

When ponding is the disposal method of choice for fly ash that is collected dry, the ash may be directly sluiced from the collector hopper with a hydro-ejector system and then pumped to the pond. An alternate system involves a vacuum pneumatic system to carry the ash from the hoppers to a water jet exhauster which is used to create the vacuum; the vacuum-producing water is used to slurry the fly ash. The slurry is discharged through an air separator tank before being transported to the disposal pond. This type of system provides for continuous fly ash removal. In some cases, provision is made for returning supernatant back to the ash sluicing system. Figure 6.6 illustrates options for wet handling of fly ash collected in dry form.

In the very limited number of cases where fly ash is collected in wet form (via wet particulate scrubbers), it is usually pumped to a pond in slurry form. The wet ash may, in some instances (typically when collected simultaneously with FGD waste), be pumped to a thickener or clarifier which partially dewaters the FGD waste and the accompanying ash.

Dewatering of fly ash wastes may also be achieved by interim ponding. The aqueous fly ash slurry is placed in the pond and the liquor decanted or evaporated. Once sufficient dewatering has occurred, the waste is dredged and disposed in a landfilling operation. Typically, two ponds are used. One pond is kept in service while the second is being dewatered and dredged. Interim ponds are similar to disposal ponds in construction. (See Section 6.1.7.2.)

If the interim ponded waste has been sufficiently dewatered to bear the wei_ht of conventional excavation equipment, various types of dozers and shovels may be used for the dredging operation. If the dewatered waste cannot safely support this type of operation, dozers and shovels may be required to work from the perimeter of the pond or from dikes and proceed into the pond as waste is removed. Even as the waste is removed, dewatered bottom ash is sometimes employed as a base road building material to allow dozers and/or scrapers to enter onto the pond.



Source: Arthur D Little, Inc.

FIGURE 6.3 FLY ASH HANDLING AND PROCESSING MODULE
Vacuum Pneumatic Conveying Options

then regenerated in a calciner, liberating sulfur dioxide, which is again recovered and either reduced to sulfur or used to make acid.

6.1.3 Coal-Fired Utility Solid Waste Handling and Processing

Waste handling and processing options for coal-fired utility wastes vary with both waste types and the physical state(s) of the wastes. This discussion of coal-fired utility waste handling and processing is segmented by waste type, since, for each waste type, a variety of waste handling and processing alternatives is available.

6.1.3.1 Fly Ash Handling and Processing--

The selection of fly ash handling and processing systems is dictated, to a large extent, by the following factors:

- the form of the waste available to the handling and processing system (e.g., fly ash is collected in dry form by ESPs and mechanical collectors, while aqueous fly ash slurries are generated by flue gas scrubbers);
- the need to handle and process fly ash wastes due to the presence of other waste species (e.g., scrubbers designed to simultaneously collect particulates and sulfur oxides yield aqueous slurries of fly ash and FGD wastes; the presence of FGD wastes may call for dewatering of the combined wastes prior to disposal); and
- the ultimate fate of the fly ash (i.e., utilization or disposal by wet ponding or dry impoundment).

In cases where fly ash is collected in dry form, the method of waste handling and processing is primarily dependent upon whether the waste will ultimately be utilized, disposed in dry impoundments, or disposed in wet ponding operations. Handling and processing operations for fly ash which will be utilized or disposed in dry form are essentially the same. In these cases, dry fly ash is conveyed pneumatically from the collection device to storage silos for intermittent transfer for disposal. For short conveying distances of 185 m (55 ft) or less, vacuum conveying is typically used. Vacuum system motive force can be produced either hydraulically or mechanically by any of three devices:

- a jet exhauster using water to create a vacuum;
- a jet exhauster using steam to create a vacuum;
- a mechanical vacuum pump which operates on electrical energy to create vacuum.

Figure 6.3 illustrates the various options available in vacuum pneumatic conveyors for fly ash handling.

applications. The few utility applications use inexpensive sources of alkaline sodium salts, such as trona. Once-through sodium systems are capable of achieving very high sulfur oxides removal efficiencies, approaching 99 percent. The type of scrubber is dependent primarily upon the degree of sulfur oxides control required. The pH is controlled in the range of 5 to 7 through the addition of fresh alkali, and a slipstream of spent liquor is removed for discharge to lined holding ponds.

Nonrecovery Dry Flue Gas Desulfurization Processes -- As discussed in Section 3.2.3, three different approaches to dry scrubbing for sulfur oxides control and particulate collection have been actively pursued, although only one--the injection of solid sorbents into the flue gas stream with collection downstream in a particulate control device--has reached commercialization. In this commercial practice, an aqueous solution of slurry sorbent is injected as a fine mist into the ash-laden flue gas in a spray chamber. The hot gas evaporates the water, and some sulfur oxides are removed through reaction with the alkali. The gas then passes to a dry particulate collector (fabric filter or electrostatic precipitator) where the fly ash and dry sorbent solids are removed and further sulfur oxides removal is achieved. The flue gas is exhausted directly to the stack without reheat, since the flue gas is not usually allowed to reach saturation in the spray dryer.

The remaining two approaches to dry FGD have not reached commercialization. Testing of dry sorbent injection has focused on the use of sodium bicarbonate nahcolite, a material not available in commercial quantities. Injection of sorbents into the boiler combustion zone is also in the testing phase.

Recovery FGD Processes -- Recovery FGD processes can also be categorized as wet and dry, according to the mode of sulfur oxides removal. As noted in Section 3.2.2, they can be further classified according to the type of byproduct produced, i.e., concentrated sulfur oxides for conversion to sulfur or sulfuric acid, sulfur only, or acid only.

Recovery FGD systems produce relatively small amounts of waste compared to non-recovery FGD systems and comprise a minor portion of the total FGD system installations or applications. The Wellman-Lord and magnesium oxide processes are the two major recovery FGD processes that have been commercially applied by utilities.

The Wellman-Lord process uses a sodium sulfite solution to absorb sulfur oxides, forming a solution of sodium bisulfite. Makeup sodium carbonate also reacts with sulfur oxides in the absorber, producing sodium sulfite. Side reactions produce some sodium sulfate, which is recovered by treatment of a purge stream. Sodium sulfite is regenerated from the bisulfite by simple addition of heat, liberating sulfur dioxide gas, which is recovered and either reduced to elemental sulfur or used to make sulfuric acid.

Magnesium oxide scrubbing of sulfur oxides produces magnesium sulfite/sulfate salts which are recovered and dried. The magnesium oxide is systems, for example, use either carbide lime or a dolomitic (high magnesium content) lime rather than commercial lime. (Dravo Corporation markets a special high magnesium content lime for FGD systems under the trade name, Thiosorbic lime.) The use of these limes effects lower oxidation rates and, therefore, better control of scrubber scaling. Also, the use of high magnesium content lime or the addition of magnesiuim oxide to commercial lime usually results in higher sulfur oxides removal efficiency and improves lime utilization for high sulfur coal systems (reducing lime stoichiometries from typical levels of 1.1-1.3 to 1.0-1.15).

A principal variation on direct limestone scrubbing involves intentional oxidation (i.e., forced oxidation) of the calcium sulfite salts formed in the scrubber to calcium sulfate. This is done to improve sulfur oxides removal efficiency, minimize scale and plugging potential, improve solids dewatering properties (by converting the wastes to gypsum), and increase limestone utilization. It is hoped that use of forced oxidation in high sulfur coal applications will reduce limestone stoichiometries from the typical levels of 1.25-1.5 to 1.05-1.1. In the simplest form of the forced oxidation process, air is bubbled through the slurry in a modified delay tank; however, two-stage scrubbing has also been used to cause intentional oxidation.

Western United States coal reserves include mostly lignites and subbituminous coals which contain far less sulfur than typical Eastern coals. Another feature of virtually all Western coals is that their ashes have high contents of calcium, sodium, and magnesium oxides. This lower required sulfur oxides removal combined with the alkalinity of the fly ash has led to the use of fly ash slurries as scrubbing liquors in several Western power plants. Fly ash alkali (FAA) scrubbing typically involves process configurations similar to lime or limestone scrubbing. The chemistry of FAA systems is much more complex due to the greater number of competing reactions. Good utilization of the ash alkali also necessitates operation at lower pH levels (3.5 to 5.0) than limestone systems. Supplemental alkali (typically lime or limestone) is frequently required.

Another wet, non-recovery FGD process is the dual alkali process. In dual alkali systems, sulfur oxides removal is accomplished with solutions of sodium salts which are then regenerated with lime to produce a waste calcium-sulfur salt similar in chemical composition to the waste produced from direct scrubbing systems. Dual alkali systems are most appropriate for medium and high sulfur coal applications where relatively high sulfur oxides removal efficiencies are required and where oxidation rates tend to be relatively low. Filters are used to recover sodium salts in order to minimize sodium carbonate makeup requirements and reduce the potential adverse environmental impacts from the high total dissolved solids (TDS) levels in the waste material.

Wet scrubbing processes can also entail the use of sodium salts, with no regeneration. However, this technology is now used principally for industrial boiler applications rather than coal-fired utilities. In this case, a liquid waste stream is produced. The high cost of the sodium reagent and the problem of liquid waste disposal have significantly limited utility

The primary advantage of wet scrubbing systems as air pollution control devices on coal-fired boilers is their ability to collect both particulate materials (fly ash) and gases (sulfur oxides). The most common application of scrubbers for coal-fired boilers is for the simultaneous control of particulate matter and sulfur oxides. However, a number of disadvantages are also associated with the use of scrubbers for particulate control:

- Compared to other particulate control systems, high energy penalties (high-pressure drops) are associated with the use of scrubbers [about 1240 Pa (0.18 psi) for fabric filters compared to 6220 Pa (0.90 psi) for venturi scrubbers].

- Scrubbers are not as efficient as other particulate control systems with regard to the collection of fine particles [less than 10^{-4} m (0.004 in)].

- Corrosion may potentially be associated with wet collection systems.

- A slurry waste is generated which may result in the need for relatively more expensive disposal operations (48).

6.1.2.2 Flue Gas Desulfurization Technology--

A wide variety of FGD processes have been developed for application on utility boilers. As discussed in Section 3.2, the technology can be grouped into two categories: non-recovery (or throwaway) systems, which produce waste material for disposal, and recovery systems, which produce salable byproducts. Nonrecovery processes make up the overwhelming majority of the technology.

There are two types of non-recovery FGD processes: (1) wet processes which involve contacting flue gas with aqueous slurries or solutions of absorbents to produce wastes in the form of solutions or slurries; and (2) dry processes which produce essentially moisture-free solid wastes through the use of spray dryers or dry adsorbent injection.

Nonrecovery Wet FGD Processes -- Direct lime and/or limestone scrubbing systems constitute the majority of operational wet FGD systems. In these systems, the flue gas is contacted with a slurry of calcium salts (calcium sulfite/sulfate and calcium hydroxide or calcium carbonate) at total suspended solids concentrations of 8 to 16 weight percent. Slurries are recirculated through open venturies or spray-tower scrubbers at high liquid-to-gas ratios. The spent liquor is collected in a delay tank to allow for completion of the precipitation reactions. Fresh alkali makeup (either slaked lime or a slurry of finely ground limestone) is added to the delay tank, and a slipstream is removed for waste solids separation. The rate of fresh alkali makeup is controlled on pH (lime systems usually operate at a pH of 6 to 7; the pH of limestone is typically 5 to 6).

There are a number of variations on conventional direct lime and limestone scrubbing systems directed toward improving sulfur oxides removal and overall scrubber system reliability. Many full-scale lime scrubbing cleaning of the fabric filter is required to prevent excessive pressure drops. Three different cleaning methods are in use:

- reverse air cleaning, the gentlest method, which entails the reverse flow of gas through the filter to dislodge collected material;
- mechanical shakers, which displace filter bags in either the horizontal or vertical direction to dislodge collected materials; and
- pulse-jet cleaning, the most severe cleaning method, in which expansion of the bag, due to the pulsing of pressurized air into the bag, causes collected material to be dislodged.

Most utility fabric filters are cleaned by the reverse air method, although shaking is also commonly employed, but to a lesser extent (46).

Filter fabrics are normally woven with relatively large open spaces [on the order of 1×10^{-4} m (0.004 in) or larger]. Since particulates of much smaller size can be readily collected by these devices, the filtering process must involve mechanisms other than sample sieving. These mechanisms include interception, impingement, diffusion, gravitational settling and electrostatic attraction. Once a cake of dust is formed on the filter, further collection is accomplished by these mechanisms (in addition to sieving)(47).

Fabric filters employed in utility applications exhibit high collection efficiency; in a number of cases, actual operating efficiencies exceeded design collection capacities which generally ranged from 99.4 to 99.7 percent (46). Unlike ESPs, the effectiveness of fabric filters is independent of coal composition. Consequently, these devices can collect the high electric resistivity fly ash (i.e., that generated as a result of burning low sulfur coal) that is not amenable to collection by electrostatic precipitation. In addition, with the recent commercialization of dry FGD scrubbing systems (through the use of spray drying or dry injection of adsorbents into the flue gas) and the resultant production of essentially moisture-free solid wastes, the use of fabric filters may increase. Another advantage of fabric filters is their high efficiency in collecting submicron particles. However, fabric filtration has been shown to be more energy intensive than electrostatic precipitation. Additionally, close control of flue gas temperatures is required to prevent acid condensation which would result in bag deterioration and shortened bag life.

Wet Scrubbing -- Wet scrubbing for particulate control involves the removal of dust from a gas stream by absorbing of the particles into suspended liquid droplets or by adhesion of the particles to the scrubber walls followed by liquid flushing into a waste disposal system (48). Intimate contact between the gas stream and liquid is required to transfer suspended particulate matter from gas to the liquid. Dust removal efficiency of scrubbers is primarily a function of the energy consumed in contacting the dust and liquid.

The electrical resistivity of fly ash has a significant influence on collection efficiency by electrostatic precipitation. High resistivity will decrease collection efficiency significantly. However, the electrical resistance of dust particles can be altered somewhat by altering the surrounding environment. As discussed previously, increases in temperature decrease the resistivity of fly ash particles. Similarly, the sulfur content of flue gas affects fly ash resistivity, since a layer of condensed, electrically conductive sulfuric acid can form on the surface of fly ash and reduce electrical resistance. Since the sulfur originally present in a given coal has a positive effect on fly ash collection efficiency, fly ash generated as a result of burning low sulfur coal will be more difficult to collect by electrostatic precipitation than that originating in a boiler burning high sulfur coal. For coals and fly ash having relatively high sodium contents, resistivity is controlled primarily by sodium concentration. In general, fly ash resistivity decreases with increasing coal alkali content.

Two types of ESPs are presently used for coal-fired utility applications, the cold-side ESP and the hot-side ESP. The basic design of both devices is similar except that hot-side ESPs are located on the hotter, 205 to 315°C (400 to 600°F) upstream side of the air preheater, while cold-side ESPs are located downstream, where the temperature is 120 to 205°C (250 to 400°F). This difference renders these devices suitable for different services; cold-side ESPs are primarily used to collect fly ash of low electrical resistance, while hot-side ESPs collect high resistivity fly ash by decreasing its resistivity due to the comparatively higher temperature of the collection environment. Hot-side ESPs, despite their ability to handle high resistivity particulates, have some serious disadvantages:

- Gas flows (volumes) are 50 percent higher than in cold-side systems because of the expansion of gases at higher temperatures.
- Precipitation rates are reduced as a result of increases in gas viscosity.
- Operating voltages are reduced primarily due to the lower densities of hot gases.
- Differential expansion may cause warping of structural components (44).

A significant advantage of electrostatic precipitation is that relative to other high efficiency collectors, ESPs exhibit low operating pressure drops -- 745 Pa (0.11 psi) -- and hence lower power requirements (45).

Fabric Filters -- In fabric filtration systems, dust-laden gas passes through a fabric in such a manner that dust particles are retained on the upstream side of the fabric, and clean gas passes through. As filtration proceeds, a filter cake builds up on the fabric which enhances particulate collection while increasing the operating pressure drop (45). Periodic to decline in the future due to implementation of more stringent air quality standards. Scrubbers are not often used for particulate control at utility boiler installations unless they are used for simultaneous particulate and sulfur dioxide removal or, when fly ash is used, as a source of alkalinity in FGD systems (e.g., fly ash alkali scrubbing) (12).

Electrostatic Precipitators (ESPs) -- Collection of particulates (fly ash) by electrostatic precipitation entails the following sequence of operations:

1. Fly ash particles become charged by colliding with gaseous ions and electrons generated in a high intensity corona discharge.

2. In the presence of an applied electric field, charged fly ash particles migrate toward a grounded collection electrode.

3. Collected fly ash material is removed from the plate by periodic rapping.

Modern ESPs are capable of achieving relatively high collection efficiencies (in some cases in excess of 99 percent). However, a number of parameters affect collection efficiency, including:

- precipitator size (i.e., specific collection area);
- applied collection field;
- gas temperature;
- electrical resistivity of the particulate matter;
- particle size; and
- gas composition.

The first three items are variables which may be adjusted in the design of an ESP. Electrical resistivity, particle size distribution and gas composition, however, depend on boiler operating conditions and the characteristics of the coal fired to the boiler. Gas composition can be altered by the introduction of additives which can subsequently reduce electrical resistivity of the particulates and thereby increase collection efficiency.

In the design of an ESP, increases in specified collection efficiency result in exponential increases in precipitator size. Thus, there is a trade-off between size (i.e., cost) and desired emission levels. Similarly, collection field requirements also increase with increasing efficiency specifications. Higher gas temperatures decrease the electrical resistivity of fly ash and, hence, increase collection efficiency. However, higher temperatures affect the volume of gas to be handled. Thus, an optimum efficiency can be obtained by selecting the proper operating temperature.

TABLE 6.1

MATRIX OF WASTE TYPES AND WASTE HANDLING/DISPOSAL MODULES

MODULE	WASTE TYPE		
	Fly Ash	Bottom Ash	FGD Waste
Raw Materials Handling and Storage			✓
Coal-Fired Utility Solid Waste Handling and Processing	✓	✓	✓
Coal-Fired Utility Solid Waste Storage	✓		
Coal-Fired Utility Solid Waste Transport	✓	✓	✓
Coal-Fired Utility Solid Waste Placement and Disposal	✓	✓	✓

Source: Arthur D. Little, Inc.

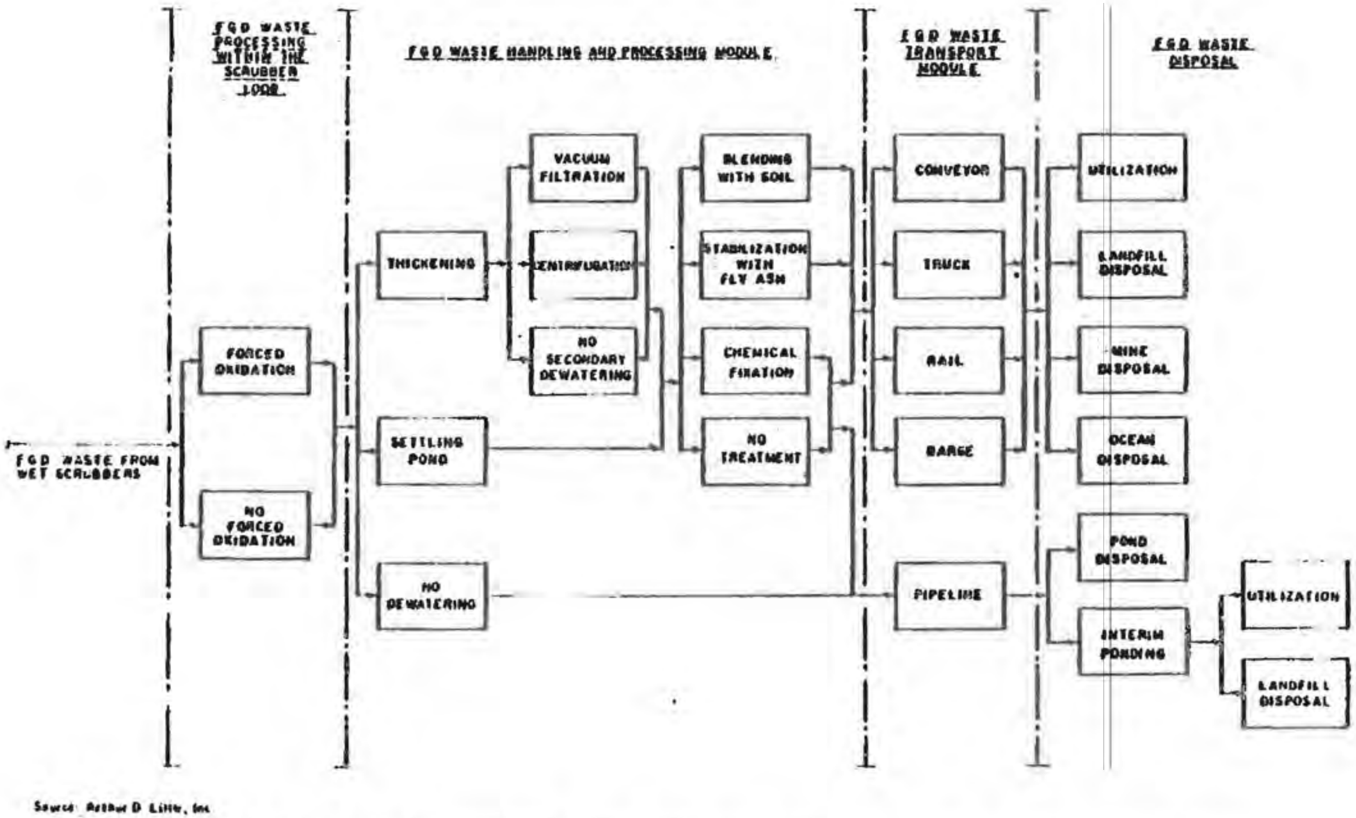
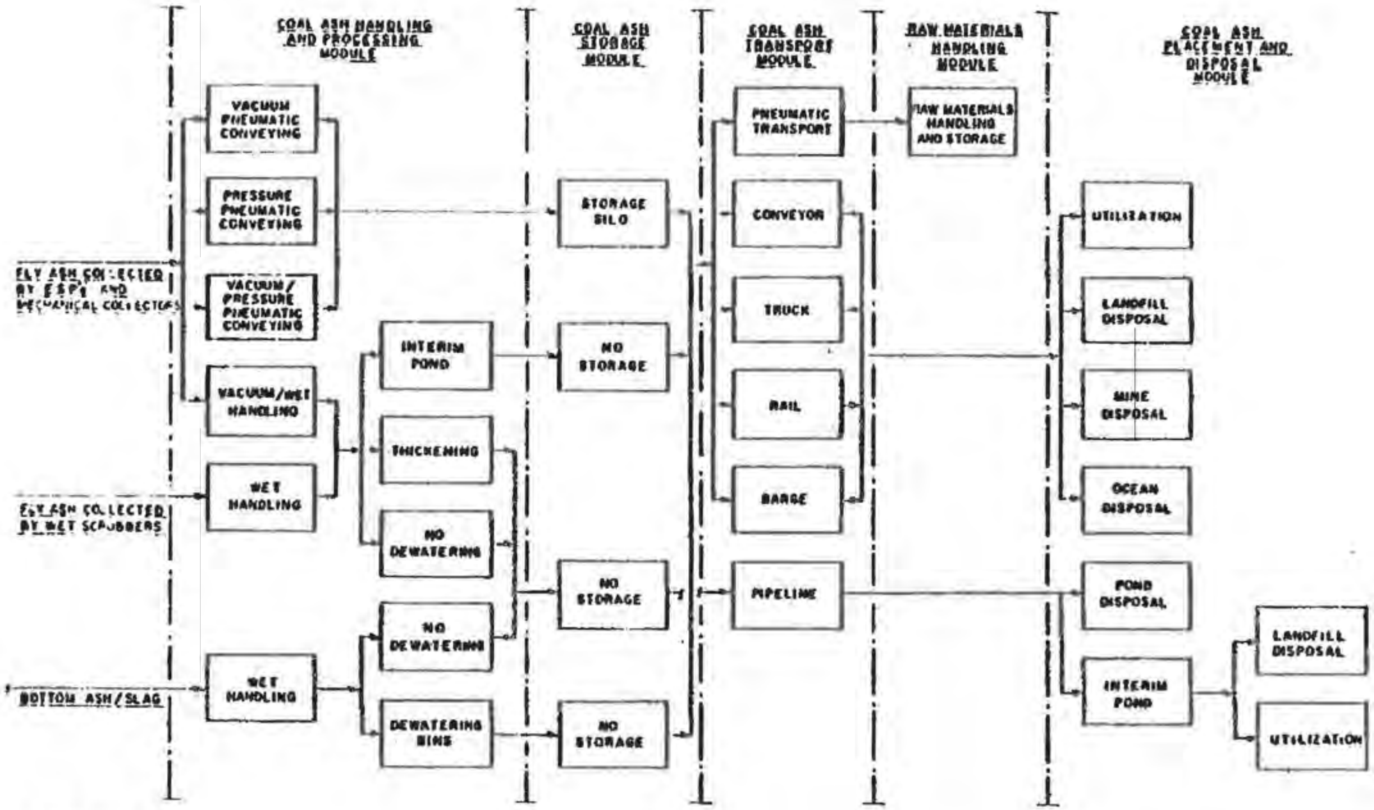


FIGURE 6.2 OVERVIEW OF WASTE HANDLING AND DISPOSAL OPTIONS FOR FGD WASTE



Source: Arthur D. Little, Inc.

FIGURE 6.1 OVERVIEW OF WASTE HANDLING AND DISPOSAL OPTIONS FOR COAL ASH

Within each module there exist a number of system design options which vary according to the waste type (i.e., fly ash, bottom ash and FGD waste) and the existing or desired physical states of the waste (i.e., dry solid wastes, aqueous slurries of solid wastes and dewatered solid wastes). In this engineering assessment, an attempt has been made to elucidate differences which can be identified within modules. The five modules can thus be viewed as five collections of engineering design alternatives. Selection of alternatives from each module which satisfy the general disposal and handling needs of a particular site results in a preliminary process specification. In some cases, more than one alternative within a given module can be required for different waste types or for wastes collected in different physical states. An overview of the five modules and the alternatives within each of the modules are presented schematically in Figures 6.1 and 6.2 for coal ash and FGD waste, respectively. As shown, some modules do not apply to all aste types. Table 6.1 lists waste types and the modules which apply to each.

In developing engineering and cost data on utility solid waste handling and disposal systems, it is difficult to divorce oneself entirely from the other aspects of the environmental control system. Hence, broad process data were developed for auxiliary areas that tend to shed substantial light on the design and cost of environmental control, including:

- the air pollution control system, which may consist of particulate and, in some cases, sulfur oxides control; and
- auxiliary systems for handling wastes other than coal ash or FGD wastes which enter the solid waste handling and disposal system.

The rest of Section 6.1 provides an overview of engineering data on the modules and auxiliary areas discussed above.

6.1.2 Coal-Fired Utility Solid Waste Collection

6.1.2.1 Particulate Control Technology--

Control of particulate emissions from coal-fired boilers can be achieved by several types of particulate control devices:

- mechanical dust collectors;
- wet scrubbers;
- electrostatic precipitators (ESPs); and
- fabric filters.

By far, ESPs are the most common particulate control devices employed by coal-fired electric generating utilities. Fabric filtration is more recently gaining acceptability for this application. The use of mechanical dust collectors, with fly ash collection efficiencies substantially lower than those of the other particulate control devices discussed here, is anticipated

SECTION 6

ENGINEERING COST ASSESSMENT OF COAL ASH AND FGD WASTE HANDLING AND DISPOSAL SYSTEMS

6.1 ENGINEERING OF COAL-FIRED UTILITY SOLID WASTE HANDLING AND DISPOSAL SYSTEMS

Coal ash and FGD waste disposal operations consist of a number of activities which include the handling of wastes from the point of their collection up to and through their ultimate disposal. Variations in collection and disposal systems necessitate a variety of waste handling, processing, storage and transport alternatives. Additionally, variations among waste types call for different approaches to waste management.

The engineering and cost data contained in this section were assembled with the modular approach outlined in Section 4.7. In general, a matrix of waste types and waste management activities was developed. For each waste type/waste management activity combination one or more engineering design option is presented. It is the combination of the appropriate modular options which leads to a preliminary engineering specification that forms the basis for the conceptual cost estimate for the integrated waste management system.

6.1.1 Coal-Fired Utility Solid Waste Handling and Disposal Options

Many options are available for handling and disposing of coal combustion solid wastes. However, all coal-fired utility waste handling and disposal operations can be divided into subsystems which fall into a relatively small number of broad categories. This categorization is the basis for the modular approach adopted for this engineering assessment. Five categories (denoted modules for the purposes of this study) of coal-fired utility solid waste handling and disposal activities have been identified:

- Raw Materials Handling and Storage;
- Coal-Fired Utility Solid Waste Handling and Processing;
- Coal-Fired Utility Solid Waste Storage;
- Coal-Fired Utility Solid Waste Transport; and
- Coal-Fired Utility Solid Waste Placement and Disposal (includes Site Monitoring and Reclamation).

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(*) All Volumes.
(**) Volume I starts.

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ABSTRACT

This report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study was conducted by Arthur D. Little, Inc., under EPA contract 68-02-3167, and involved characterizing wastes, gathering environmental data, assessing environmental effects, and evaluating the engineering/costs of disposal practices at six selected sites in various locations around the country. Results of the study are providing technical background data and information to EPA, State and local permitting officials, and the utility industry for implementing environmentally sound disposal practices.

Data from the study suggest that no major environmental effects have occurred at any of the six sites. For example, data from wells downgradient of the disposal sites indicate that the contribution of waste leachate to the groundwater has generally resulted in concentrations of chemicals less than the primary drinking water standards established by EPA. Although occasional exceedances of the standards were observed, these were not necessarily attributable to coal ash and FGD waste. A generic environmental evaluation based on a matrix of four waste types, three disposal methods, and five environmental settings (based on climate and hydrogeology) shows that technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, measures must be taken to avoid adverse environmental effects. However, site-specific application of good engineering design and practices can mitigate most potentially adverse effects of coal ash and FGD waste disposal. Costs of waste disposal operations are highly system- and site-specific.

NOTICE

The information in this document has been funded by the United States Environmental Protection Agency under EPA Contract No. 68-02-3167 to Arthur D. Little, Inc. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EPA-600/7-85-028b
June 1985

FULL-SCALE FIELD EVALUATION OF WASTE DISPOSAL FROM COAL-FIRED ELECTRIC GENERATING PLANTS

by

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16. ABSTRACT The six-volume report summarizes results of a 3-year study of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired electric generating plants. The study involved characterization of wastes, environmental data gathering, evaluation of environmental effects, and engineering/cost evaluations of disposal practices at six sites around the country. Study results provide technical background data and information for EPA, state and local permitting officials, and the utility industry for implementing environmentally sound disposal practices. Study data suggest that no environmental effects have occurred at any of the six sites; i.e., data from wells downgradient of the disposal sites indicate that waste leachate has resulted in concentrations of chemicals less than the EPA primary drinking water standards. A generic environmental evaluation--based on a matrix of four waste types, three disposal methods, and five environmental settings--shows that, on balance, technology exists for environmentally sound disposal of coal ash and FGD wastes for ponding, interim ponding/landfilling, and landfilling. For some combinations of waste types, disposal methods, and environmental settings, mitigation methods must be taken to avoid adverse environmental effects. Costs of waste disposal operations are highly system and site specific.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Ashes	Pollution Control	13B	21B
Waste Disposal	Flue Gases	Stationary Sources		
Wastes	Desulfurization		14G	07A,07D
Coal	Cost Engineering		21D	14A
Combustion				
Electric Power Plants			10B	

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TABLE 5.46

ANNUAL COST SUMMARY
(Late 1982 Estimates)[a]

Plant Name: Smith
Plant Location: Bay County, Florida
Utility Name: Gulf Power Company

Operating Load Factor (percent): 70
Nameplate Generating Capacity (MW): 340
Waste Generation (dry metric tons/yr):
Fly Ash -109,000
Bottom Ash - 12,500

WASTES	ANNUAL COSTS ($1000) Fly Ash	Bottom Ash	Coal Pile Runoff and Plant Wastes	Total
MODULE				
• Waste Handling and Processing				
- System Exclusive of Recycle Water System	$ 275.9	$ 144.9	$ -	$ 420.8
- Recycle Water System	211.5	23.5	-	235.0
• Waste Transport	535.4	257.8	-	793.2
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	1,435.3	159.4	-	1,594.7
SUBTOTAL MODULAR COSTS	$2,458.1	$ 585.6	$ -	$3,043.7 ($25.10/dry metric ton)
RELATED ENVIRONMENTAL SYSTEMS				
• Miscellaneous Plant Waste Handling and Transport Systems	$ -	$ -	$ 690.3	$ 690.3
• Air Pollution Control	NA[b]	-		NA[b]
TOTAL ANNUAL COSTS	$2,458.1 +NA[b]	$ 585.6	$ 690.3	$3,734.0 +NA[b]

[a] ENR Cost Index 3931.11 (1913=100)
365.97 (1967=100)

[b] NA = Information not available.

Source: Arthur D. Little, Inc. estimates.

Annual costs developed for the Smith Plant waste handling and disposal operation are presented in detail in Table G-24, Appendix G and are summarized in Table 5.46. The unit cost for the Smith Plant ($25.10/dry metric ton) is very close to those of the remaining two study sites, (Allen, $23.70/dry metric ton and Sherburne County, $26.60/dry metric ton) even though these plants are significantly larger and would be expected to exhibit more significant economies of scale. However, the added capital charges for the pond liner at the Sherburne County Plant and the more complex waste handling system at Plant Allen are considerable and overshadow the expected differences. While the difference in unit costs for the Smith Plant and Plant Allen do not differ greatly, they do, however, follow the general trend of economies of scale.

For all study sites practicing pond disposal (the Allen, Sherburne County and Smith Plants), the annual cost for the waste placement and disposal module ranges from 45 to 55 percent of the total annual cost. The next major annual cost element at these plants is the waste transport module, which averages roughly 25 to 30 percent of the total waste handling and disposal costs.

TABLE 5.45

CAPITAL COST SUMMARY
(Mid. 1982 Estimates)[a]

Plant Name: Smith
Plant Location: Bay County, Florida
Utility Name: Gulf Power Company
Nameplate Generating Capacity (MW): 340

WASTES	CAPITAL COSTS ($1000) Fly Ash	Bottom Ash	Coal Pile Runoff and Plant Wastes	Total
MODULES				
• Waste Handling and Processing				
– Exclusive of Recycle Water System	$ 964	$1,002	$ –	$1,966
– Recycle Water System	795	88		88
• Waste Transport	1,882	560	–	2,442
• Waste Placement and Disposal (Includes Site Monitoring and Reclamation)	9,476	1,052	–	10,528
SUBTOTAL MODULAR COSTS	$13,117	$2,702	$ –	$15,819 ($47/KW)
RELATED ENVIRONMENTAL SYSTEMS				
• Miscellaneous Plant Wastes Handling and Transport	–		3,109	3,109
• Air Pollution Control	33,122	–	–	33,122
TOTAL CAPITAL COSTS	$46,239	$2,702	$3,109	$52,050 ($153/KW)

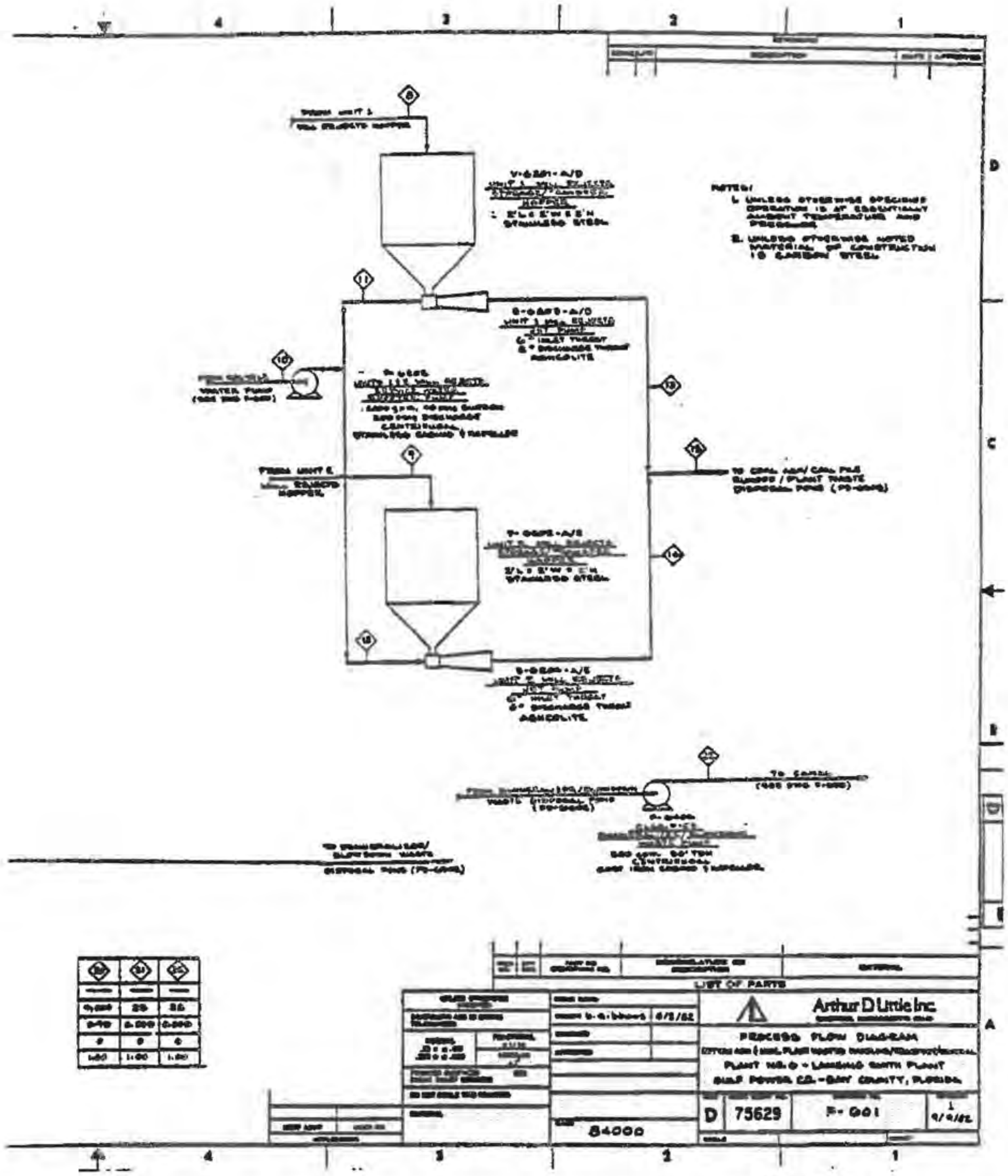
[a] ENR Cost Index = 3931.11 (1913=100)
365.97 (1967=100)

Source: Arthur D. Little, Inc. estimates.

TABLE 5.44

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR
SMITH PLANT
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES	
Power Plant	
Plant Size (MW)	34[illegible]
Boiler Type	Pulverized Coal
Heat Rate (M joules/kWh; Btu/kWh)	12; 11,40[illegible]
Location	Florida
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	[illegible]
Waste Generated (dry basis)	
Fly Ash/Bottom Ash Ratio	90/10
Fly Ash Generation (metric tons/yr; tons/yr)	109,000; 120,000
Bottom Ash Generation (metric tons/yr; tons/yr)	12,500; 13,600
FGD Waste Generation (metric tons/yr; tons/yr)	--
Ash Utilization	None
Coal Properties	
Coal Type	Bituminous
Sulfur Content (Percent)	[illegible]
Ash Content (Percent)	1[illegible]
Heating Value (M joules/kg; Btu/lb)	27.[illegible], 11,60[illegible]
Air Pollution Control	
Particulate Control	Cold-Side ESP's Hot-Side ESP's
Particulate Removal (Percent)	99
Sulfur Oxides Control	None
Disposal Site	
Type	Pond
Design Life (yr)	30
Land Area (m^2; acre)	1,214,[illegible]00; 30[illegible]
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; [illegible].15 m top soil; reseeding
Liner (type; m; ft)	None
Distance from Plant (km; mile)	< 0.40; [illegible].25


LIST OF PARTS
Arthur D Little Inc
PROCESS FLOW DIAGRAM
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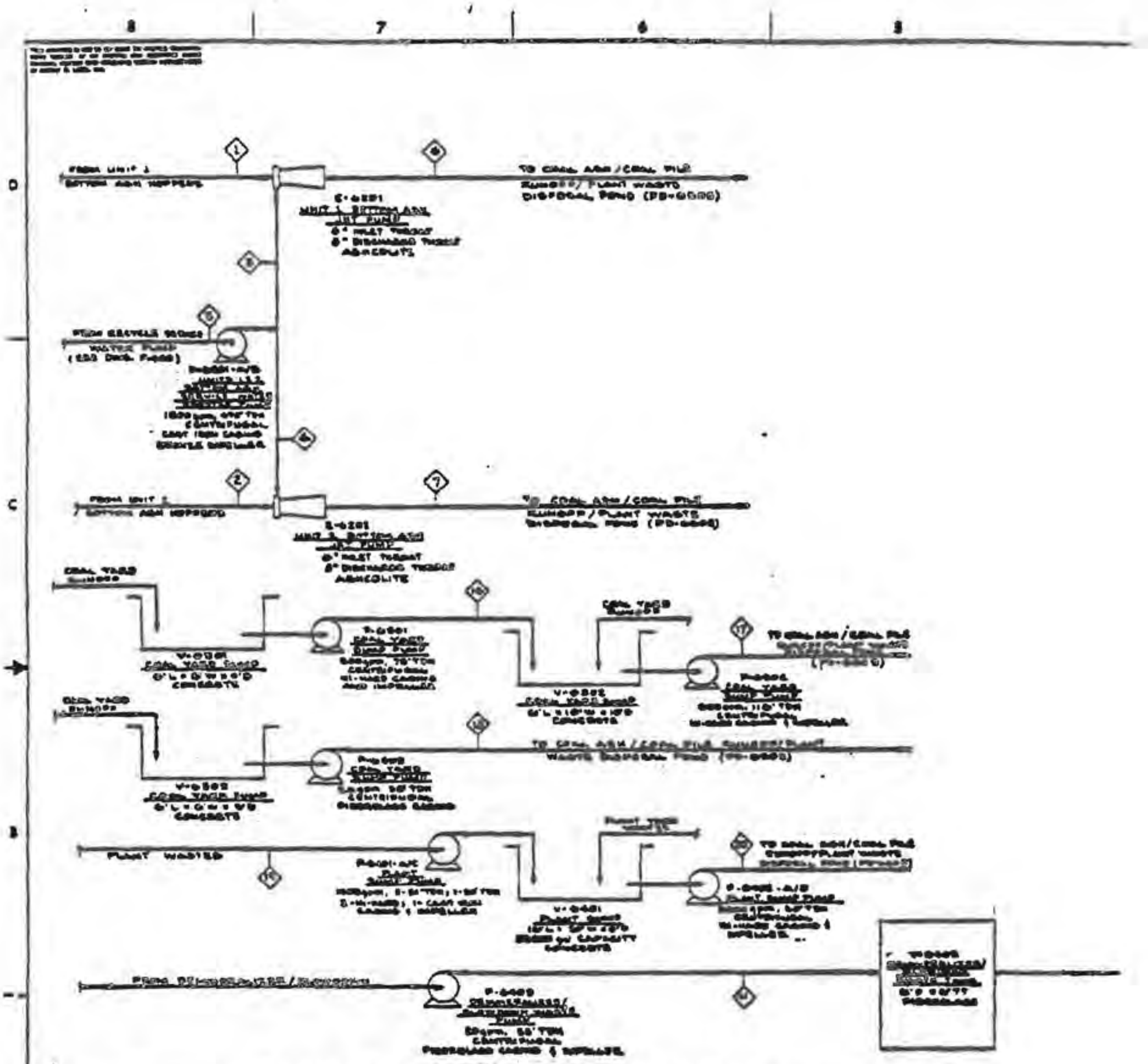
84000

FIGURE 5.52

- Doc. Ex. 8636 -



DESIGN CONDITIONS - TOTAL STREAM FLOW PER 24 HOUR DAY, FULL LOAD

STREAM NO. / ITEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
TONS SOLIDS/DAY	[illegible]	[illegible]	—	—	—	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—	[illegible]	[illegible]	[illegible]	—	—	—	—
TONS WATER/DAY	—	—	[illegible]	[illegible]	2,700	1,190	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MGPD	—	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% SOLIDS	100	100	0	0	0	[illegible]	[illegible]	100	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPECIFIC GRAVITY	[illegible]	[illegible]	1.00	1.00	1.00	1.01	1.01	[illegible]	[illegible]	1.00	1.00	1.00	1.01	1.01	1.01	1.00	1.00	1.00	1.00

FIGURE 5.52

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plant include mill rejects, which are transported to the disposal site by way of a separate pipeline. Coal pile runoff and plant wastes are also directed to the ash disposal pond. The former is transported to the pond by two pipelines. General plant wastes are transported to the pond via a separate pipeline. Process flow diagram F-601, Figure 5.52, is a process flow diagram of the bottom ash, mill rejects and miscellaneous aqueous plant wastes handling and transport system.

Disposal Operation--A single diked pond is used for disposal of coal ash and mill rejects. The dikes have been raised on three occasions by excavating ash from the dewatered placement, mixing the ash with soil, and constructing the dike extension using the admixed material. The pond is 672,200 m^2 (165 acres) in surface area and is located 365 m (1200 ft) from the plant.

Overflow from the ash disposal pond is collected in a drainage ditch and is recycled to the plant for use as ash sluicing water. Recycled water is subject to pH control using sulfuric acid.

In addition to the process descriptions and process flow diagrams provided herein, a list of area accounts (Table G-6) and a detailed equipment list (Table G-12) were developed for the Smith Plant coal ash handling and disposal system and are presented in Appendix G.

5.7.6.2 Cost Assessment--

On the basis of the engineering design information developed for the Smith site, detailed capital and operating costs were estimated for the waste handling and disposal systems. However, to provide consistency among the cost estimates developed for all of the study sites, it was necessary to specify certain engineering premises which were consistent for the six sites (e.g., plant service life, load factor, heat rate, reclamation procedure, etc.). The engineering design premises which pertain to the Smith Plant cost estimates are listed in Table 5.44.

Detailed capital cost estimates for the Smith Plant coal ash handling and disposal system are presented in Appendix G, Table G-18. A summary of these cost estimates is presented in Table 5.45. This table provides the modular capital costs for the two waste types encountered at this plant. The capital costs for the Smith Plant waste handling and disposal system, when compared to those for the other study sites, support the hypothesis that the pond disposal module comprises a significantly larger fraction of the overall system costs than does the landfill disposal module. Additionally, the Smith Plant has the highest waste handling and disposal costs ($47/kW) of the three study sites practicing pond disposal (the remaining plants exhibit unit costs as low as $36/kW). Two issues should be considered in this respect:

- the Smith Plant is relatively small and thus there is little economy of scale; and
- the Smith Plant practices water recycle which adds to the waste handling cost.

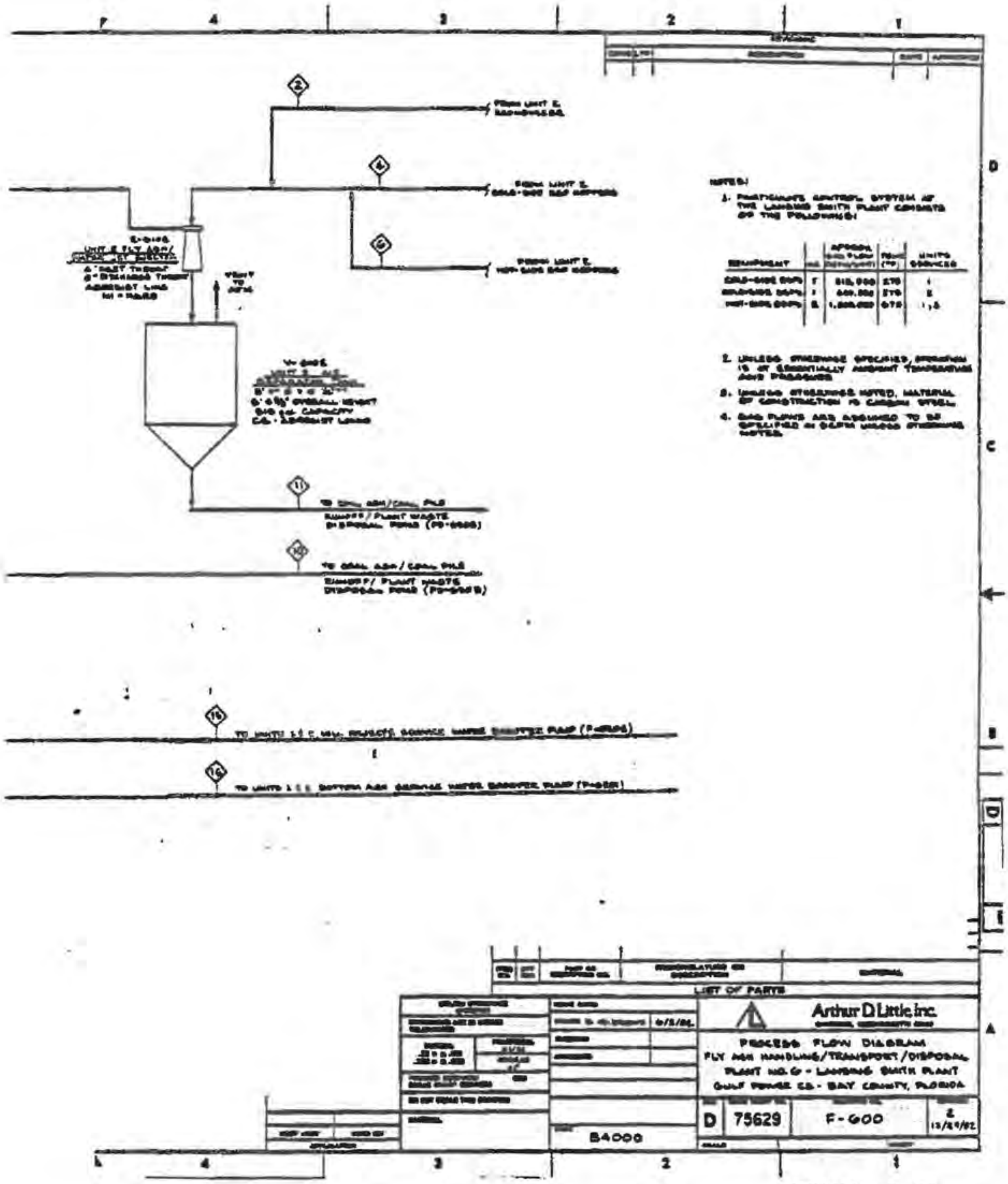
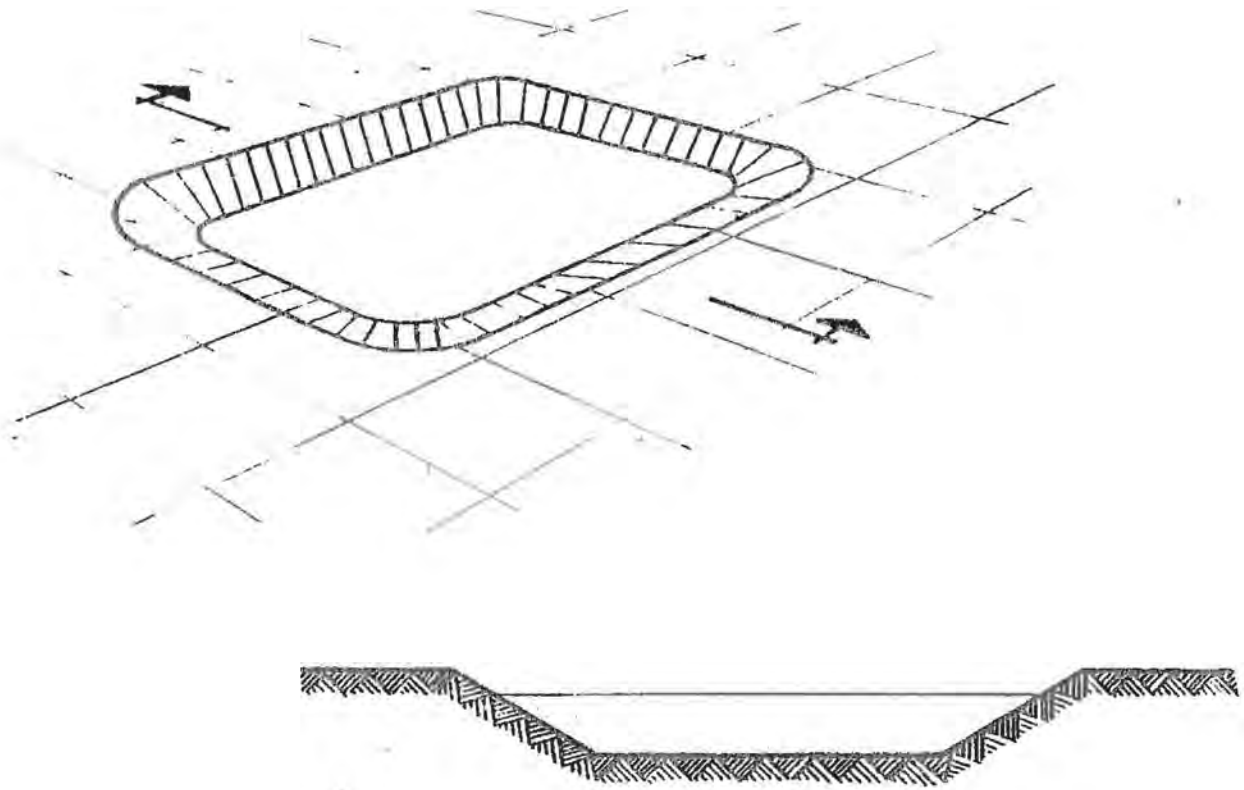

LIST OF PARTS
Arthur D Little, inc.
PROCESS FLOW DIAGRAM
FLY ASH HANDLING/TRANSPORT/DISPOSAL
PLANT NO. 6 - LANSING SMITH PLANT
GULF POWER CO. - BAY COUNTY, FLORIDA
D
75629
F-600
B4000

FIGURE 5.51



Source: Reference 17

FIGURE 6.20 AN INCISED DISPOSAL POND.

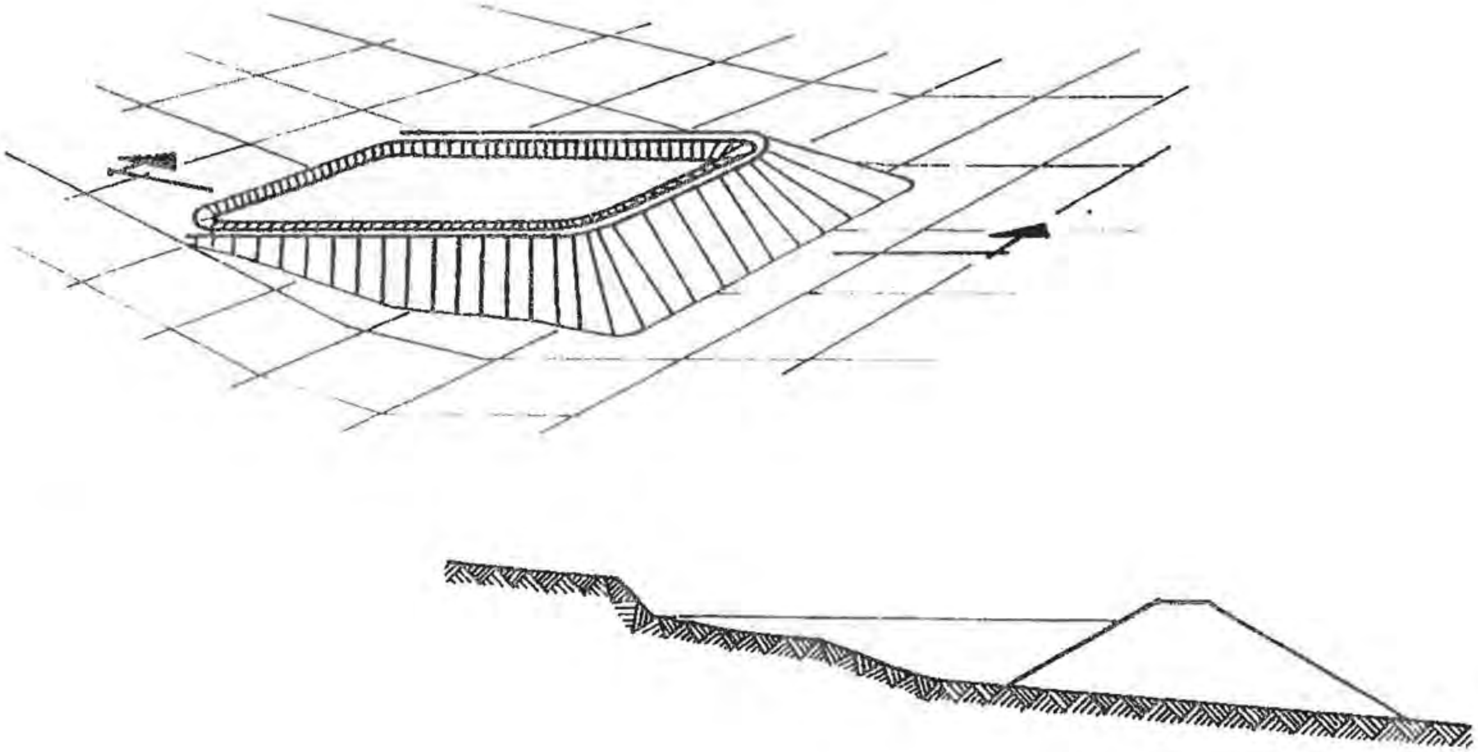


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FIGURE 6.21 A SIDE-HILL DISPOSAL POND.

- use of high quality materials of construction;
- selection of proper material zoning to ensure self-healing in the event of cracking;
- reduction in the natural drainage area to limit the volume of run-off entering the pond to ensure balance between inflow and outflow; and
- maintenance of and design provisions for a large freeboard such that the worst conceivable inflow conditions could be contained within the pond without overflowing.

Another important consideration in pond design is the control of leachate movement. The conventional approach to this problem is to site ponds in areas where the underlying soil has low permeability. Dams are constructed of borrow material with low permeability to minimize seepage. If the permeability of the wastes and the underlying soils are not sufficiently low to control seepage to desired levels, artificial liners or sealants can be employed. Where needed, the potential options for liners are:

- Cohesive borrow, if available near the disposal site, which can be placed and compacted to a suitable depth and offer a cost-effective and efficient liner.
- Clay sealants, such as bentonite mixed with granular soils, which provide acceptably low permeabilities and can be expected to self-seal in the event of a rupture. Their main drawback, however, is a high transport cost when not available locally.
- Chemical sealants can be sprayed into the soil to plug the interstices. These can be difficult to apply, but are less expensive than clay sealants in areas where swelling clays are unavailable. However, chemical sealant liners are more permeable than those of clay.
- Synthetic liners, which are the most effective liners. They are easy to install, although punctures can seriously nullify their effectiveness. Field experience with such liners in large ponds is limited.
- Stabilized FGD wastes themselves can serve as liners.

One important point with respect to constructing either of the two earth fill-type liners (cohesive borrow and/or clay sealants) is that, presuming the liner material can be compacted to achieve a coefficient of permeability of about 10^{-7} to 10^{-8} cm/sec, a minimum thickness of 0.5 to 0.6 m (18 to 24 in) should be specified. This is because even if a comprehensive quality control program is enacted, it is virtually impossible to ensure that a uniform liner thickness of less than 0.5 to 0.6 m (18 to 24 in) has been placed with current construction and compaction techniques.

No reliable data are available on the long-term effects of FGC waste leachates on disposal site liner materials. The permeability of synthetic liners is claimed to be zero, but the durability of such liners in a utility waste disposal site has not been demonstrated. Clay liners have more strength, ductility, and durability than synthetic liner materials because of their inherent plasticity and buffering capacity; however, clays possess finite permeability.

As mentioned previously, wastes are transported to ponds as slurries via pipelines. The placement of wastes in ponds entails dumping the materials into the pond at a set discharge point. This type of placement can cause an uneven buildup of waste. To overcome this problem, movable tremie raft systems are sometimes used to allow for movement of the discharge line, thereby promoting uniform buildup of the wastes on the pond floor. These systems also reduce turbidity in the reservoir water. In other instances, the discharge point for the pipeline entering the pond will physically be moved from time to time over the course of the pond's life.

Bottom ash can be segregated from fly ash and/or FGD waste and used for a variety of disposal site construction purposes. A potential use for bottom ash is in constructing drains located both below and within disposal ponds. For purposes of seepage control and stability, many substantial dikes require underdrains beneath the downstream toe of the facility to control the phreatic level within the dike. In cases where a new waste basin is being built to replace an existing facility, bottom ash might be used as borrow for the underdrain. Gradations of both the bottom ash and the dike borrow will be required to verify that the bottom ash meets acceptable filter criteria. If not, a graded sand filter or filter fabric must be placed between the bottom ash and the dike.

Another potential use for bottom ash is in the construction of dewatering drains located within ponds. Most ponds are equipped with a pipe and riser outlet system which skims the top of the pond and discharges water from the basin. Often it is difficult to control the suspended solids of the water being discharged (i.e., suspended fly ash, cenospheres, etc.). A drain can be installed on the upstream face of the dike. This drain should consist of a perforated (slotted) pipe surrounded by bottom ash. The perforated pipe connects to a solid pipe which then extends through the dike. As the waste accumulates in the basin, the lower portions of the bottom ash drain may clog with the fine waste, but the water from the pond seeps into a higher level of the bottom ash drain, into the perforated pipe and out of the basin. After abandonment, such a drain will also aid in dewatering the waste deposit. In this type of application, gradations of the bottom ash will be required to determine the size of the openings (slots) in the perforated pipe.

Most state dam safety regulations require that ash basins be equipped with the means to drain water from the basins in the event of an emergency (i.e., dike instability). Decant pipes are often installed in the lowest portion of the basin and are equipped with a riser and gates to meet this requirement. These discharge pipes are usually placed lower than the plant, making recycling of the pond water impractical. The previously described pipeline connected to the bottom ash upstream drain might have enough head to enable the pond water to be recycled by gravity back to the plant.

Deep dynamic compaction is a way to increase the density of wastes in drained disposal ponds. Utility solid wastes disposed in ponds typically do not achieve the density of similar wastes placed in landfills. Consequently, disposal of utility wastes in ponds requires a larger area than does landfill disposal of comparable quantities of waste. In addition, ponded utility wastes typically have a higher coefficient of permeability than do similar landfilled wastes. After retirement, post disposal land use of ponds is typically limited because of the soft consistency of the waste in the ponds.

Deep dynamic compaction consists of repeatedly dropping a heavy block, usually constructed of concrete, from a crane onto the area being densified. Deposits of cohesionless soil have been densified to depths as great as 9 to 12 m (30 to 40 ft) by this method. Additional disposal life can be obtained by deep dynamic compaction of previously abandoned ponds. Similarly, waste deposits adjacent to existing dikes might be densified to allow the dike to be raised by the upstream construction method and create additional disposal capacity. Finally, subsurface conditions at abandoned ponds situated in otherwise desirable areas might be improved with deep dynamic compaction to make the site suitable for development.

6.1.7.3 Landfill Disposal of Coal-Fired Utility Solid Wastes—
Dry FGC waste disposal methods can involve any one of the following operations:

- dry collection and direct landfilling of coal ash and dry sorbent FGD wastes;
- dewatering and landfilling of coal ash and FGC wastes; and
- landfilling of fixated and stabilized FGC wastes.

The exact nature of a particular operation depends on the type of waste disposed and disposal site.

Most dry disposal operations involve landfilling. Landfill design may be based on three common configurations:

- <u>The heaped landfill</u>, which is structurally the simplest form of fill. This type of landfill is typically used in areas with level terrain. Although this design offers advantages in terms of slope stability, minimal site preparation requirements, and minimized groundwater pollution, it does not blend with the surrounding terrain and is, therefore, aesthetically undesirable.
- <u>The side hill landfill design</u>, which is often used in areas of hilly terrain where the natural slope of one side of a hill or valley may provide containment. The side hill landfill must be prepared properly to ensure stability. Properly constructed, these landfills blend well with many existing terrains and can provide valuable property when reclaimed.

- The valley fill design, which is the most common type of landfill. It is often the most complex in terms of original site preparation. Natural valleys or ravines are often sources of surface water runoff and may have springs along side slopes. In such cases, surface water and groundwater control is usually necessary to avoid water accumulation and a potential leachate problem. Drainage must be provided and, in some cases, hydrologic modifications are needed to divert water flow around the landfill.

The three common landfill configurations are shown in Figures 6.22 through 6.24.

Proper landfill design requires control of both leachate movement and runoff. The former may be controlled through the use of liners such as those discussed in Section 6.1.7.2, although this is not presently a common practice. Stabilization and fixation processes reduce waste permeability, thereby reducing leachate movement. However, to achieve full environmental benefits from waste processing and compaction during placement, proper design is necessary to control runoff. Conventional runoff control practice consists of retaining runoff in temporary retention basins, thereby allowing suspended solids to settle prior to discharge or use of the overflow.

Because landfilled wastes are disposed of in essentially dry form, the physical stability measures required for disposal of wet wastes (i.e., dike construction, etc.) are not applicable. Unlike pond disposal, the focus of landfill design, then, is not on construction. Instead, operations that ensure the inherent stability of the placed wastes take precedence. In general, such operations at the landfill area involve dumping, spreading and compaction. Usually, only small sections of the landfill are worked at any one time.

Spreading equipment can include dozers, loaders, scrapers, and/or graders. Use of the crawler dozer is usually preferred, due to its firm grip regardless of weather conditions. In applying dewatered scrubber sludge to a landfill, the sludge is brought to the site and spread into thin layers which are usually less than 0.7 m (2 ft) thick. Dry coal ash is generally spread in lifts ranging from 0.3 to 1 m (1 to 3 ft). The spreading is normally confined to as small an area as possible to maximize equipment utilization and control dust or mud. In most instances, two areas will be alternately used. Trucks haul the wastes to one area while dozers spread the wastes in the second area. Lifts are built up to a total ultimate fill height which is site specific but generally may range from 9 m (30 ft) to over 25 m (82 ft).

Once the waste has been spread, it may be compacted to increase its density and strength. Various types of compaction equipment are used:

- rubber-tired rollers;
- segmented pad compactors; or
- vibratory compactors.

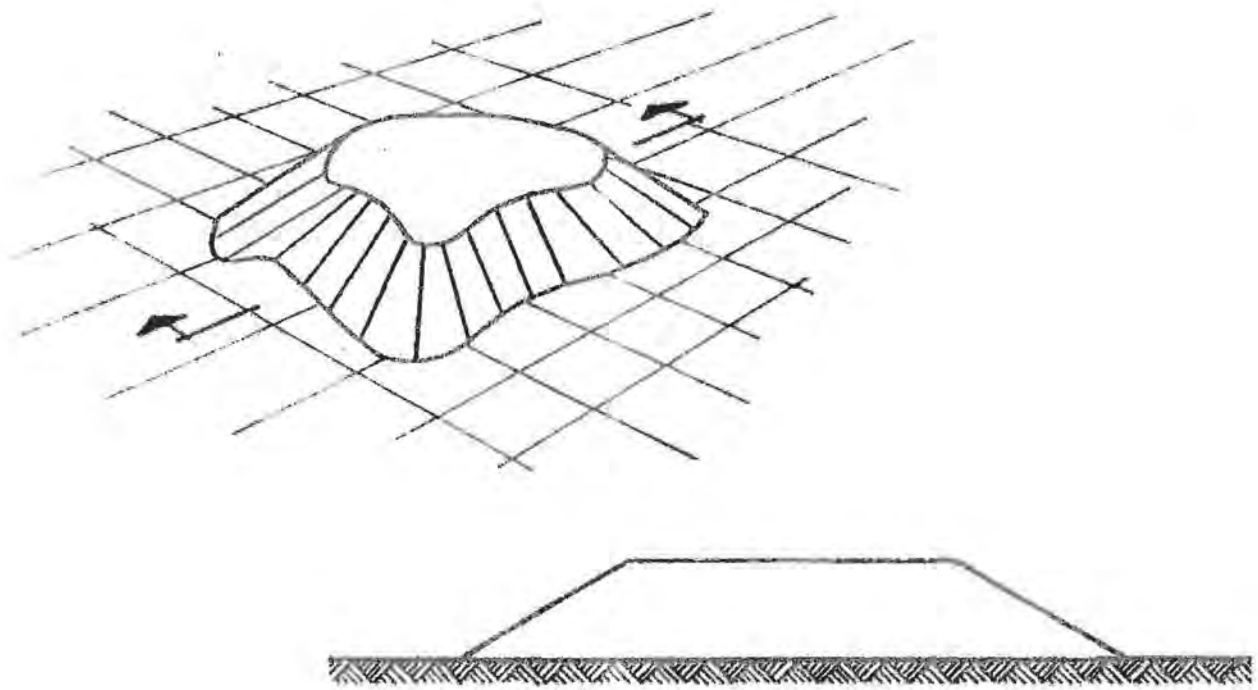

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FIGURE 6.22 A HEAPED LANDFILL CONFIGURATION.

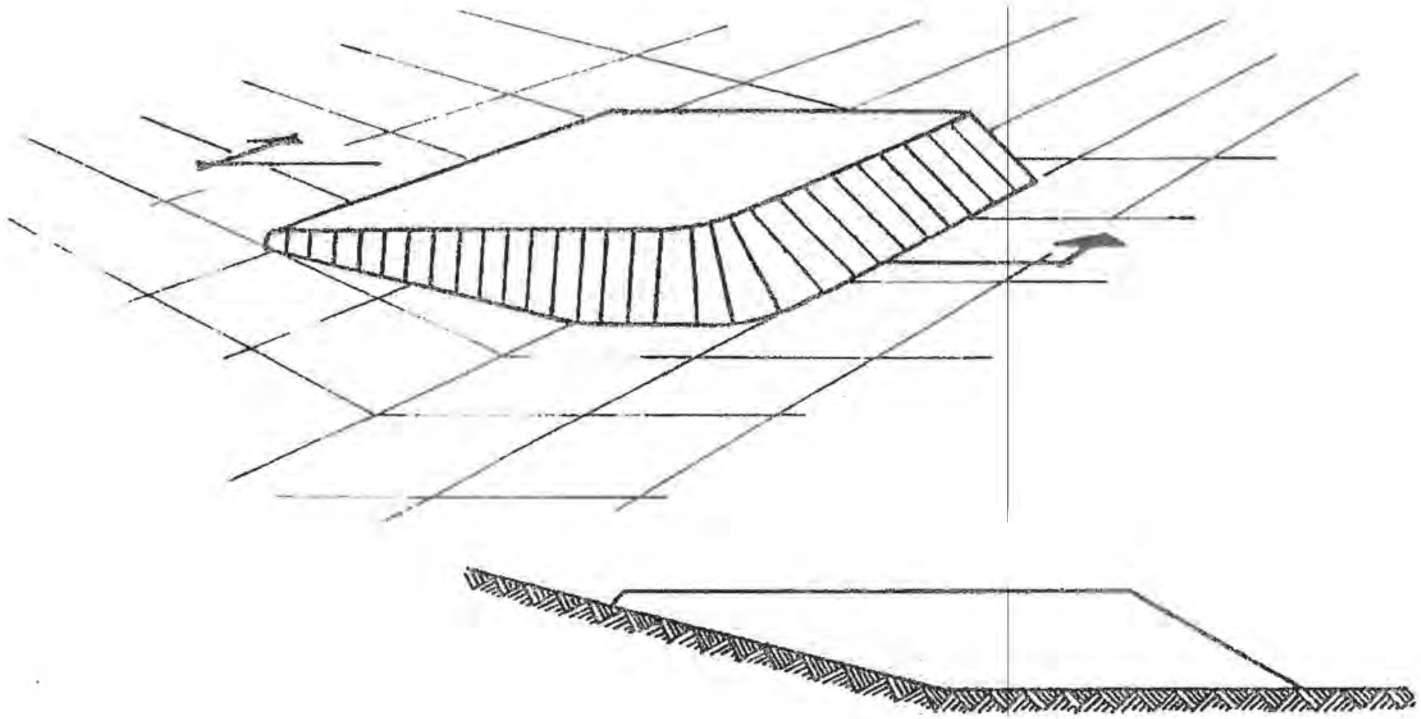

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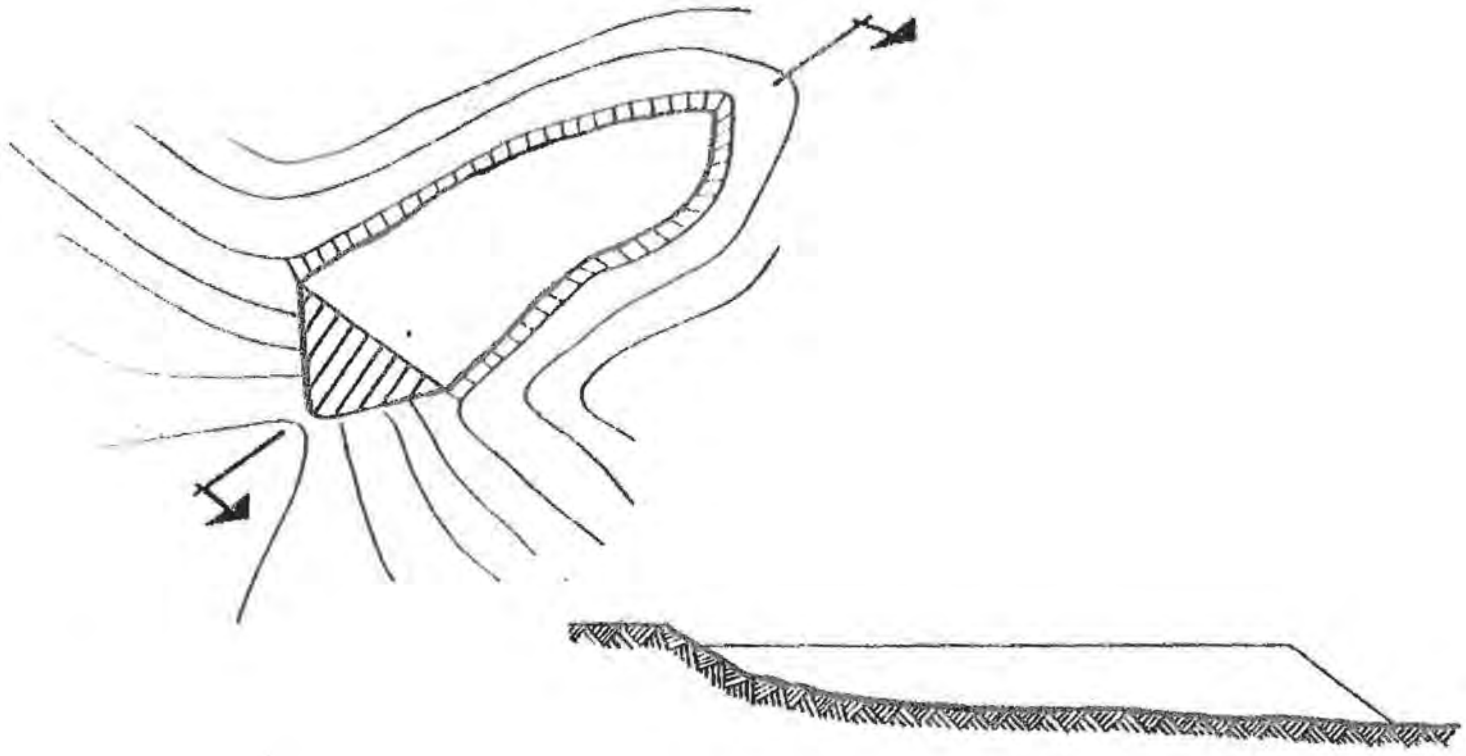
FIGURE 6.23 A SIDE-HILL LANDFILL.



Source: Reference 17

FIGURE 6.24 A VALLEY-FILL DISPOSAL CONFIGURATION.

The type of compactor is very dependent on the type of waste being landfilled. Compactors are available in both self-propelled and towed models. However, where placement rates exceed 75 kg/sec (300 tons/hr), a self-propelled model is usually preferred.

Segregating bottom ash from the FGC waste stream and using it in selected applications controls water migration from utility waste landfills. A common problem at many FGC waste landfills is natural seepage (from springs, for instance) and surface infiltration through the fills. This water often collects in pervious zones of the landfill and slowly migrates out of the fill as leachate. Placing pervious bottom ash within the lowest levels of the FGC waste fill can be an inexpensive way to create an underdrain beneath the waste deposit. Rainfall that infiltrates through the fill and water from natural seeps can be collected by the bottom ash drain and transported to the toe of the fill. At this point, the water can 'e collected and treated if necessary or otherwise discharged.

Physical instability is a potential problem for all utility wastes, including stabilized wastes. Geometric factors such as height and slope angle in a waste/ash fill are interrelated. Stability depends on the combination of fill height, slope angle, and waste properties (i.e., density, degree of saturation, effective cohesion, effective angle of shearing resistance, and behavior during shearing). For a given material, safe fill height decreases with increasing slope angle.

Underlying materials may lead to instability of a waste deposit if the stresses in those materials exceed the strength of the materials under the site-specific loading conditions (i.e., failure may occur because of the weakness of the underlying strata). Weak compressible soils would be potential problem materials in this context.

Instability problems may be ameliorated by compaction, which produces several changes: elimination of voids (between chunks, not between individual particles); increase of waste density; bonding of particles moved closer together through stabilization reactions; and increase of effective stress and residual total stress levels. The stability of settled sulfite wastes under compaction equipment will vary with the solids content of the wastes (assuming no chemical stabilitzation of wastes) and probably with the type of compaction equipment (static, rubber-tired, steel roller, sheepsfoot, vibratory, etc.). Sulfite-rich FGD wastes tested to date may be incapable of supporting compaction equipment of any kind unless high solids contents are achieved first. Liquefaction may be a more serious threat in sulfate-rich FGD wastes, especially under vibrat ry loading.

During dry periods, dust can be a problem. A water truck equipped with a rear spray bar should suffice for controlling road dust. In cold, dry climates, the use of calcium chloride crystals may be more effective.

6.1.7.4 Mine Disposal of Coal-Fired Utility Solid Wastes--

Disposal of coal-fired utility wastes in worked-out mines is receiving increased attention. Surface coal mines and underground room and pillar mines for coal, limestone, or lead/zinc ores offer potential, although coal mines, and in particular surface area coal mines, are the most likely candidates for waste disposal, since they offer the greatest disposal capacity and are frequently tied directly to power plants. Many new coal-fired power plants are "mine-mouth" (located within a few miles of the mine), with the mine providing dedicated coal supply. Since the quantity (volume) of coal ash and FGD wastes produced is considerably less than the amount of coal burned, such mines typically would provide disposal capacity throughout the life of the power plant.

Disposal of coal ash and FGD wastes in surface mines is a reasonably well developed technology, although the practice is not widespread. In general, inactive surface mines are considerably less promising than active mines for waste disposal. Unreclaimed surface mines can be used for disposal of wastes between remaining spoil banks which offer suitable sites for disposal. However, because of recent surface mine reclamation legislation, the number of sites and total capacity for wastes available in the future will be limited.

In active surface mines, there are three options for coal ash and FGD waste placement:

- in the working pit, following coal extraction and prior to return of overburden;
- in the spoil banks, after return of overburden but prior to reclamation; and
- mixed with or sandwiched between layers of overburden.

The overriding consideration with respect to disposal at active mines is that minimal disruption of mining or reclamation activities should occur. This provides a number of constraints on the disposal system. The physical condition (consistency) of the wastes must be amenable to handling, transport, and placement by earth-moving equipment, with minimal potential impact on the mining operations. For pit-bottom disposal this means that the wastes at the time of placement or immediately thereafter should have as a minimum the consistency of a soil-like material with little or no liquefaction potential. A slurry-like material, or a waste with a tendency to flow either when placed or when overburden is dumped on top of it, could present significant operational problems or unacceptably high costs for containment measures. More leeway exists for disposal in V-notches (between spoil banks); however, here again soil-like materials or relatively cohesive materials that are relatively easily handled and transported will result in the least cost and minimal disruption of reclamation activities. At the least, FGD wastes must be well filtered (55 percent solids or higher), admixed with dry fly ash, or treated.

The amount (volume) of waste disposed in any surface mine should not exceed the amount of coal removed. The objectives of strip mine reclamation include returning the mined terrain to topographic configurations similar to the original terrain. Returning significantly more waste to a mine than coal extracted could slow down the mining and reclamation activities. In most cases, this does not represent a constraint, since the wastes returned to the mine will be only those resulting from burning the coal removed. Depending on the type of coal, the particulate and sulfur oxide control system, and emission standards to be met, the volume of total dry waste will vary from less than 10 percent of the coal burned to slightly over 50 percent.

Finally, minimal use should be made of existing mine equipment for transport and placement of the wastes at the mine. Dedicated equipment is preferred and, in most cases, mandatory. In almost all scenarios, waste is most easily placed by truck dumping. The use of coal trucks for this purpose could lead to unacceptable delays in coal mining operations due to the additional time for waste loading and discharging (and possibly cleaning operations). Furthermore, most large mines use large bottom-dump trucks for coal haulage. These are designed to carry as much as 135 metric tons (150 tons) of coal and are usually constructed of aluminum. Some types of FGC waste can corrode aluminum; additionally, the bottom dumping of wastes would be impractical. Such trucks are not designed for easy maneuvering, and operating them (or any other equipment) on a freshly dumped layer of waste would be difficult. The type of truck used for transport and placement will greatly affect the quantity of waste that can be easily disposed.

Pit-bottom dumping is probably the most common, simplest, and least disruptive method of surface mine disposal. Transport and placement of the wastes is most easily accomplished with rear-dump trucks. Access to the pit floors is usually good, since roads are maintained in relatively good condition for coal mining and hauling equipment. Also, there is usually adequate time for waste placement between coal removal and overburden replacement.

Major potential problems are interference with coal removal in the working pit due to instability of adjacent spoil banks caused by the underlying wastes and the possible congestion in the working pit due to the two-truck transport systems (one for coal and one for wastes). Most of these problems are avoidable by proper scheduling of mining and disposal activities and control of waste properties and placement. In some cases, it may be advisable to concentrate waste dumping on the side of the pit farthest from the highwall (against the newly created spoil bank) to provide a region where no waste exists when the next cut is taken and the overburden dumped on the waste.

V-notch or spoil bank disposal, as with pit-bottom disposal, would involve truck dumping, and many of the constraints described above for waste characteristics and disposal operations will apply. This method involves somewhat more effort than pit-bottom disposal, since roads must be cut into the spoil banks at the base of the vees to allow access by waste trucks. This can be accomplished with relative ease in most cases with standard dozers and road-grading equipment. While it requires more effort, it may also offer some advantages in that the disposal is less likely to impact directly the coal removal operation. There is less pit congestion, less potential of creating spoil bank instability, and generally less stringent scheduling requirements. For these reasons, spoil bank disposal may often be preferred over pit-bottom disposal.

Waste disposal operations can also be adapted to allow mixing of the waste and overburden. This can be accomplished readily in contour strip mines where haulback methods are used and in some western mines where overburden is handled by truck. However, in many strip mines, mixing waste and overburden or sandwiching waste between layers of overburden may require too much additional handling of materials and place added constraints on the dragline or shovel operation. Thus, in most mines, this type of operation is not expected to be practical.

Many disposal system configurations are possible, depending on the type of waste, distance between the power plant and mine and the type of placement. In general, though, the distance between the mine and power plant is the overriding factor which dictates the amount of handling and the types of transfer facilities required.

Underground mine disposal is not presently well developed. Methods developed for backfilling certain materials (mine spoil or coal processing wastes) in active mines can presumably be modified for use with coal ash and FGD wastes. Hydraulic and pneumatic flushing of fly ash into inactive portions of active and abandoned mines has been practiced.

6.1.7.5 Monitoring of Coal-Fired Utility Solid Waste Disposal Sites--

The monitoring of an FGC waste disposal site may consist of air, surface water, and groundwater monitoring. The typical minimum number of water monitoring points are:

- Surface water
  - ash pond discharge;
  - sedimentation pond outlet;
  - upstream surface flow; and
  - downstream surface flow.

- Groundwater
  - upgradient at one point; and
  - downgradient at three points.

Surface and groundwater monitoring programs involve collecting samples from specific locations over a set period of time. In monitoring surface water, samples are taken directly from the body of water by manual or automatic means. Groundwater monitoring is usually carried out by providing access to groundwater via monitoring wells. Such wells are installed by drilling contractors. Pumping equipment, either above ground or in the well, is required to obtain samples. An alternate method of obtaining samples is with bubble samplers. Such wells incorporate two tubes, one which is pressurized with gas during sampling, thereby causing the groundwater in the second tube to be moved to the surface.

6.1.7.6 Reclamation of Coal-Fired Utility Solid Waste Disposal Sites--
It is difficult to specify the ultimate use of land on which utility waste disposal is planned or practiced. However, it is important to recognize engineering constraints on post-closure land use. Post-closure land use tends to be limited by nature of the loads created or the sensitive nature of the structures or facilities to be built on the site. For example, placement of fill in a uniform layer over the entire waste deposit is likely to be feasible, but imposition of concentrated loads (e.g., footings in a building) might cause bearing failure with rapid plunging of the loaded element into the wastes. Vibratory loads as from machinery foundations could have adverse effects on unfixated FGD wastes. The rate of application of load also is extremely important--loads applied slowly may allow consolidation of the wastes during loading, yielding higher strength than for material loaded rapidly. Rapid application of load increases shearing stresses and may decrease shearing resistance if the st.ucture of the wastes is disturbed.

Reclamation of coal ash and FGD waste disposal sites generally consists of covering the disposal site with suitable soil and/or clay materials followed by revegetation. Erosion control measures may also be taken.

Reclamation plans for coal ash and FGD waste disposal sites should be carefully formulated and account for a number of factors, including:

- federal and local effluent guidelines for sites generating point-source discharges (these standards are applicable even upon retirement of a site);
- proposed site uses following closure of the disposal site;
- surrounding land use which may affect the viability of the proposed site uses following closure;
- climatological effects which influence the selection of plant species for revegetation, planting schedules and erosion control structure;
- local vegetation which may provide insights into the types of plants suitable for use in revegetation;
- surrounding soil types which could be employed for cover material;
- water erosion, both due to raindrops and surface runoff, and the ability of proposed vegetation cover to cur'ail such effects; and
- slope lengths and gradients which may induce or reduce erosion.

The proposed post-closure uses for a disposal site will, to some extent, determine the requirement of the reclamation program. Not all sites are suitable for all possible post-closure uses, since the stability of the placement is critical to some end uses.

Three categories of soils can be used for disposal site reclamation. These include: 1) topsoil, 2) friable subsoil, and 3) low permeability cover lining materials. Of primary concern in reclamation is determination of the required soil cover depth. In some cases, state regulations mandate a minimum cover depth of 0.6 m (2 ft). At sites where such regulations are not in effect, less soil cover can be used. However, the quality of soil cover material will influence the depth required to support vegetation and, therefore, will influence the quantity required for reclamation. The cost of reclamation is highly dependent upon the quantity of soil cover required.

Typically, three layers of material are applied to the graded disposal site in the following sequence:

- an impermeable layer to serve as a protective seal preventing recharge and leachate generation (if mandated by state/local regulation or deemed necessary by the utility);
- an intermediate subsoil with good rooting characteristics; and
- an upper topsoil zone with high biological activity and nutrient content.

Most blade-type machinery may be used to spread soil cover, although care must be taken not to compact the upper two layers of soil to a density which results in poor root permeability or low soil oxygen content. The lowest soil layer, which, if required, should be impervious, should be densified as much as possible to minimize permeability. These layers should air dry following spreading but before compaction to prevent crust formation which makes plant growth difficult.

Plants for revegetation should be well adapted to site conditions; native species would, in most cases, be suitable. In cases where seeds for such plants are unavailable or prohibitively expensive, species which can inexpensively provide adequate surface coverage and which are adaptable to site soil and climate conditions can be used. Such species must be readily available and capable of propagating. Finally, plants employed for revegetation must be compatible with post-closure land use.

Following final soil cover placement, fertilizer, lime, or other soil additives may be applied to the site. Disk harrowing of the surface to a depth of 0.25 to 0.20 m (6 to 8 in) can be used to mix such additives. Seeds are planted in a uniform distribution by one of four common methods:

- broadcast,
- seed drill,
- hydroseeding, and
- aerial seeding.

Of these methods, hydroseeding is most commonly used. In this method, seed and, in some cases, fertilizer and mulch are sprayed on the surface as a slurry. Broadcast and aerial seeding are undesirable methods of seed application, since distribution is generally non-uniform. Seed drill application cannot be used on many sloping areas, but is a good method in terms of distribution and depth of the seed placement. Following seeding, mulching is commonly required to protect the area from soil erosion and to provide a good environment for germination and plant development. Hay, straw, wood chips, and other artificial materials may be used as mulching materials. With hay or straw, stabilization methods to prevent loss of the mulching materials are required. These methods include chemical binding of these materials together and crimping them to the surface to secure their position.

Runoff flow entering the reclaimed site should be limited. In some instances, a system of diversion ditches and waterways has been constructed to prevent erosion from runoff. Additionally, entrapment structures which limit the amount of sediment leaving a site, such as settling ponds, check dams, vegetative buffers, and filters, may be used.

6.2 COSTS OF COAL-FIRED UTILITY SOLID WASTE HANDLING AND DISPOSAL

6.2.1 Overview

A variety of studies have been undertaken to analyze the costs associated with handling and disposing solid wastes from coal-fired power generation. Generalized studies of FGC process technology have recently incorporated analyses of associated waste handling and disposal costs and a number of conceptual design and cost studies of these systems have been undertaken by government agencies and private organizations, notably EPA and EPRI. Additionally, evaluations of site- or system-specific solid waste handling and disposal operations have been performed by a number of utilities, engineering firms and other consulting organizations.

Unfortunately, the design and operating assumptions in these economic studies, as well as the battery limits for the disposal systems evaluated in the various studies, differ considerably. Costs are reported for a wide range of conditions: different plant sizes; different coal types; various operating load factors and plant lifes; different degrees of waste processing; and different unit cost factors and base years. In addition, cost estimates in the literature often represent hypothetical plants for which the engineering designs and cost premises underlying the cost estimates are unknown. Also, costs are generally presented in lump-sum form covering an entire waste handling and disposal facility, thereby eliminating any real use of that data when trying to estimate the cost of a generic waste handling and disposal system.

Hence, direct comparisons and use of these cost estimates for projections are difficult, at best. Consequently, until now, no one data base existed that enabled one to estimate easily, quickly and accurately the capital and operating costs of coal ash and/or FGD waste handling and disposal systems. This section provides a generic cost estimation methodology which can serve as the basis for developing these costs.

6.2.2 Capital and Operating Cost Curve Development

6.2.2.1 **Background--**

In recognition of the need for a quick, easy, and accurate method for preparing conceptual capital and operating cost estimates for the waste handling and disposal system of a proposed new coal-fired utility plant, a set of cost curves was developed as part of this project. The use of conceptual cost estimating curves is especially desirable when more detailed cost estimates are not required. The set of cost curves presented here is structured in such a way that one can estimate both the capital and annual modular costs for the handling, processing, storage, transport, and ultimate disposal of any or all of the three major wastes (i.e., fly ash, bottom ash, FGD waste) generated at coal-fired power plants. In this way, for a given combination of utility plant size (i.e., electric power generating capacity) and waste type(s), one can utilize the cost curves to estimate (late-1982 basis) the capital and operating costs for the entire waste handling and disposal system or for any of the individual corresponding process modules comprising that system.

The cost curves presented here were developed with both the engineering cost data base developed for the six disposal sites evaluated during this project (see Section 5) and engineering cost data found in the literature.

In evaluating the site-specific engineering/cost data for utilization in the development of the generic waste type process module capital and annual cost curves, it became obvious that this cost data would require adjustment. This would put the cost data developed for these six sites and the cost data found in the literature on a common basis. In other words, to the extent practicable, the cost data were adjusted to eliminate any effect caused by unusual site specific conditions. For example, in developing the generic capital cost curve for the transport of ash by sluice pipeline it was necessary to ensure that all data points (both from the open literature and our six site evaluation) were all on the same engineering design basis [i.e., a plant to disposal pond distance of 1.6 km (1.0 mile)]. This required adjusting the length of piping, number of valves, etc. and ultimately the capital cost associated with these elements for a number of case study examples.

The type of plant and/or disposal site-specific factors and conditions which had to be evaluated and adjusted to a common basis ranged from transport distances to site preparation activities. Some of the more important site-specific factors which required noting and/or adjustment before the corresponding cost data developed from the six site engineering/cost assessment could be used are summarized below:

- More complex piping was required at the Allen Plant for coal ash handling due to presence of five small units (totaling 1155 MW) in contrast to newer plants which would probably employ only two larger units (600 MW) to achieve the same generating capacity.

- The pressure (pneumatic) conveying system used at the Dave Johnston Plant utilizes atypical, expensive Nuva Feeders to feed fly ash from electrostatic precipitator hoppers into pressurized conveying lines.

- Coal ash haul trucks in use at the Dave Johnston Plant are off-the-road type which are more costly to purchase.

- Site preparation at the Dave Johnston Plant included excavating more soil than would be required for use in reclamation activities, as was not the case at other plants wi n landfill operations.

- Distance to transport coal ash and FGD wastes at the Elrama Plant (from plant to landfill) is 19.2 km (12.0 miles), while the common basis for most studies is 1.6 km (1.0 mile).

- No clearing or grubbing was required at the Elrama landfill, since this area was the site of an abandoned strip mine.

- FGD waste handling/processing at the Elrama Plant included maximum dewatering using thickeners, vacuum filters and pug mills.

- FGD waste handling/processing at the Sherburne County Plant included less dewatering using thickeners.

- Distance to transport coal ash and FGD wastes at the Sherburne County Plant (from plant to ponds) is 0.4 km (0.25 mile), while the common basis used is 1.6 km (1.0 mile).

- Coal ash and FGD waste disposal ponds at the Sherburne County site are clay-lined.

- Coal ash landfill (gravel pits) at the Powerton site are lined with Poz-O-Pac®.

- Bottom ash handling/processing at the Powerton Plant includes dewatering bins.

- Coal ash and FGD handling system at the Sherburne County site includes a supernatant recycle system.

- The coal ash handling system at the Smith plant includes a supernatant recycle system.

- Distance to transport coal ash at the Smith Plant (from plant to pond) is 0.4 km (0.25 mile), while the common basis used is 1.6 km (1.0 mile).

- The fly ash to bottom ash ratio for the Powerton Plant is 40/60, because cyclone-fired boilers are used. Pulverized coal-fired boilers generally result in a 80/20 fly ash to bottom ash split.

All these factors were evaluated and often resulted in adjustments being made, when practicable, to various process module capital and annual costs. Following the adjustments, both the unadjusted and adjusted data points were used to develop and then evaluate the generic curves and their band.

Waste disposal cost data in the literature were compiled, evaluated, and adjusted, to the extent practicable, and updated to late-1982 dollars (to put them on the same basis as data developed for the six study sites). Table 6.4 lists the sources of cost data that were utilized. While the cost data found in the literature were adjusted to put all data on a common basis, the data were obtained from many different studies, all of which used many different assumptions. Taken collectively, however, the various cost data can be and were used to determine the approximate, overall range of costs expected for the handling and disposal of utility wastes. This was accomplished by plotting the appropriate cost data and using a combination of engineering judgement and the mathematical method of least squares curve fitting to obtain the most appropriate curve with the best fit for the given data. These curves are presented as bands which incorporate the variations in costs due to system variations. In some cases, due to a paucity of cost data, it was not possible to define the exact limits of the cost curve bands. In these cases a conservative approach was taken in which variations were compared to those of other systems and a conservative factor applied to the curve fit by the least squares method.

This simplified method for determining utility waste disposal system costs is intended to provide conceptual cost estimates which have accuracy limits of plus 30 percent and minus 10 percent; these should never be substituted for more detailed estimates prepared from a site-specific engineering cost data base. At the level of accuracy for which conceptual estimates are intended to be used, effects due to such site-specific factors as geology, soil conditions, terrain, land availability, local labor rates, etc., are not specifically addressed. Consequently, it should be recognized that this simplified cost estimating procedure is a tool for planning purposes where the effects of such site-specific conditions have a less significant impact on the desired cost accuracy.

The basic engineering design and economic premises for which these curves are applicable are summarized in Tables 6.5 and 6.6, respectively. From Table 6.5, it can be seen that the cost curves presented are applicable for estimating the capital and operating cost (within the accuracy limits noted above) for the waste handling and disposal of fly ash, bottom ash and/or FGD waste from new coal-fired utility plants with generating capacities ranging from 200 to 3,000 MW. The boiler is assumed to be of the pulverized coal-fired (dry bottom) type which produces a fly ash/bottom ash ratio of 80/20. The ash and sulfur contents of coal employed range from 12 to 15 percent and 0.5 to 3.5 percent, respectively. Particulate removal is accomplished by ESPs, and sulfur oxides removal is attained by conventional

TABLE 6.4

SUMMARY LISTING OF FGC WASTE DISPOSAL ENGINEERING COST STUDIES UTILIZED IN DEVELOPING COST CURVES

		Waste Types Evaluated			Disposal Options Evaluated			Reference No.
Contractor	Sponsor	Coal Ash	FGD Waste	Coal Ash & FGD Waste	Pond	Landfill	Mine	
Arthur D. Little, Inc.	EPA	✓	-	✓	✓	✓	-	-
Arthur D. Little, Inc.	EPA	-	-	✓	-	-	✓	5
Aerospace Corp.	EPA	-	-	✓	✓	✓	-	49
Aerospace Corp.	EPA	-	-	✓	✓	✓	-	50
Aerospace Corp.	EPA	-	-	✓	✓	✓	-	16
Environmental Research & Tech., Inc.	EPRI	✓	-	✓	-	-	✓	51
Engineering Science	DOE	✓	-	✓	✓	✓	✓	52
GAI Consultants, Inc.	EPRI	✓	-	-	✓	✓	-	21
Michael Baker Jr., Inc.	EPRI	✓	-	✓	✓	✓	✓	53
Michael Baker Jr., Inc.	EPRI	-	-	✓	✓	✓	-	17
Michael Baker Jr., Inc.	EPRI	-	-	✓	✓	✓	-	54
Tennessee Valley Authority	EPA	✓	-	-	✓	✓	-	55
Tennessee Valley Authority	EPA	-	-	✓	✓	-	✓	56
Tennessee Valley Authority	EPA	-	-	✓	-	✓	-	57
Tennessee Valley Authority	EPA	-	-	✓	✓	✓	-	58

Source: Arthur D. Little, Inc.

TABLE 6.5

SUMMARY OF BASIC ENGINEERING DESIGN PREMISES FOR GENERIC COST CURVES
FGC WASTE HANDLING AND DISPOSAL

ENGINEERING DESIGN PREMISES	
Power Plant	
New or Retrofit	New
Plant Size (MW)[a]	200-3000
Boiler Type	Pulverized Coal-Fired Dry Bottom
Heat Rate (M joules/kWh; Btu/kWh)	10-12; 9,750-11,400
Location	United States
Service Life (yr)	30
Load Factor (Lifetime Average Percentage)	70
Fly Ash/Bottom Ash Ratio	80/20
Coal Properties	
Sulfur Content (Percent)	0.5-3.5
Ash Content (Percent)	12.0-15.0
Heating Value (M joules/kg; Btu/lb)	22.0-26.7; 9,500-12,000
Air Pollution Control	
Particulate Control	ESPs
Particulate Removal (Percent)	>99
Sulfur Oxides Control	Conventional Lime Scrubber with or without Forced Oxidation
Alkali Stoichiometry	1.1
SO_2 Removal (Percent)	>70
Disposal Site	
Type	Pond/Landfill
Design Life (yr)	30
Terrain	Level
Groundwater Monitoring Wells (Number)	6
Reclamation (Closure)	0.45 m cover soil; 0.15 m top soil; reseeding
Liner	None
Distance from Plant (km; miles)	1.6; 1.0

[a] Large plants employing multiple 500 MW units.

Source: Arthur D. Little, Inc. estimates.

TABLE 6.6

SUMMARY OF BASIC ECONOMIC PREMISES FOR GENERIC COST CURVES
FGC WASTE HANDLING AND DISPOSAL

Economic Premises	
Year of Capital and Annual Cost Estimates	Late-1982
Capitalization of Site Construction (Percent)	100
Capitalization of Site Reclamation (Percent)	100
Capital Charge Factors[a]	
• Process Equipment and Disposal Site	0.147
• Mobile Equipment	0.280[b]
• Reclamation	0.035
System Battery Limits	Waste Handling/Processing to Ultimate Disposal
Land Cost ($/m^2; $/acre)	0.79; 3200

[a]These capital charge factors were employed in the preparation of the first year annual costs for the six study sites and in the adjustments made to cost data found in the literature, when practicable.

[b]The capital charge factor for mobile equipment includes an allowance for interim replacement.

Source: Arthur D. Little, Inc., estimates.

lime or lime/forced oxidation scrubbing. Disposal options include both ponding and landfilling, with a distance of 1.6 km (1 mile) between the plant and the disposal site. The disposal site proper, whether a pond or landfill, will include a total of six groundwater monitoring wells. In addition, the waste placement/disposal module will include the cost for site reclamation, which will entail covering the pond(s) (naturally dewatered) and/or landfill(s) with 0.45 m (1.5 ft) of cover soil followed by 0.15 m (0.5 ft) of top soil with subsequent seeding and mulching.

The most important economic premises (in Table 6.6) to note include the following:

- Both capital and annual costs are reported in late-1982 dollars.
- Annual capital charges for process equipment and the disposal site were taken as 14.7 percent of the total capital investment.
- Annual capital charges for mobile equipment were taken as 28.0 percent of the total capital investment (wherever practicable).
- Annual capital charges for reclamation were taken as 3.5 percent of the total capital investment.
- Capital costs include 100 percent capitalization of site construction and site reclamation.
- The system battery limits begin at in-plant waste handling and go up to and include the placement and ultimate disposal of the waste.

Factors for capital charges were determined using the methods proposed by the Electric Power Research Institute (EPRI)(43). These methods are discussed below.

6.2.2.2 Process Equipment/Disposal Site--

Capital charges for the coal ash and FGD waste handling and disposal system (exclusive of mobile equipment and disposal site reclamation) were assumed to be 14.7% of the total capital investment on the basis of a 30-year operating life. The capital charge factor was calculated as follows:

• Total Return (Weighted Cost of Capital)	10.00%
• Book Depreciation (Sinking Fund)	0.61%
• Allowance for Retirement Dispersion	0.56%
• Levelized Annual Income Tax	4.70%
• Levelized Annual Accelerated Depreciation Factor	(2.47)%
• Levelized Annual Investment Tax Credit	(0.77)%

- Property Taxes, Insurance, etc. 2.00%

LEVELIZED ANNUAL FIXED CHARGE RATE* 14.63%→14.7%

6.2.2.3 Mobile Equipment--

Mobile equipment capital charges were calculated to be 28%, based on a 10-year mobile equipment life. This took into account the need for interim replacement of mobile equipment within the 30-year operating life of the plant.

The EPRI Technical Assessment Guide discusses interim replacements (pp. VII-2, VII-3 and VII-19, Reference 43). The approach outlined in the EPRI guide and that used in this study result in identical capital charges for mobile equipment, although the means of calculating these differs slightly.

EPRI defines an equivalent capital cost as:

$$EC = BPC + (F)(CR) \qquad (1)$$

where:

EC = equivalent capital cost

BPC = cost of plant that is not affected by interim replacement

CR = cost of plant that requires interim replacement

F = factor that puts all plant capitalization on a common time basis

In this case capital charges are calculated as:

$$CC = (X)(EC) \qquad (2)$$

where:

CC = capital charges

X = capital charge factor for total plant life

Alternatively, a capital charge factor for interim replacements was defined separately from the factor for items that have lives equal to the plant life. This factor was defined as:

$$XR = (X)(F) \qquad (3)$$

where:

*Based on 30-year book life and 20-year tax life. Flow through accounting used. (See page V-9, Reference 43.)

XR = capital charge factor for items that require interim replacement

In this case, capital charges were calculated as:

$$CC = (X)(BPC) + (XR)(CR) \quad (4)$$

This equation is equivalent to equation (2) when the expression for EC is substituted:

$$CC = (X)(EC)$$

$$= (X)\ [BPC + (F)(CR)]$$

$$= (X)(BPC) + (X)(F)(CR)$$

$$= (X)(BPC) + (XR)(CR) \quad (5)$$

Thus, the annual costs for mobile equipment used in this study are consistent with the EPRI Guide (43).

Further, F is defined as:

$$F = \left[\frac{CRF\ (r,N)}{CRF\ (r,LR)}\right] \left[\frac{FCR_R}{FCR_P}\right] \times \left\{1 + \sum_{p=1}^{n_r-1} \left[\frac{(1+i)}{(1+r)}\right]^{P \times LR}\right\} \quad (6)$$

where:

CRF = capital recovery factor at discount rate, r for life, N = plant life or LR = replacement life

FCR_j = fixed charge rate for j, j = R or P

R = interim replacement

P = plant

i = inflation rate

r = discount rate

(p.VII-9, Reference 43)

In this case:

$$F = \left(\frac{0.1061}{0.1627}\right) \left(\frac{0.19}{0.14}\right) \left\{1 + \left(\frac{1.06}{1.10}\right)^{10} + \left(\frac{1.06}{1.10}\right)^{20}\right\} \quad (7)$$

and

$$XR = (0.147)\ (1.9) = 0.28 \rightarrow 28\% \qquad (8)$$

6.2.2.4 Reclamation--

Capital charges for reclamation were estimated as the annual annuity payment (assuming 10% earnings on investment) required to produce a fund sufficient to pay for reclamation costs inflated over the 30-year life of the disposal site. The annual payment, estimated at 3.5% of the total capital cost for reclamation, was calculated as follows:

$$F = P\ (1 + i)^N \qquad (9)$$

where:

F = future cost of reclamation in year, N

N = life of plant

P = present value of plant

i = inflation rate

In order to produce a fund of magnitude, F, at the end of the plant's servicer life an annuity paid annually is required:

$$A = F \left(\frac{r}{(1 + r)^N - 1} \right) \qquad (10)$$

where:

r = rate

N = duration of payments

Equations (9) and (10) can be combined to yield:

$$A = P\ (1 + i)^N \left(\frac{r}{(1 + r)^N - 1} \right) \qquad (11)$$

The capital charge factor, then, is the factor that when applied to the present value of reclamation yields an annual cost (i.e., an annuity) that can be invested to yield the desired fund at the end of the plant's service life. In this case the factor, Z, is:

$$Z = (1 + i)^N \left(\frac{r}{(1 + r)^N - 1} \right) \qquad (12)$$

For our study:

$$Z = (1 + 0.06)^{30} \left(\frac{0.10}{(1 + 0.10)^{30} - 1} \right) \qquad (13)$$

$$Z = 0.035 \rightarrow 3.5\%$$

6.2.3 Capital and Annual Cost Curves

Capital cost curves in late-1982 dollars, with a range of absolute accuracy of plus 30 percent and minus 10 percent, were developed. As previously noted, the cost curves presented here are based on two primary data bases: (1) the engineering cost data base developed for the six waste disposal sites evaluated during this project; and (2) engineering/cost data available in the open literature. Of these two data bases, more emphasis and a higher level of confidence was placed on the data resulting from the evaluation of the six waste disposal sites, since these estimates were based on detailed process descriptions, process flow diagrams, material balances, equipment lists, and equipment specifications. Most engineering information was developed during site visits and through contacts with plant personnel who provided engineering data, as explained in Section 4.

The total fixed capital investment includes direct capital investment for equipment, installation and service facilities; piping and insulation; transport lines; foundations and structures; site preparation and earthwork; roads; electrical and instrumentation; buildings and mobile equipment (trucks and earthmoving equipment). Materials, labor/fabrication and installation costs are also included.

The total capital investment also includes indirect capital investment. Indirect capital investment is comprised of items such as contractor's overhead, contractor's profit, engineering design and supervision, architect/engineering fee, allowance for start-up, and contingency. The total capital investment consists of the total fixed investment plus allowances for start-up modifications and the cost of land, site monitoring and site reclamation activities.

First year annual cost estimates in late-1982 dollars were developed on the basis of 6,100 hours per year of operation at full load. First year annual costs include both direct and indirect costs. Direct costs are the cost for such items as: raw materials, utilities (i.e., process water, electric power, diesel fuel and chemicals), operating expenses (e.g., operating and mobile equipment labor, supervision and maintenance materials and labor, etc.), and subcontracted items (e.g., pond dredging). Indirect costs include such items as payroll and plant overhead expenses and capital charges.

Generic capital and annual cost curves were developed for the various waste types and process modules discussed in Section 6.1. Due to the wide number of system design variations available within any given module, it was, in some cases, appropriate to provide more than one curve for certain waste type and module combinations. Even with such provisions, each curve presented represents the costs of a set of system designs. Thus, a band of costs, rather than a single cost curve applies. The remainder of this section presents the generic cost curves and discusses the engineering premises for each of the curves and the effect of process variations on costs.

Capital cost curves (capital cost versus power plant size, MW) were developed for fly ash and bottom ash handling and disposal; similar curves (capital cost versus FGD waste generation, metric tons) were developed for the handling and disposal of FGD waste. Cost curves for the handling and disposal of FGD wastes were plotted with capital cost versus FGD waste generation rate rather than power plant size. This is because FGD waste generation rates vary widely for any given plant size; therefore, the cost of FGD waste handling and disposal is too dependent on the sulfur content of coal used for any one plant size to have a meaningful cost relationship in terms of plant size. Similarly, annual cost curves (annual cost versus power plant size, MW, and annual cost versus ash generation, metric tons/year) were developed for fly ash and bottom ash waste handling and disposal; in addition, cost curves (annual cost versus FGD waste generation, metric tons/year) were developed for the handling and disposal of FGD waste. For the same reason as mentioned above, cost curves for the handling and disposal of FGD waste were not developed in terms of annual cost versus plant size, MW.

Fly Ash Handling and Processing

For the purpose of developing generic cost curves, we identified three process design variations for fly ash handling and processing:

- wet handling of fly ash without recycle of supernatant;
- wet handling of fly ash incorporating supernatant recycle; and
- dry fly ash handling.

It was necessary to segregate the wet and dry fly ash handling options, since the design criteria and costs of these vary significantly and a single cost band could not account for the cost differences between these two options. Additionally, the use of supernatant recycle systems in conjunction with wet fly ash handling also impacts design requirements and system costs. Thus, it was appropriate to develop costs for these two options separately.

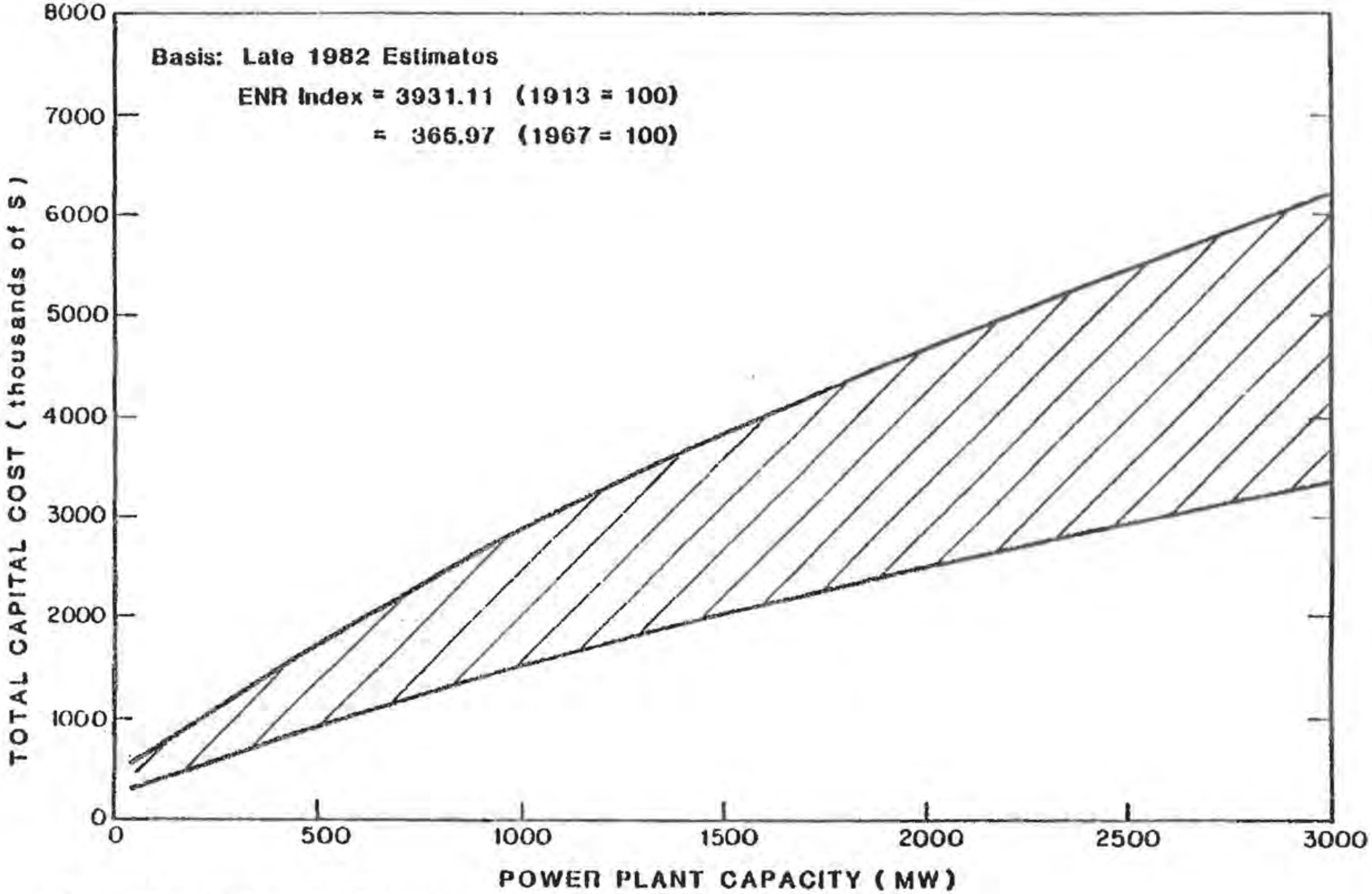
Cost differences for fly ash handling also arise within each of the three options noted above. Considering wet fly ash handling, exclusive of recycle provisions, system design (and thereby cost) variations arise primarily as a result of differences in fly ash collection modes (i.e., wet collection by scrubbers versus dry collection by ESPs and baghouses). In many wet collection systems, fly ash and FGD waste are collected simultaneously. In such systems the water processing (i.e. dewatering) requirements are dictated primarily by the presence of FGD wastes rather than by the fly ash itself; in many cases fly ash in these systems undergoes significantly more processing than would typically be required. Costs for such processing is relatively expensive, both in terms of capital and annual expenditures. This cost assessment does not address fly ash dewatering , either by interim ponding or the employment of mechanical dewatering devices (e.g., thickeners), due to the paucity of available cost data for such systems. It is important to note, however, that the use of interim ponds for dewatering fly ash is not widely practiced. Also, use of this practice is not expected to grow in the future. Additionally, fly ash is typically only dewatered via mechanical dewatering devices when collected simultaneously with FGD waste. At the present time, the simultaneous collection of fly ash and FGD waste (e.g., in the case of fly ash alkali scrubbing) is not a common practice and is not expected to grow significantly in the future.

Wet handling systems for fly ash collected by scrubbers, exclusive of any dewatering provisions, are relatively less costly than those for dry wastes, since such systems do not require the slurrying equipment required for wet handling of dry wastes. In general, the cost of simpler wet fly ash handling systems (e.g., handling of fly ash collected in scrubbers without dewatering) would be expected to fall in the lower ranges of the cost curve band, while more complex systems (e.g., vacuum pneumatic conveying of dry fly ash to a slurrying device) would exhibit costs in the higher regions of the band. Figures 6.25 (capital costs), 6.26 and 6.27 (annual costs) provide generic cost curves for wet fly ash handling where no supernatant recycle is practiced.

The discussion of costs for wet fly ash handling systems with supernatant recycle closely parallels that for similar systems which do not include recycle provisions. The only major difference between these two types of systems is the recycle system which is, itself, relatively simple in design and has few design alternatives. Thus, the discussion in the preceding paragraph details the major concerns with respect to the cost curves for fly ash handling systems which incorporate supernatant recycle; these curves are provided as Figures 6.28 (capital costs), 6.29 and 6.30 (annual costs).

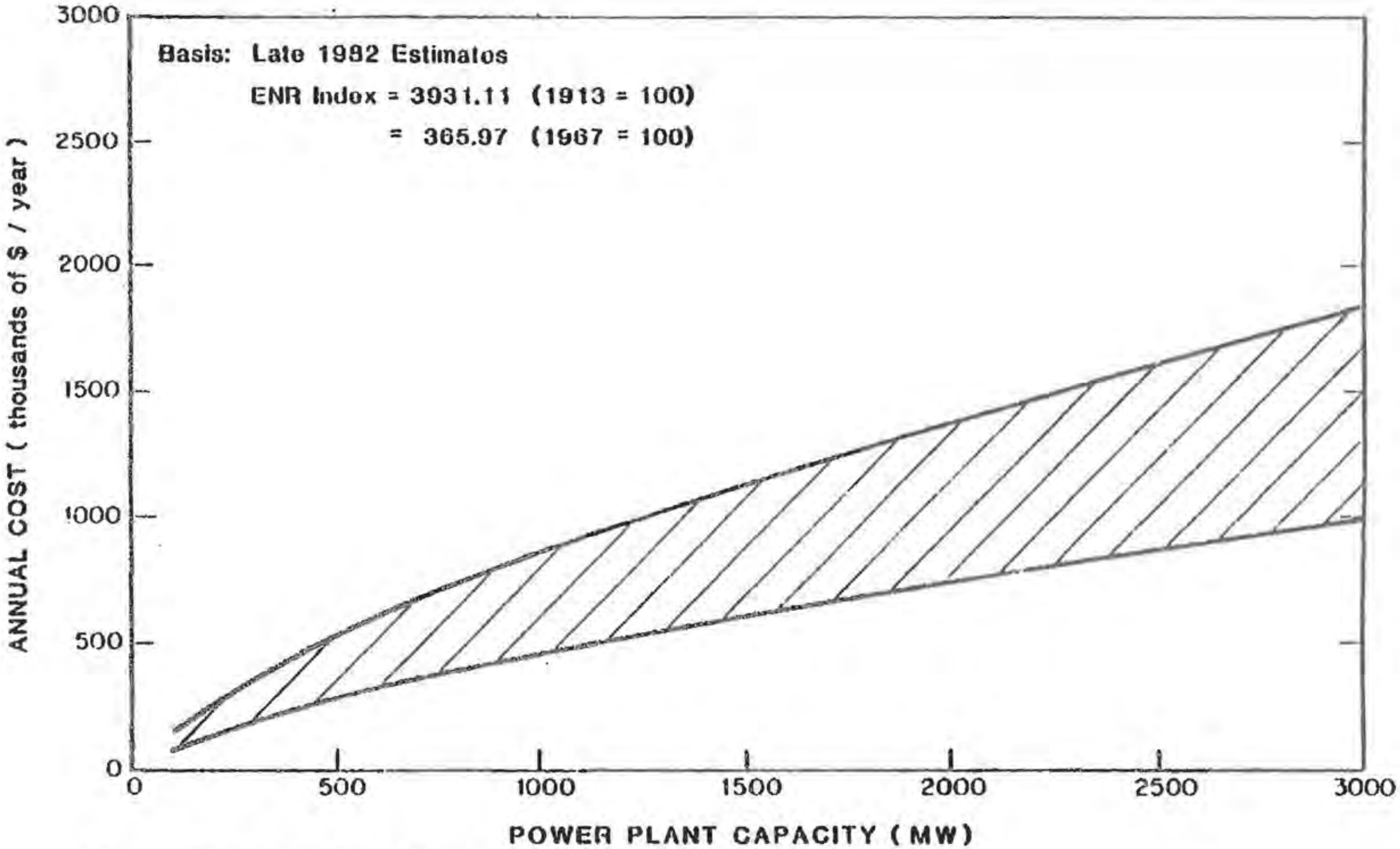
Dry fly ash handling also has many process variations. The simplest and least costly systems are used for short conveying distances; vacuum systems are typically chosen for this service. For longer conveying distances, pressure pneumatic conveying is required. Such systems can be very costly due to the expense associated with equipment required to feed fly ash from the ESP or mechanical collector hopper discharge to the conveying line, as well as the costs associated with the large amount of piping required for long conveying distances. In some cases, vacuum/pressure combination systems are used to overcome the operating difficulty associated with feeding ash from the hoppers. In general, costs are related to conveying distances, with costs in the lower portion of the capital and annual cost curve bands relating to shorter conveying distance. The generic capital cost curve is presented as Figure 6.31, while annual costs are shown in Figures 6.32 and 6.33.

<u>Bottom Ash Handling and Processing</u> -- Two sets of capital and annual cost curves which pertain to two handling and processing options are provided for bottom ash. In one option [Figures 6.34 (capital costs), 6.35 and 6.36 (annual costs)] wet handling of bottom ash without supernatant recycle is



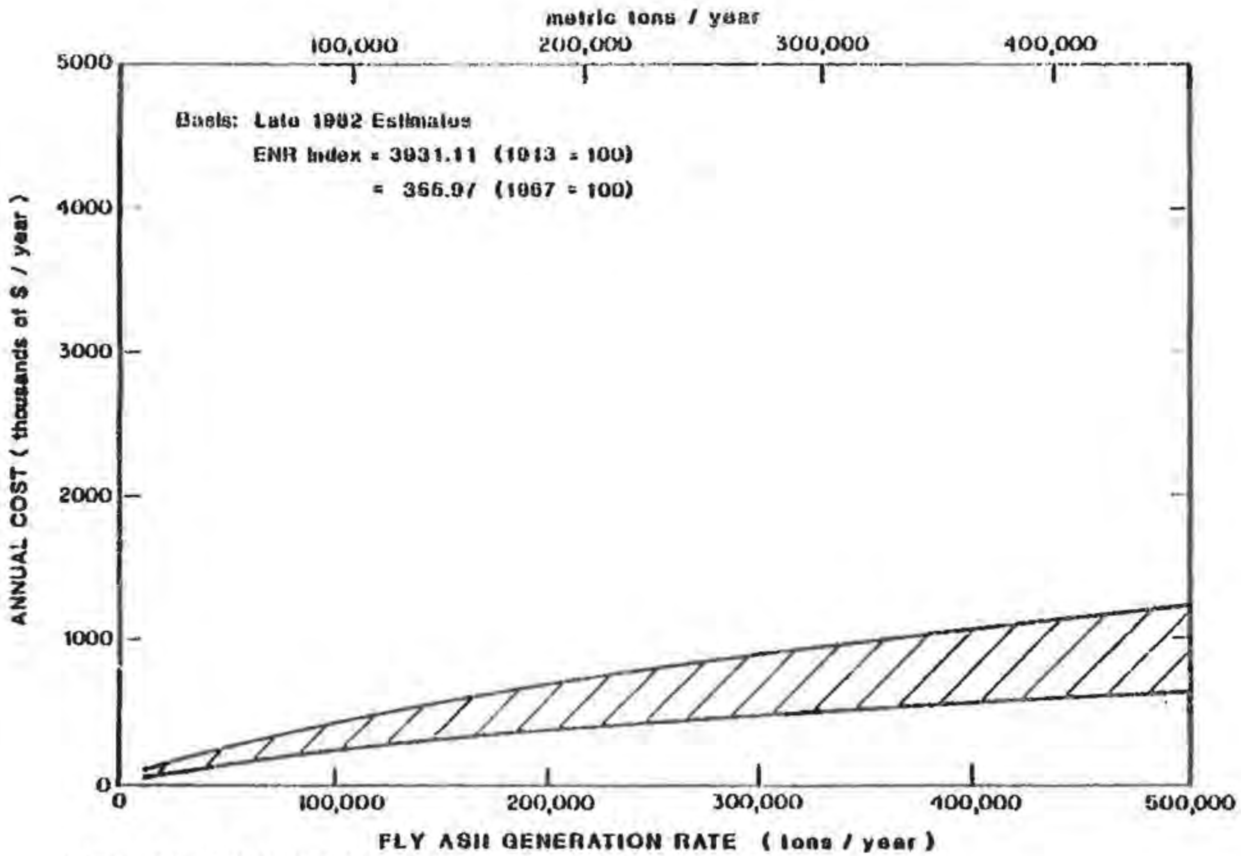
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.25 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH HANDLING and PROCESSING
(Wet Handling Without Recycle)



Source: Arthur D. Little, Inc. Estimates

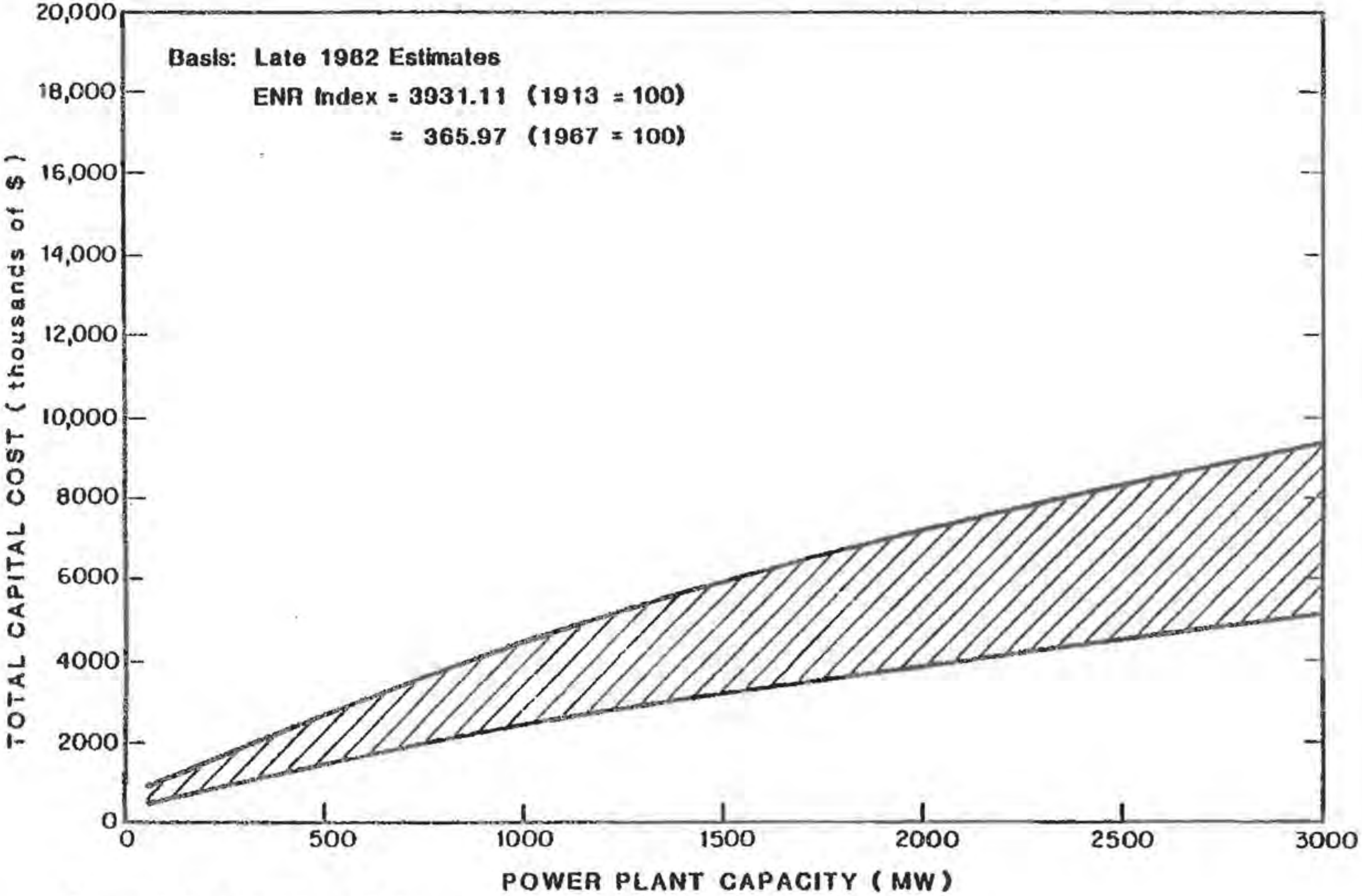
FIGURE 6.26 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH HANDLING and PROCESSING
(Wet Handling Without Recycle)



Source: Arthur D. Little, Inc. Estimates

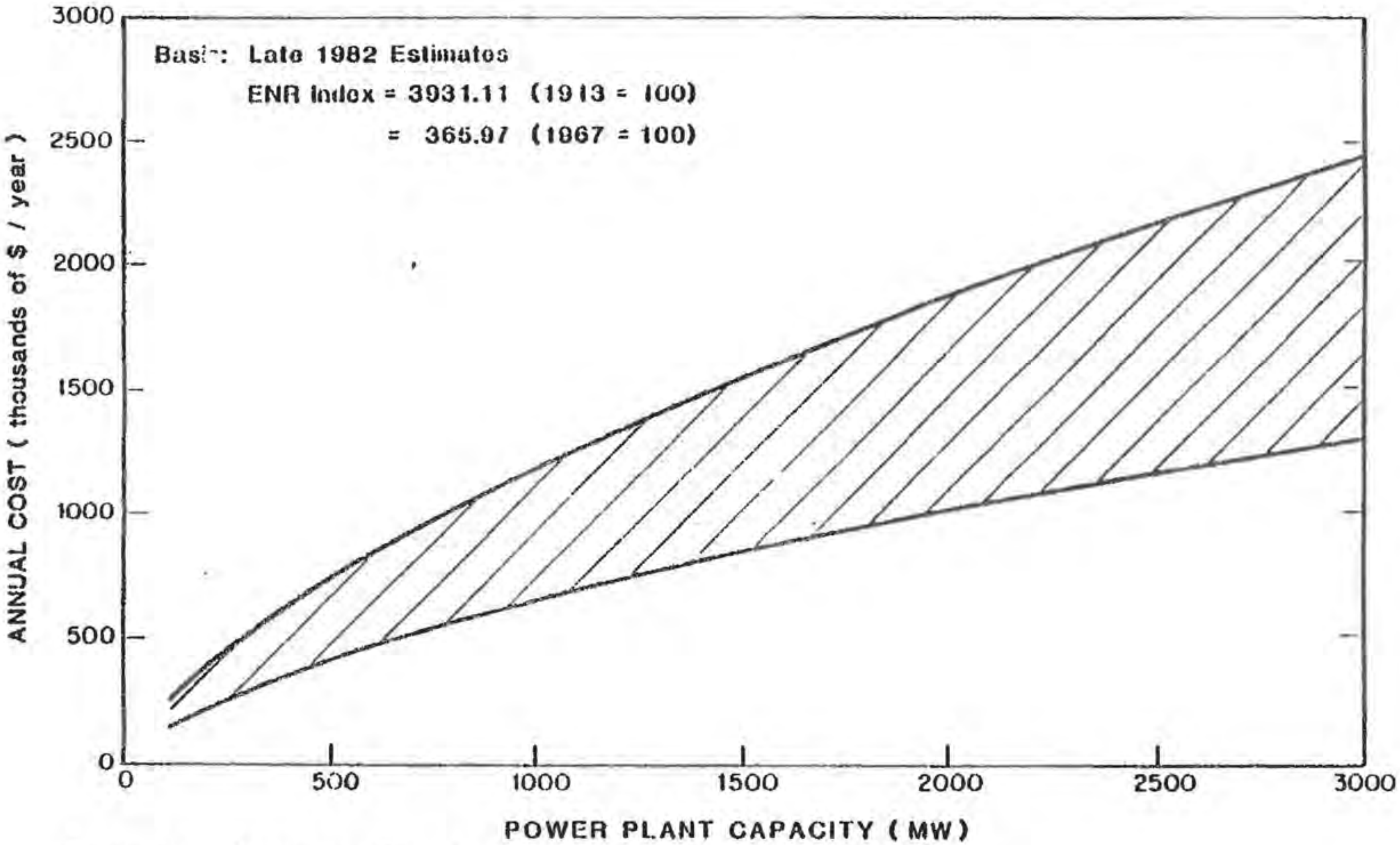
FIGURE 6.27 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH HANDLING and PROCESSING
(Wet Handling Without Recycle)

6-77



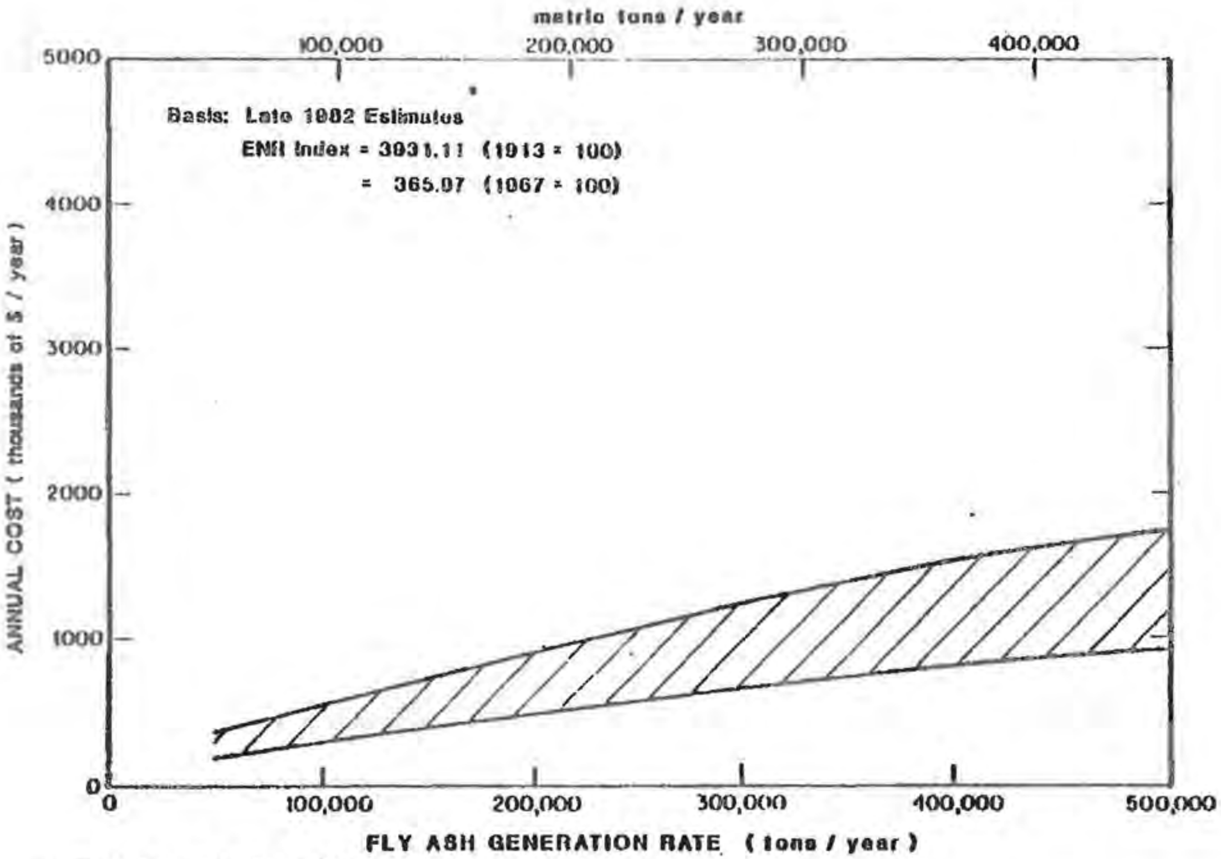
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.28 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH HANDLING and PROCESSING
(Wet Handling With Recycle)



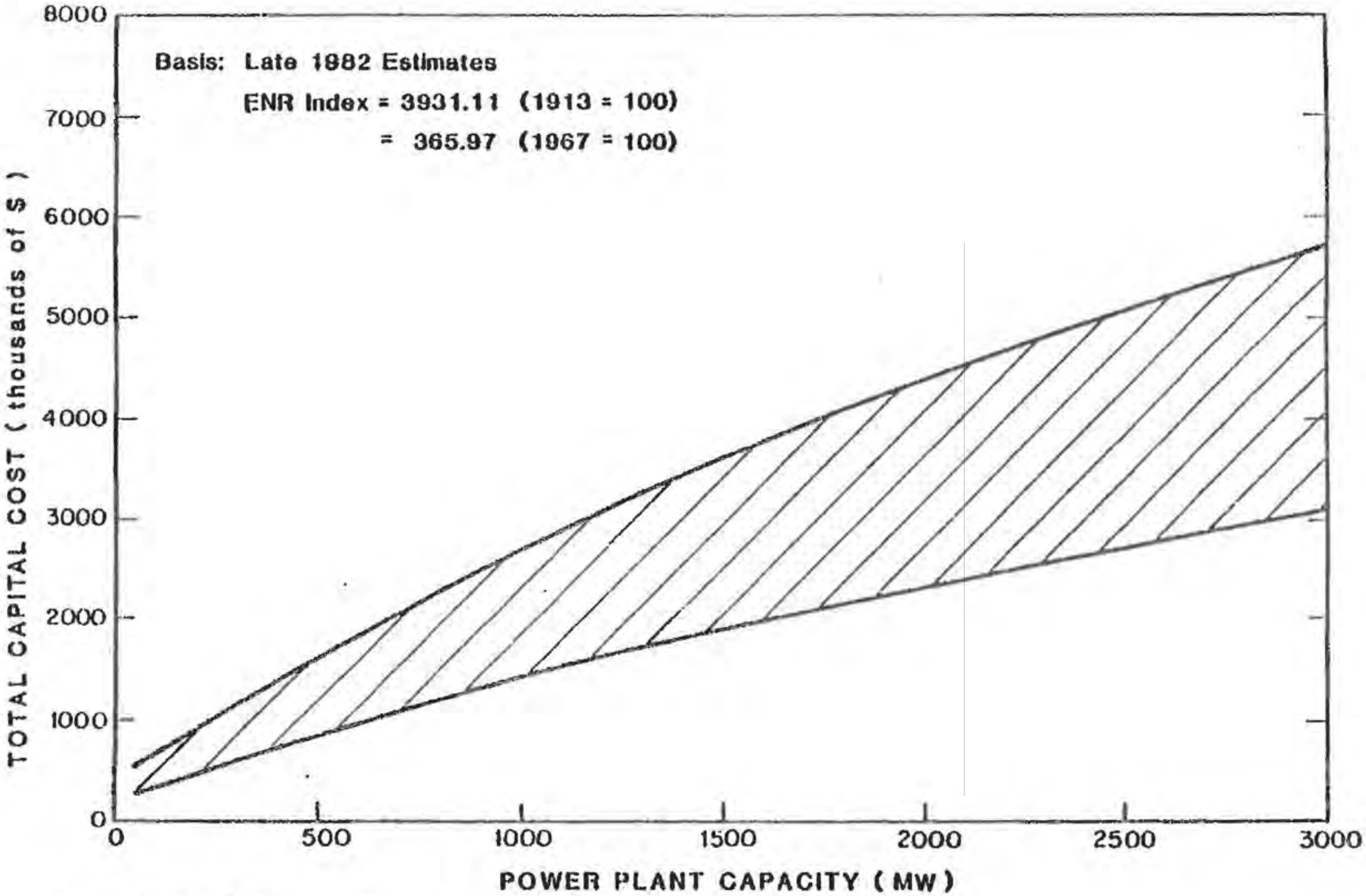
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.29 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH HANDLING and PROCESSING
(Wet Handling With Recycle)



Source: Arthur D. Little, Inc. Estimates

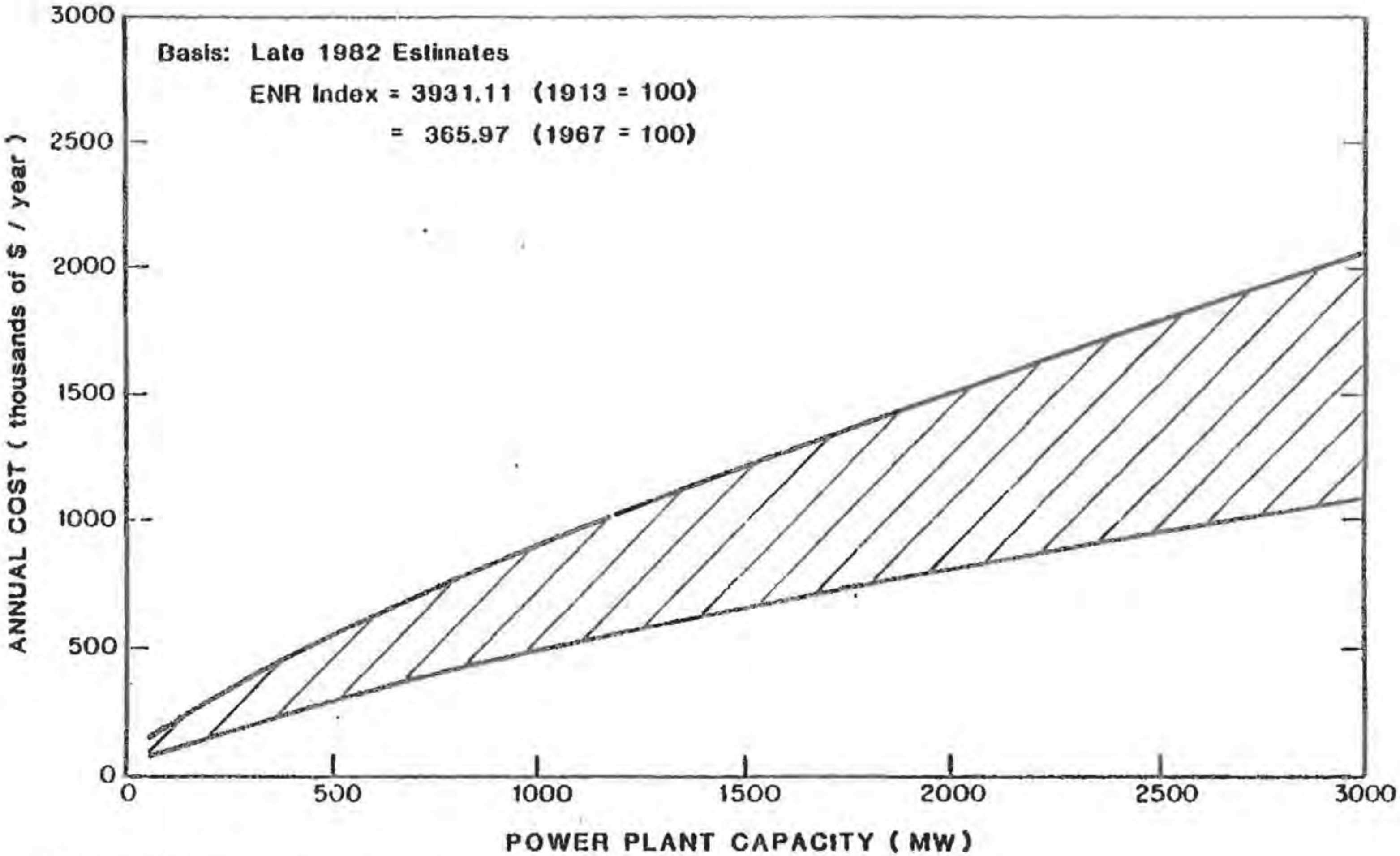
FIGURE 6.30 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH HANDLING and PROCESSING
(Wet Handling With Recycle)



6-80

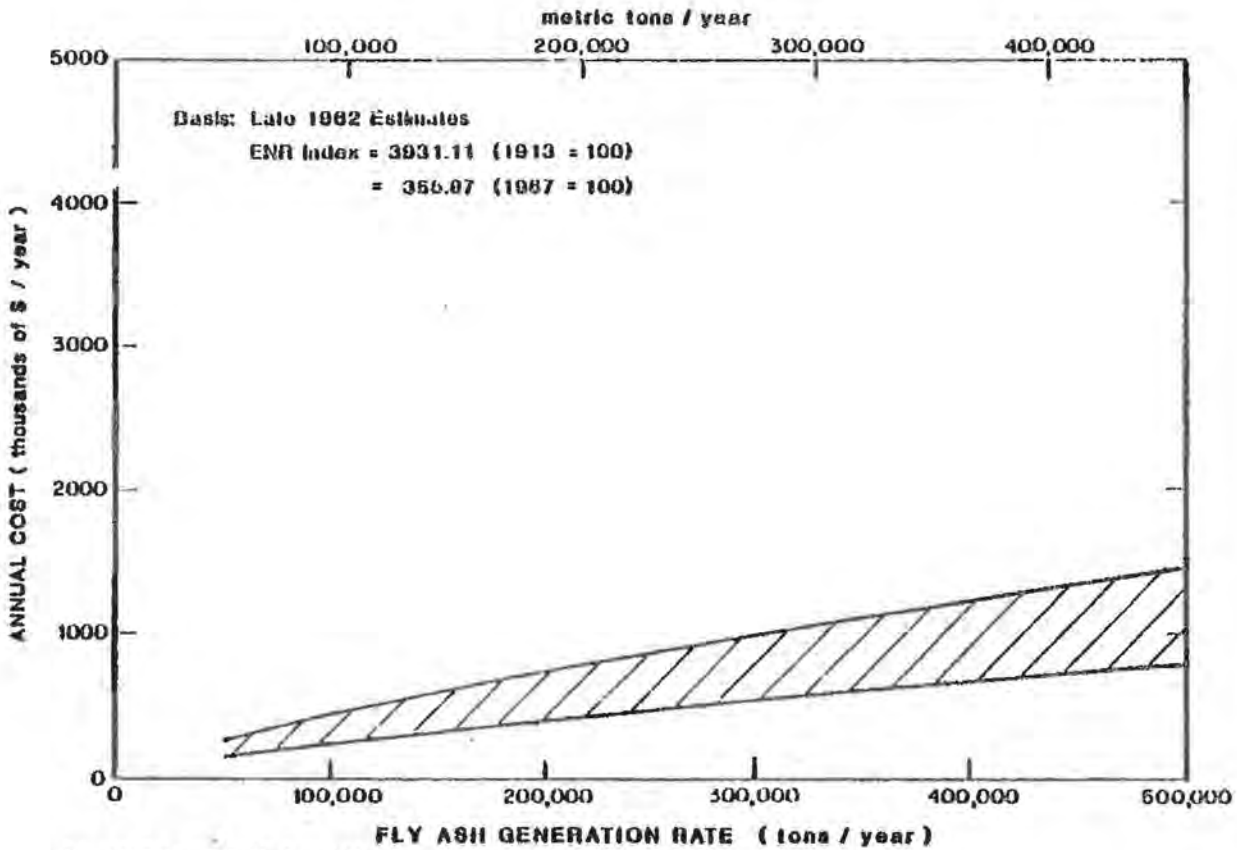
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.31 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH HANDLING and PROCESSING
(Dry Handling)



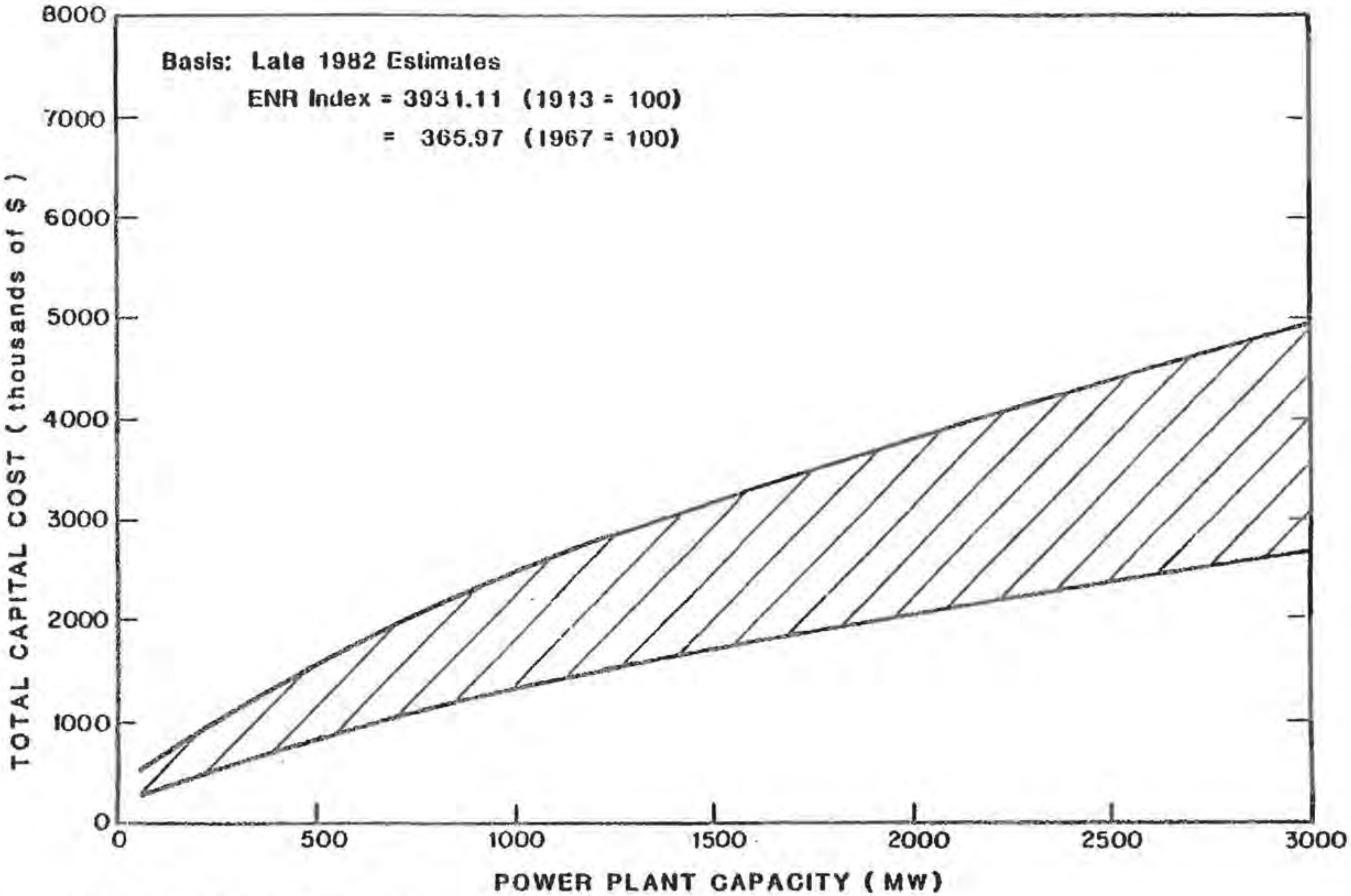
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.32 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH HANDLING and PROCESSING
(Dry Handling)



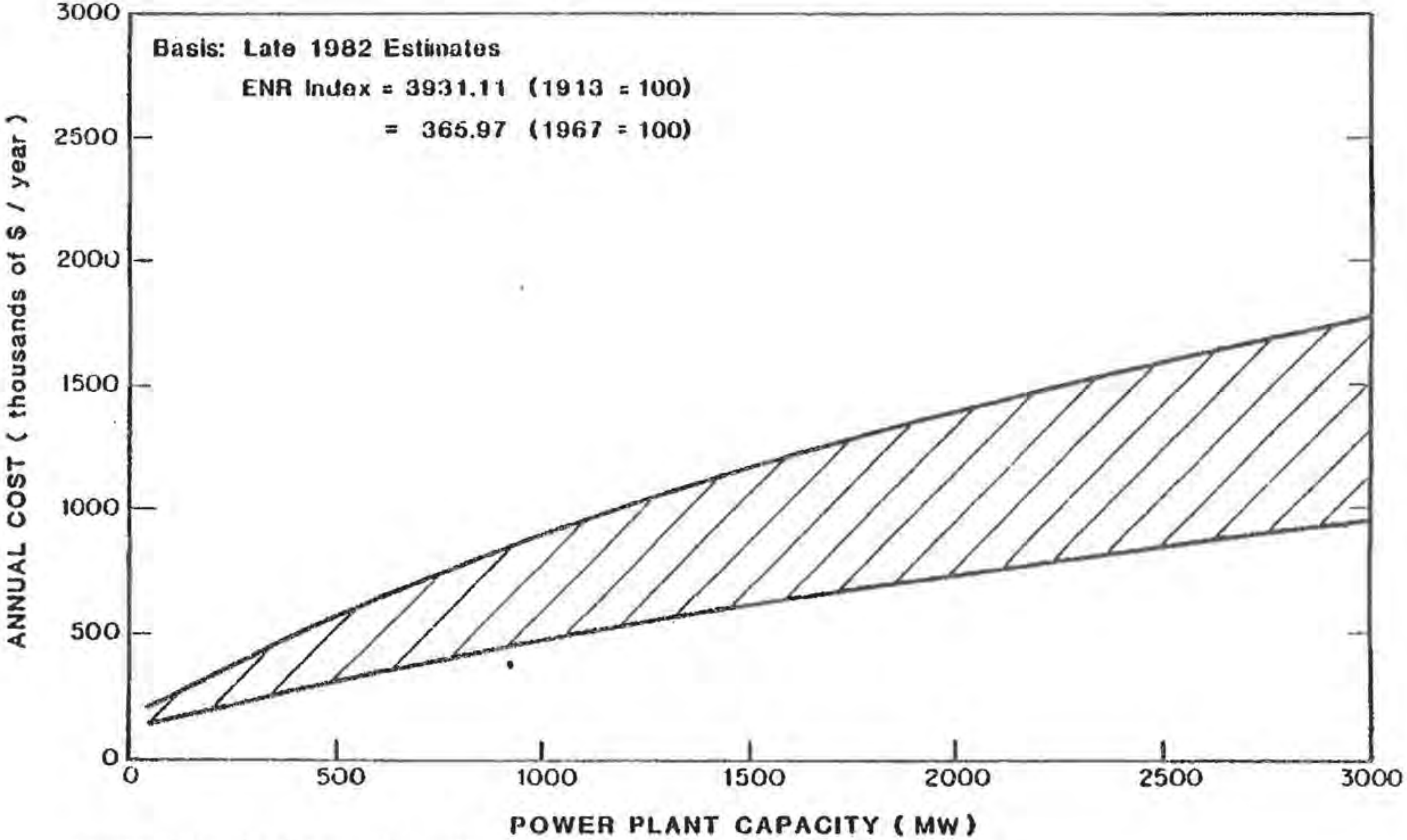
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.33 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH HANDLING and PROCESSING
(Dry Handling)



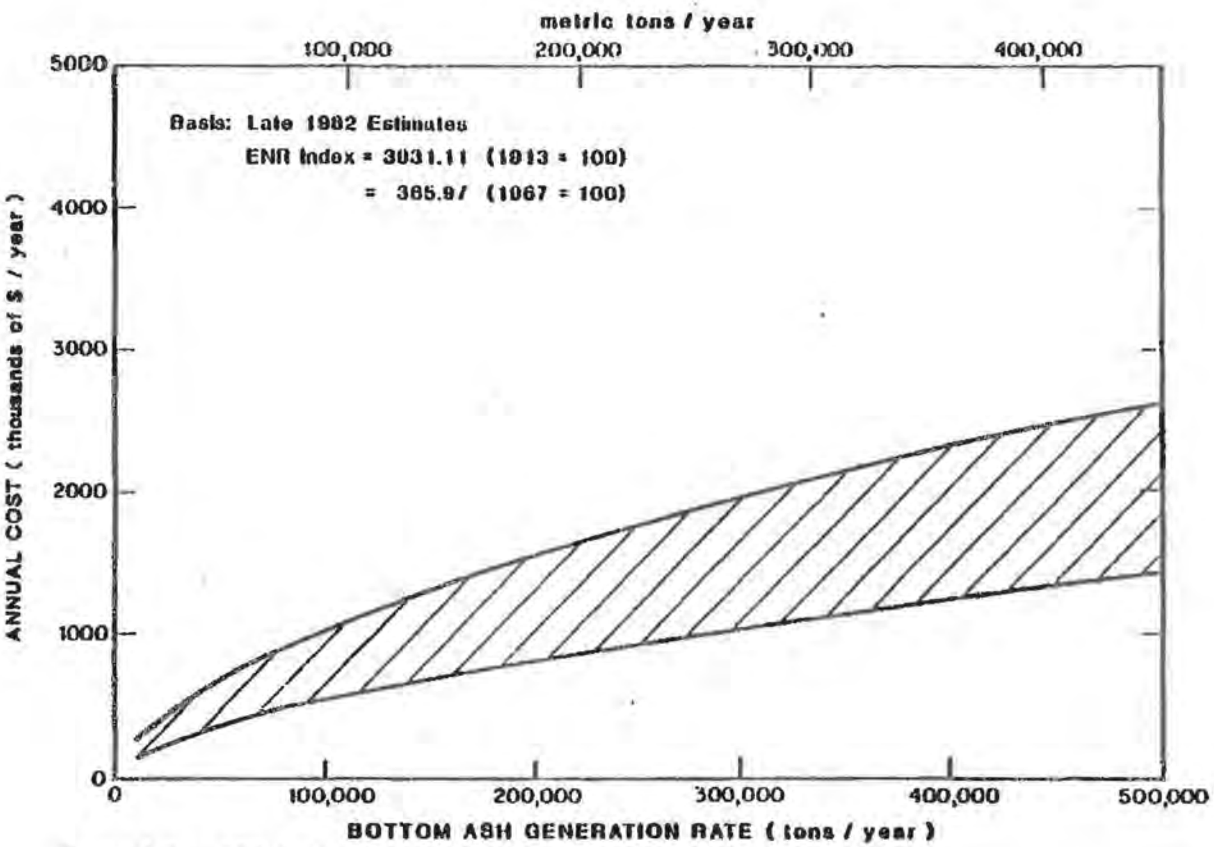
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.34 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH HANDLING and PROCESSING
(Wet Handling Without Recycle)



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.35 ANNUAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH HANDLING and PROCESSING
(Wet Handling Without Recycle)



Source: Arthur D. Little, Inc. Estimates

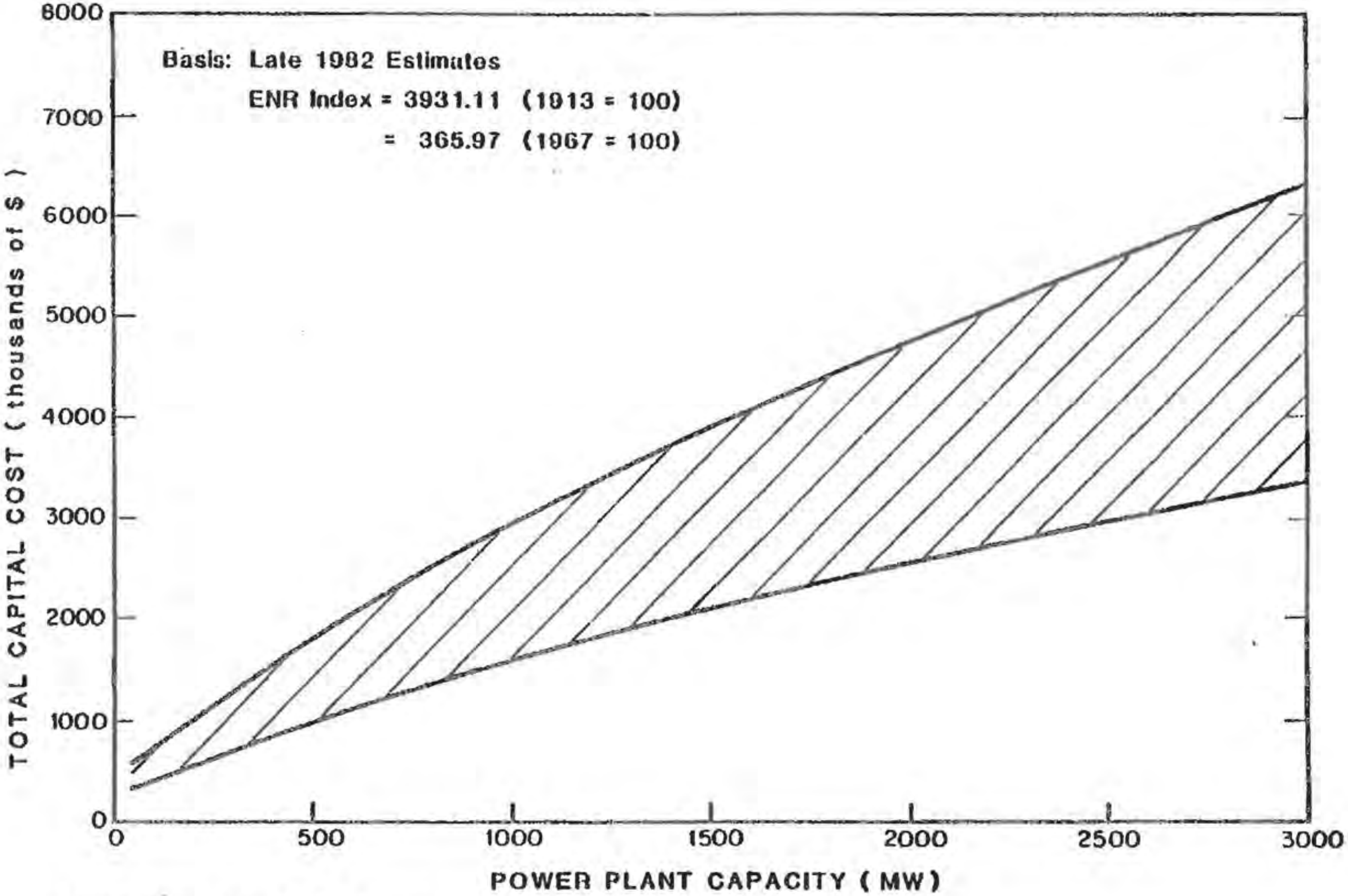
FIGURE 6.36 ANNUAL COST VERSUS BOTTOM ASH GENERATION RATE
BOTTOM ASH HANDLING and PROCESSING
(Wet Handling Without Recycle)

considered, while the other option [represented in Figures 6.37 (capital costs), 6.38 and 6.39 (annual costs)] refers to wet bottom ash handling systems which incorporate supernatant recycle provisions. In both cases, cost variations are dictated by the use or absence of bottom ash dewatering. The use of interim ponds for dewatering was not considered in preparing the bottom ash handling and processing cost curves, due to a paucity of available interim pond cost data (see Fly Ash Handling and Processing). Thus, for bottom ash handling and processing, the only dewatering alternative considered with respect to the development of cost curves was the use of hydrobins (i.e., dewatering bins). Bottom ash handling and processing costs for systems incorporating hydrobins will typically fall in the higher ranges of the cost band than those for simple wet handling systems which are used in conjunction with sluice pipeline transport systems.

FGD Waste Handling and Processing -- Capital and annual costs developed for FGD waste handling and processing are presented in Figures 6.40 and 6.41, respectively. Costs for FGD waste handling and processing varies according to the degree of processing employed, which ranges from no processing to dewatering and finally to dewatering with stabilization or chemical fixation. The lower ranges of the capital and annual cost curve bands correspond to costs for FGD waste handling with limited or no processing. The upper region of the band relates to extensive processing (i.e., primary and secondary dewatering of the waste followed by chemical fixation). The intermediate cost curve regions generally pertain to systems which incorporate only dewatering for FGD waste processing. In this case, as with fly and bottom ash wastes, the cost of interim ponding was not considered in developing the cost curves. To date, the use of interim ponds for the purpose of dewatering FGD wastes is very limited; in addition, it is not anticipated to grow in the future.

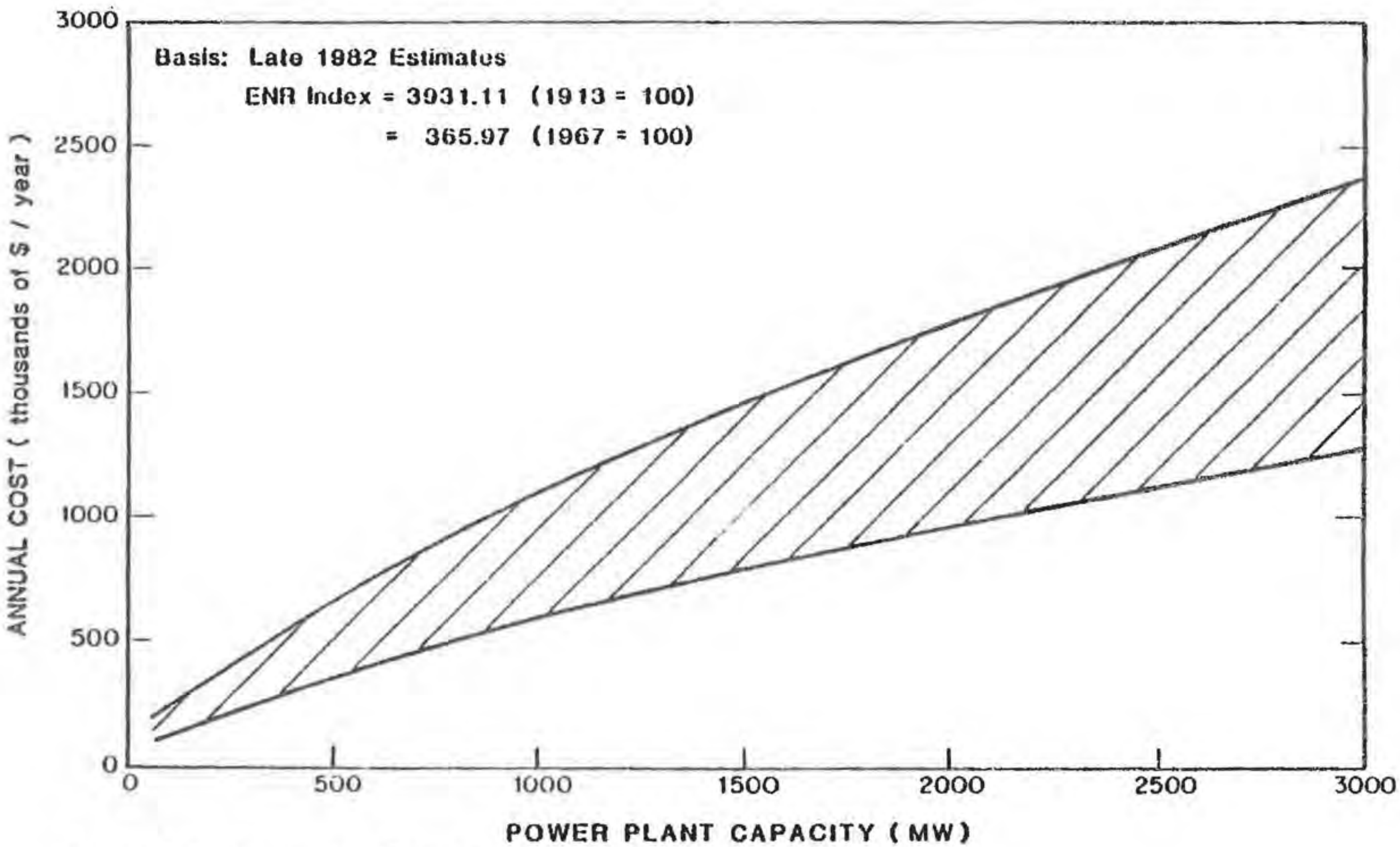
Fly Ash Storage -- Fly ash storage capital costs are dominated by the cost of the storage structure (i.e., the cost of the silo, bin, etc). The major cost variables with respect to storage structures are: (1) the size and number of structures required and (2) the material of construction. The cost curves provided for fly ash storage are based on the premise that the number of storage vessels and vessel sizes are optimized with respect to cost. Fly ash storage in structures constructed of relatively lower cost materials, such as carbon steel, would be expected to have relatively lower costs (and, hence, would fall in the lower ranges of the cost curve band) than those constructed of more costly materials, such as rubber-lined steel. The choice of materials of construction are site specific, depending on the chemical properties of the ash to be stored. The cost curves for fly ash storage are presented in Figures 6.42 (capital costs), 6.43 and 6.44 (annual costs).

Raw Materials Handling and Storage -- The capital and annual cost curves for the raw materials handling and storage module are provided in Figures 6.45 and 6.46, respectively. The upper ranges of the cost curves pertain to raw materials handling and storage associated with CSI or Dravo chemical fixation processes where multiple additives, and therefore multiple storage



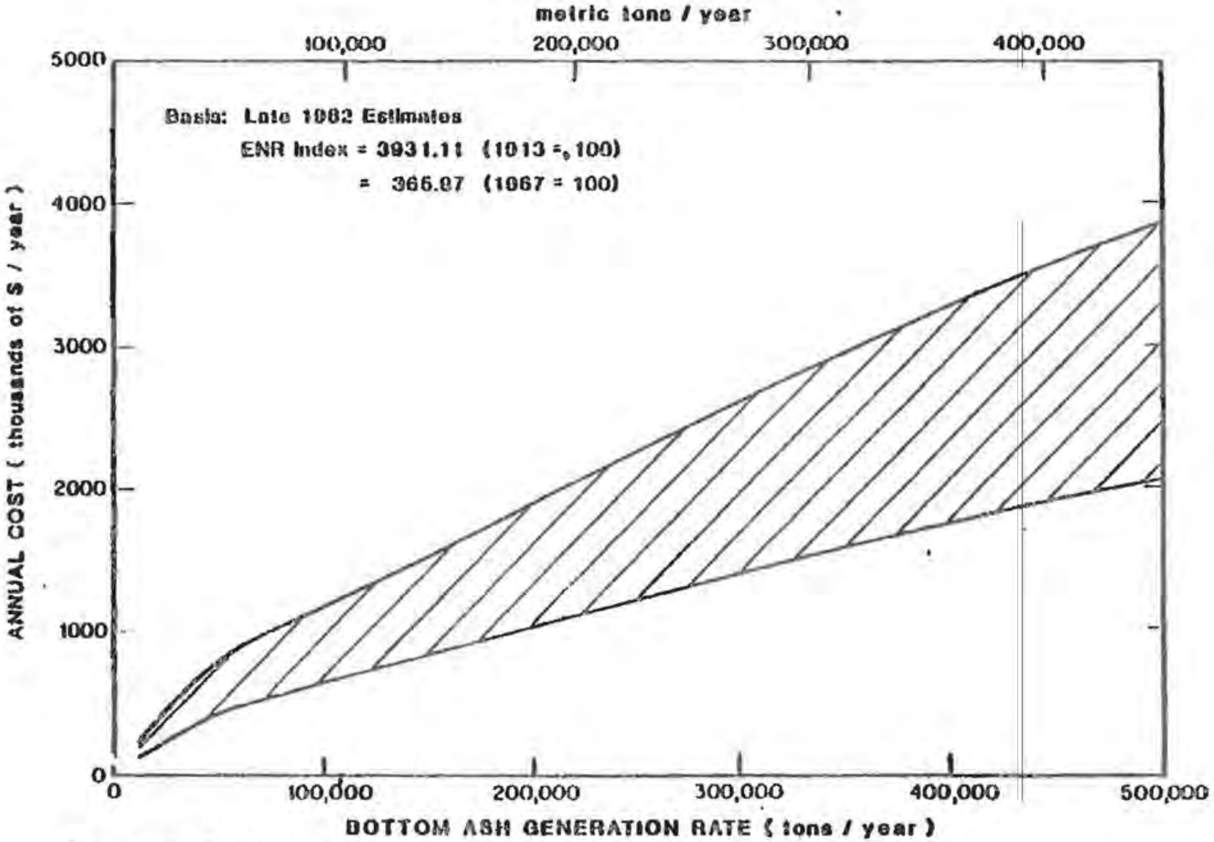
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.37 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH HANDLING and PROCESSING
(Wet Handling With Recycle)



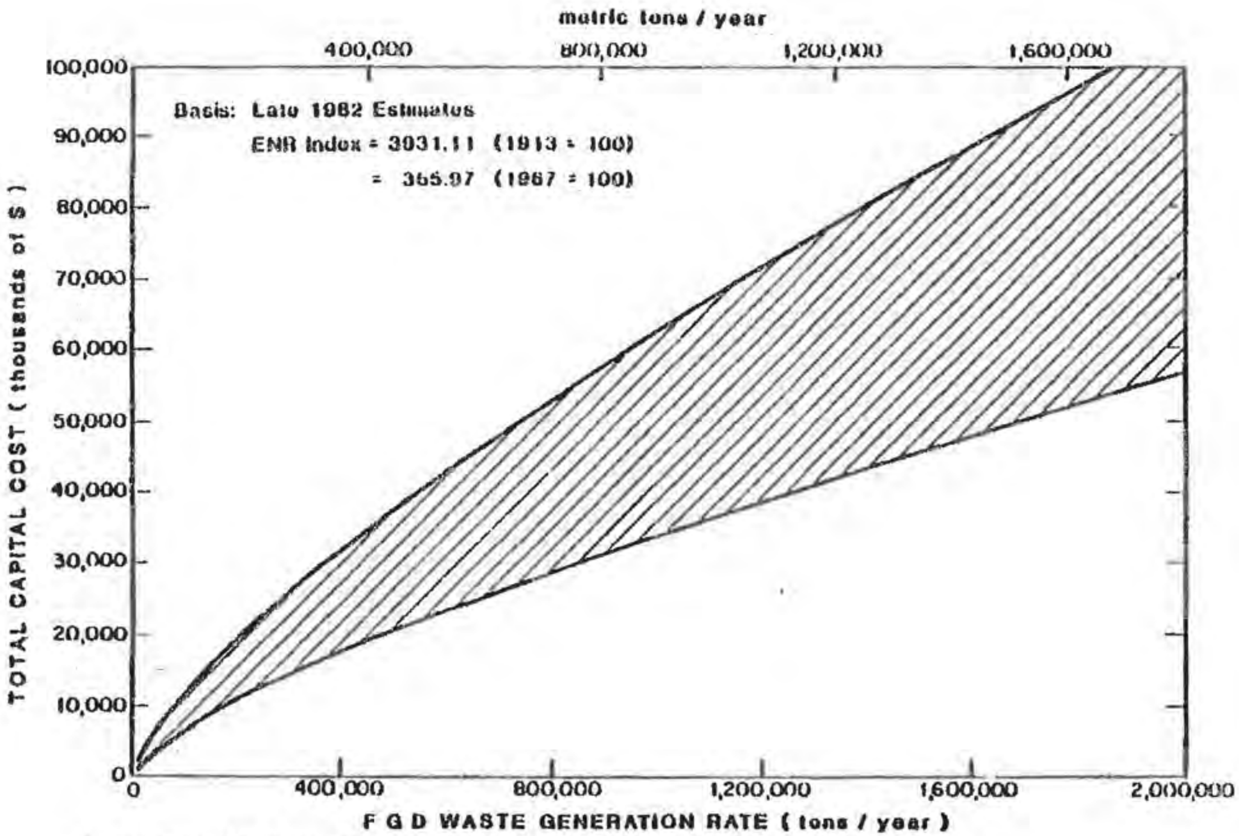
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.38 ANNUAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH HANDLING and PROCESSING
(Wet Handling With Recycle)



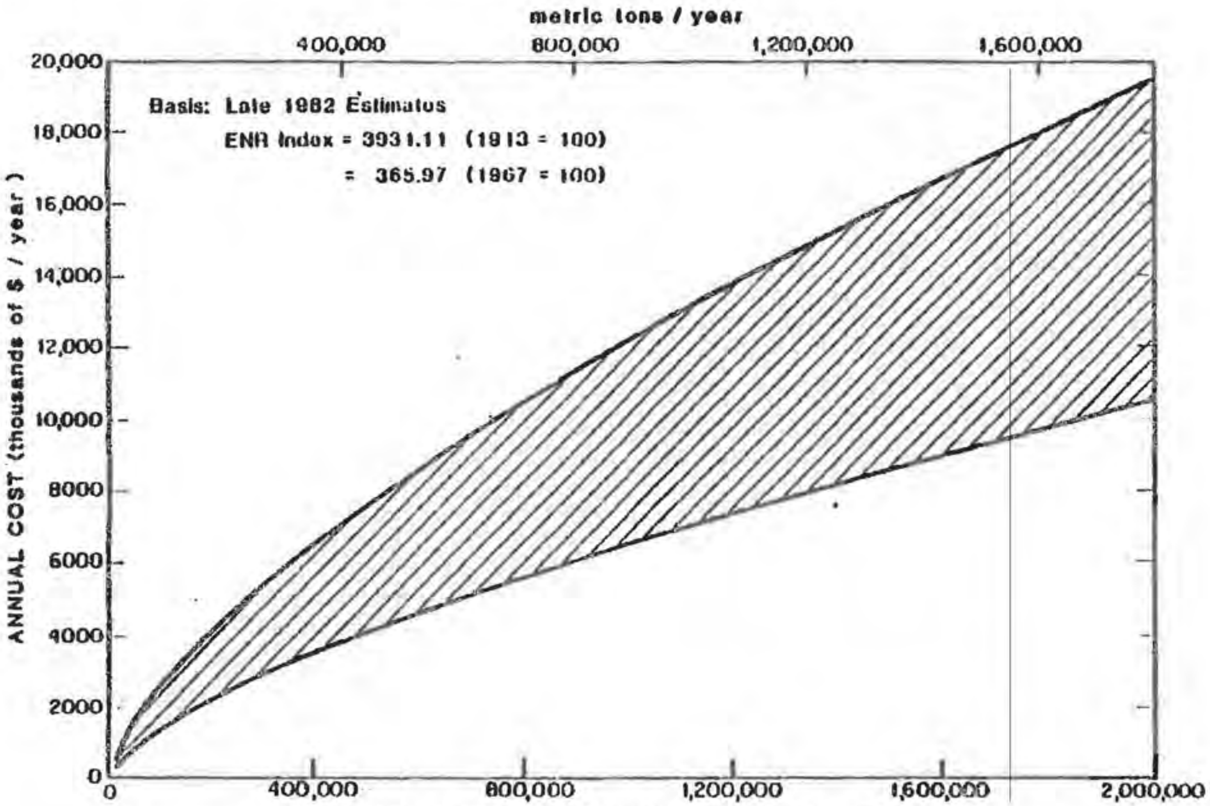
Source- Arthur D. Little, Inc. Estimates

FIGURE 6.39 ANNUAL COST VERSUS BOTTOM ASH GENERATION RATE
BOTTOM ASH HANDLING and PROCESSING
(Wet Handling With Recycle)



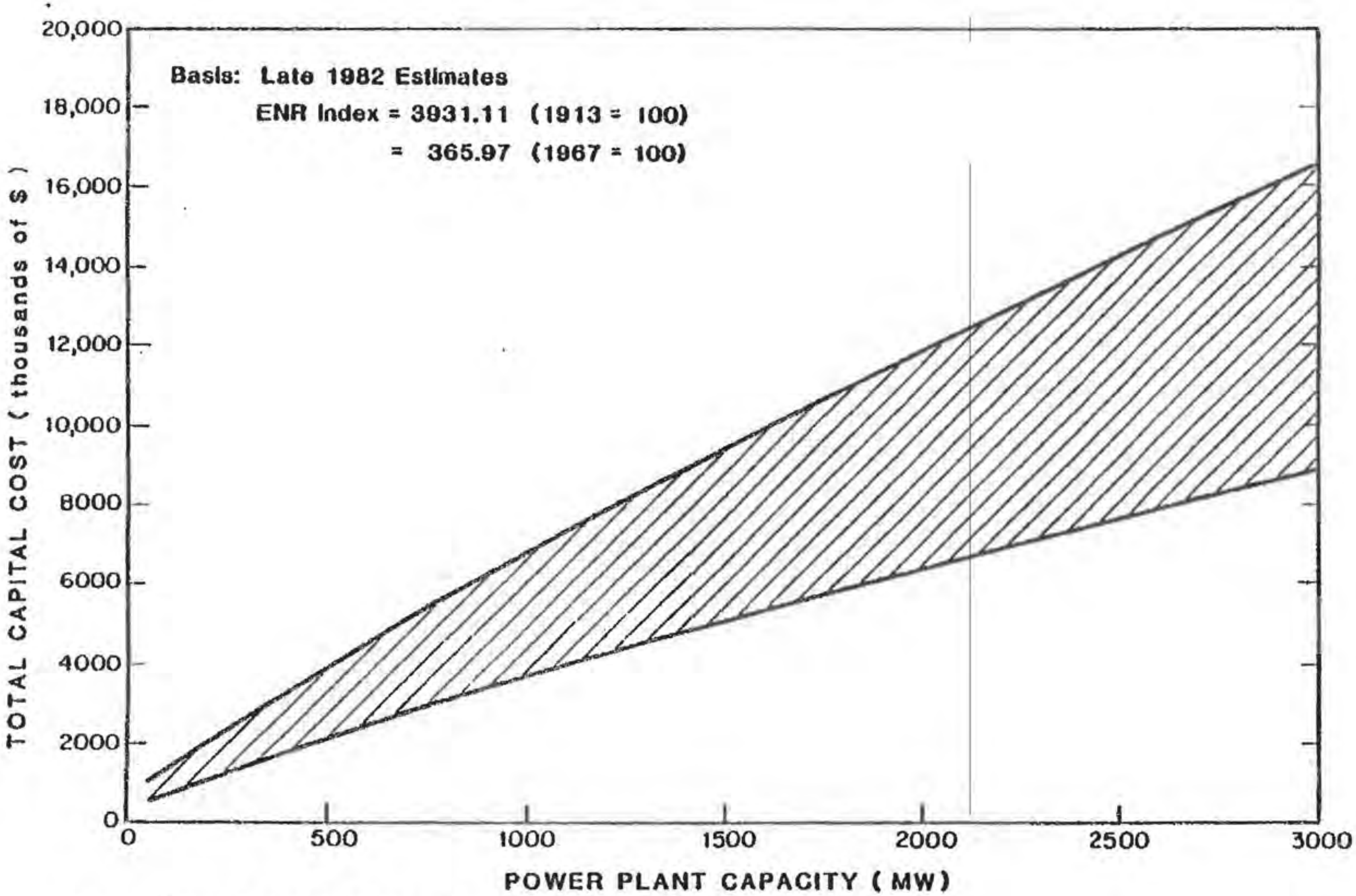
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.40 TOTAL CAPITAL COST VERSUS F G D WASTE GENERATION RATE
FGD WASTE HANDLING and PROCESSING



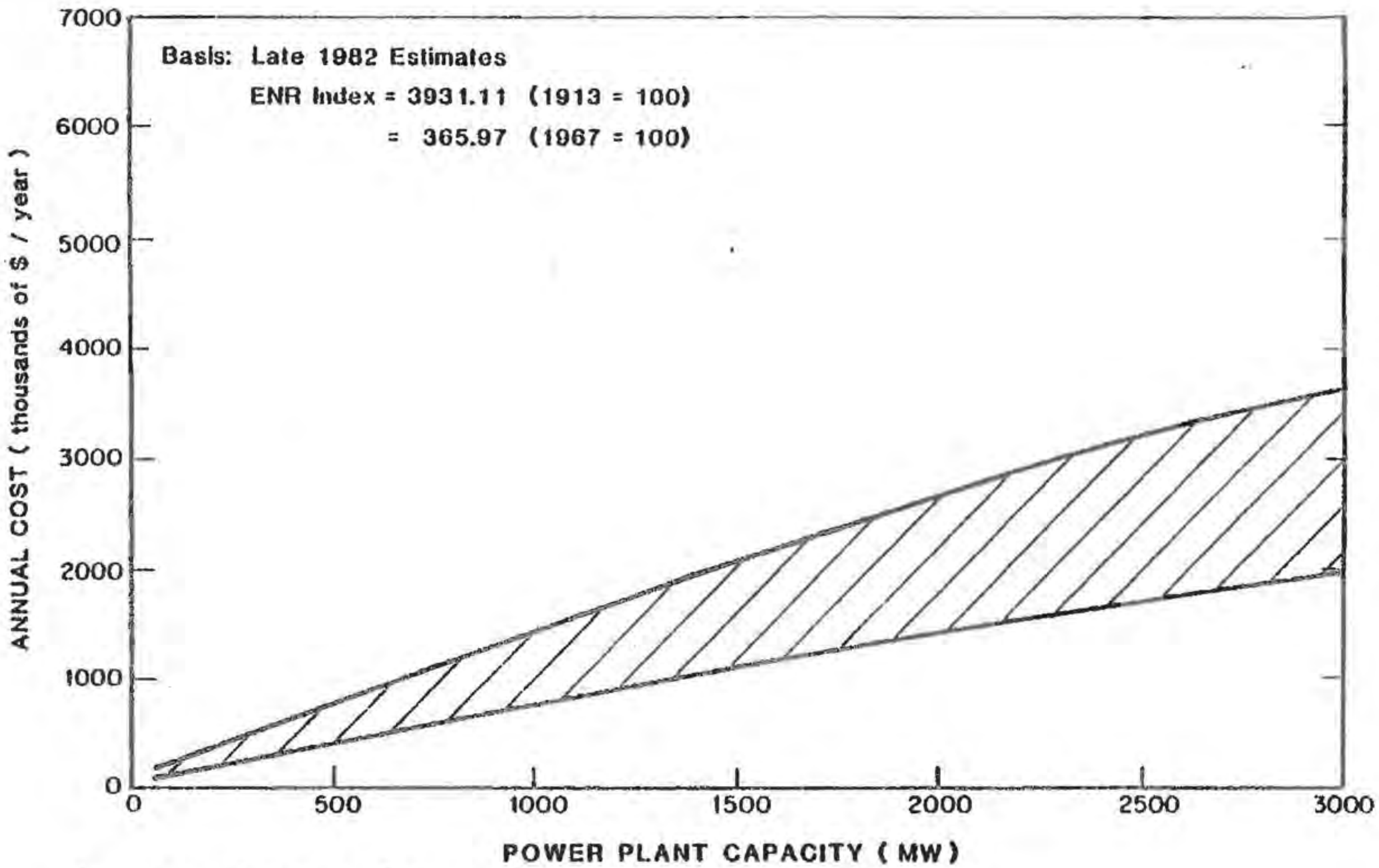
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.41 ANNUAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE HANDLING and PROCESSING



Source: Arthur D. Little, Inc. Estimates

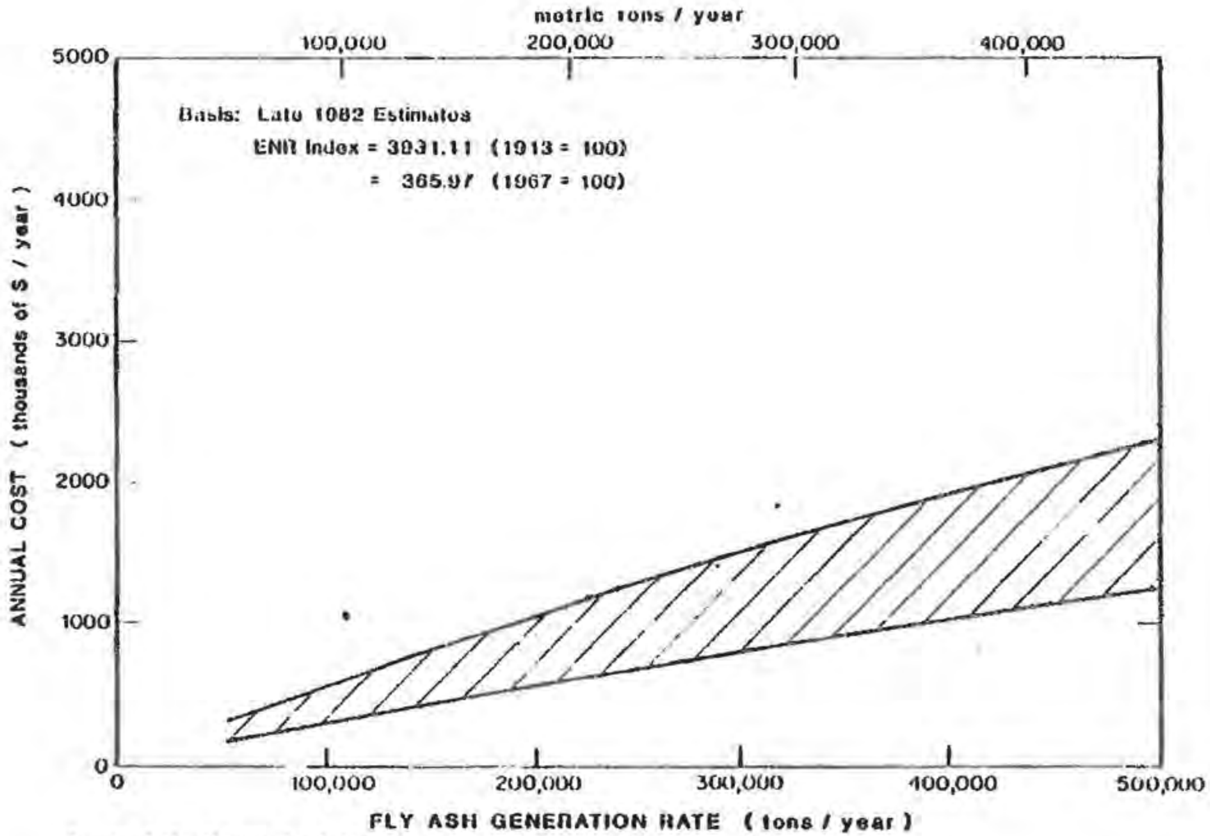
FIGURE 6.42 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH STORAGE



Source: Arthur D. Little, Inc. Estimates

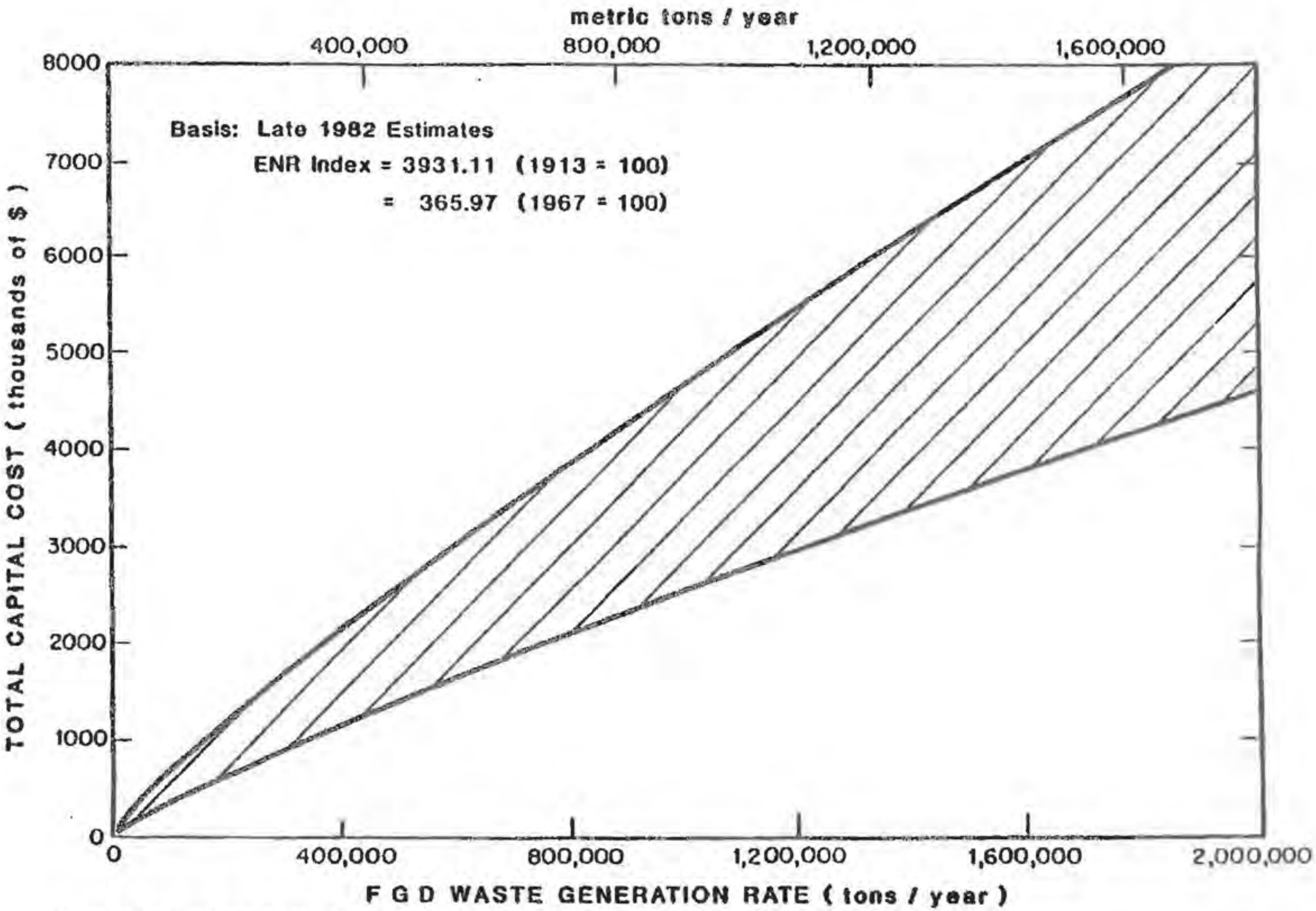
FIGURE 6.43 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH STORAGE

76-9



Source: Arthur D. Little, Inc. Estimates

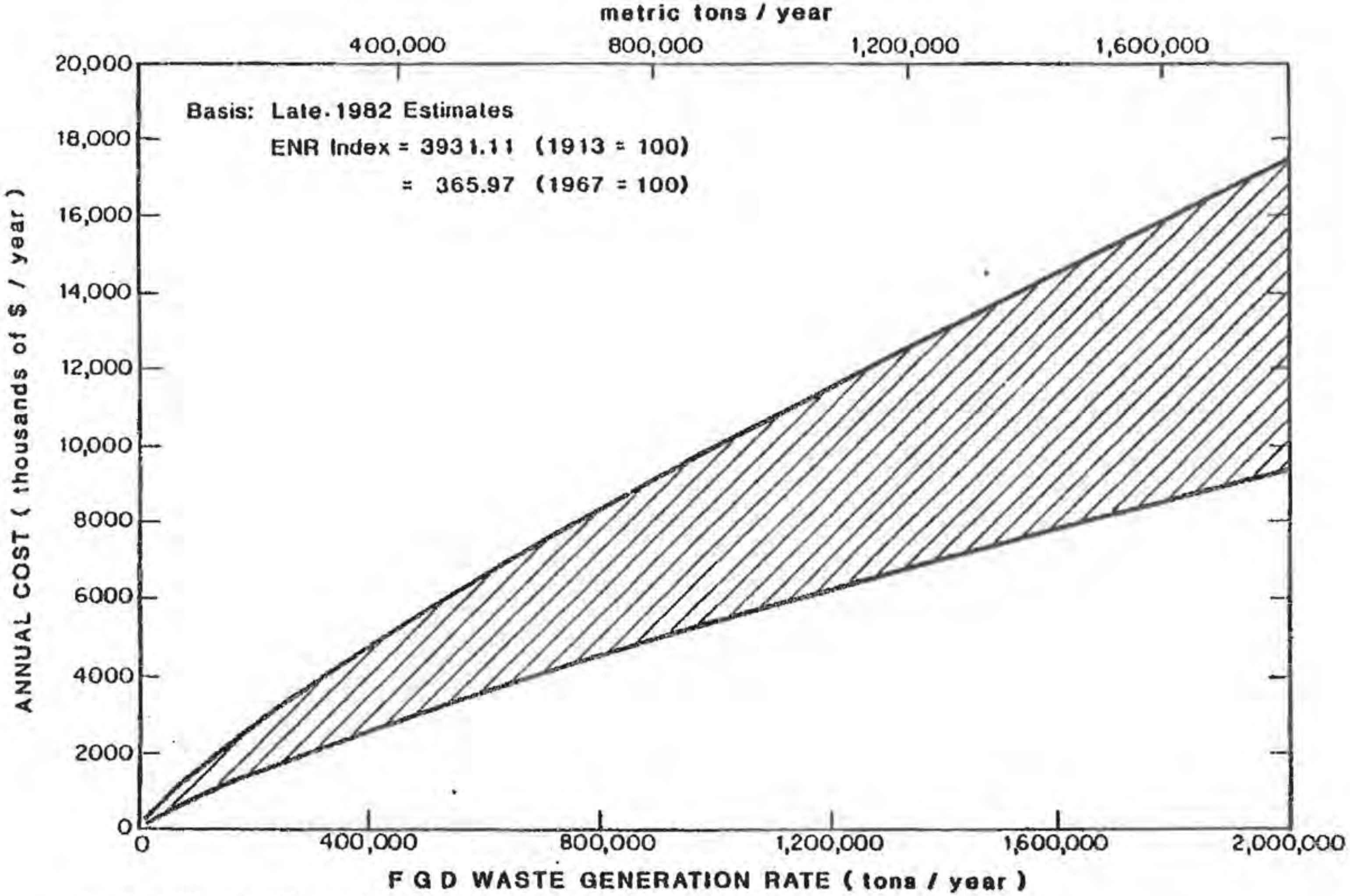
FIGURE 6.44 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH STORAGE



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.45 TOTAL CAPITAL COST VERSUS F G D WASTE GENERATION RATE
RAW MATERIALS HANDLING and STORAGE

96-9



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.46 ANNUAL COST VERSUS F G D WASTE GENERATION RATE
RAW MATERIALS HANDLING and STORAGE

systems, (potentially with some common elements) are required. For FGD waste stabilization processes (i.e., fly ash blending) where only one additive is used, the lower ranges of the cost curves apply.

Coal Ash and FGD Waste Transport -- Two types of transport options are available for coal-fired utility solid wastes, wet and dry systems. For this reason, two sets of capital and annual cost curves were developed for each of the three coal-fired utility waste types (fly ash, bottom ash and FGD waste). For each waste type, capital and annual cost curves were developed for wet transport by pipelines; a second set of curves pertaining to truck transport of dry wastes was also developed.

The transport modules for each of the three waste types show little variation with respect to design parameters that affect costs. Thus, the following discussion pertains to all three types of coal-fired utility solid wastes.

Capital and annual costs for pipeline transport vary according to the following parameters:

- transport distance;
- pipeline material of construction; and
- terrain.

The cost curves presented for pipeline transport of fly ash (Figure 6.47 for capital costs and Figures 6.48 and 6.49 for annual costs), bottom ash (Figure 6.50 for capital costs and Figures 6.51 and 6.52 for annual costs) and FGD wastes (Figures 6.53 and 6.54 for capital and annual costs, respectively) do not consider variability of transport distance. A transport distance of 1.6 km (1 mile) was assumed for the purposes of this study. Of course, for different transport distances, costs will vary. At present, correction factors to account for such differences have not been developed (see Section 6.3) due to insufficient data.

Pipeline materials of construction vary according to the erosive and corrosive nature of the media transported. The selection of pipe materials is highly site-specific because of the wide range of waste characteristics. With respect to the capital and annual cost curves, pipelines constructed of lower cost materials (e.g., carbon steel) will exhibit costs in the lower regions of the cost band. The costs for pipelines constructed of more expensive materials (e.g., butyl rubber-lined steel, nickel/chrome alloy, fiberglass, etc.) will fall in the upper range of the cost curve band.

The effect of terrain on costs was not considered in this study; the terrain considered was assumed to be reasonably level.

Truck transport capital and operating cost curves were prepared for fly ash (Figure 6.55 for capital costs and Figures 6.56 and 6.57 for annual costs), bottom ash (Figure 6.58 for capital costs and Figures 6.59 and 6.60

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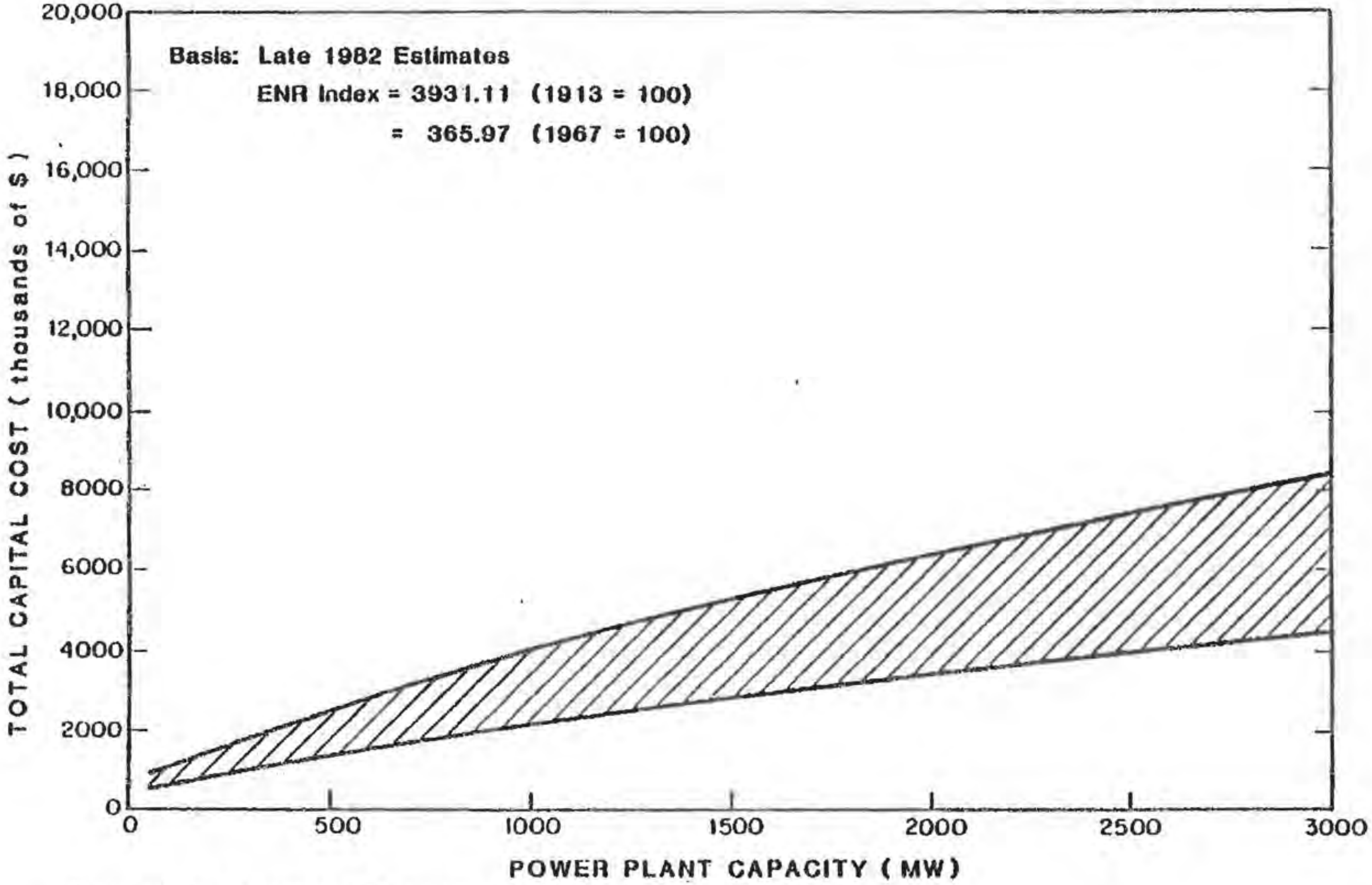
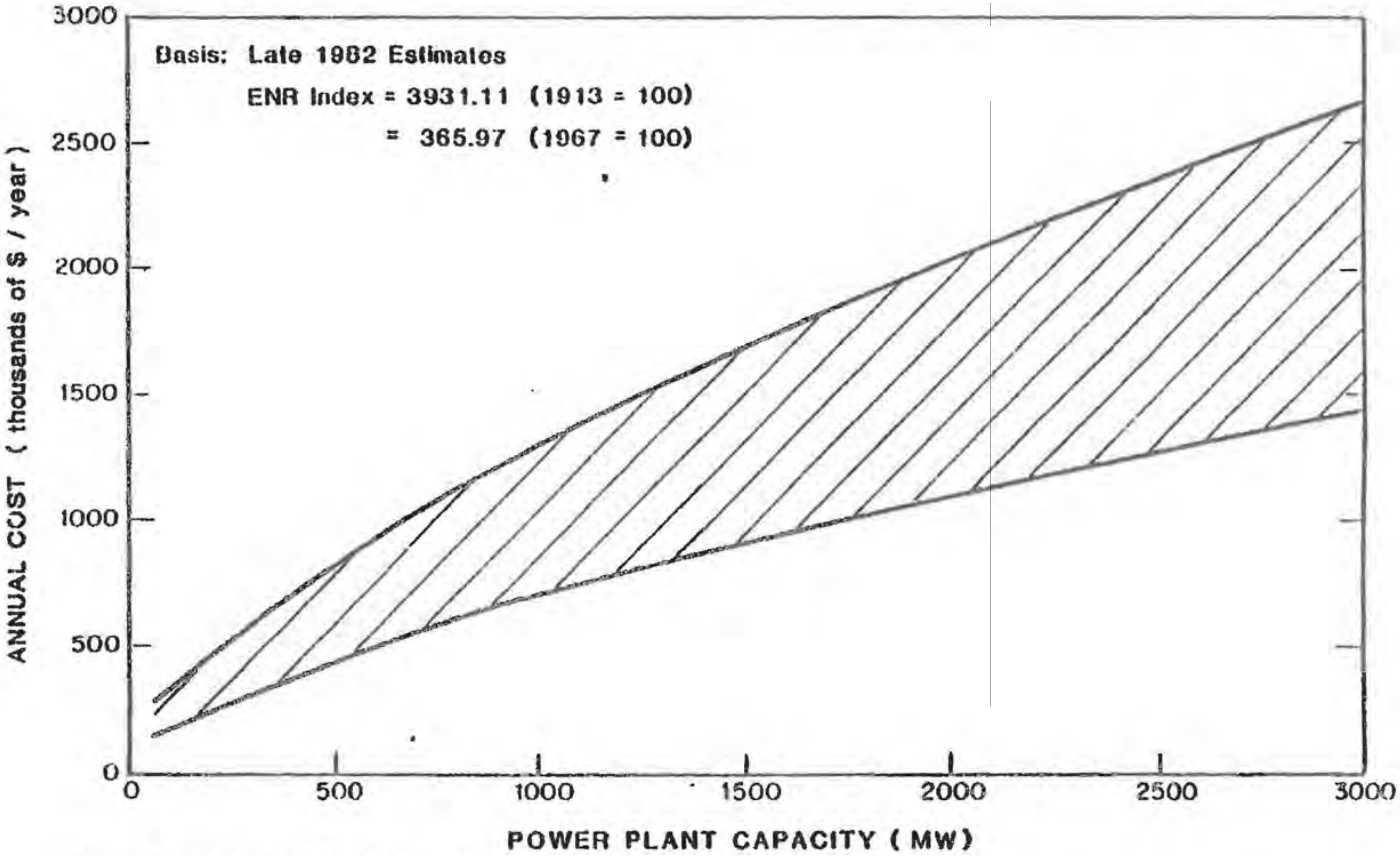


86-9

Source: Arthur D. Little, Inc. Estimates

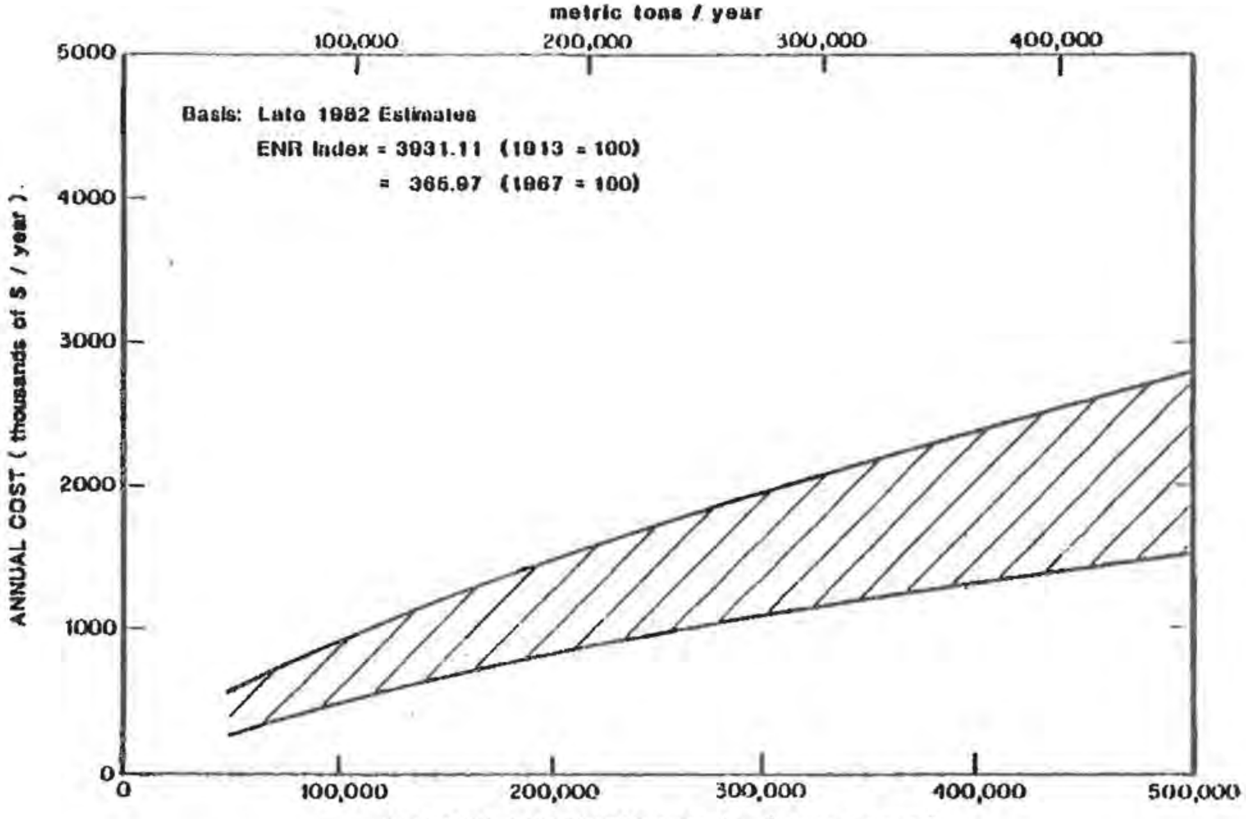
FIGURE 6.47 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH TRANSPORT (Wet Sluicing)

6-99



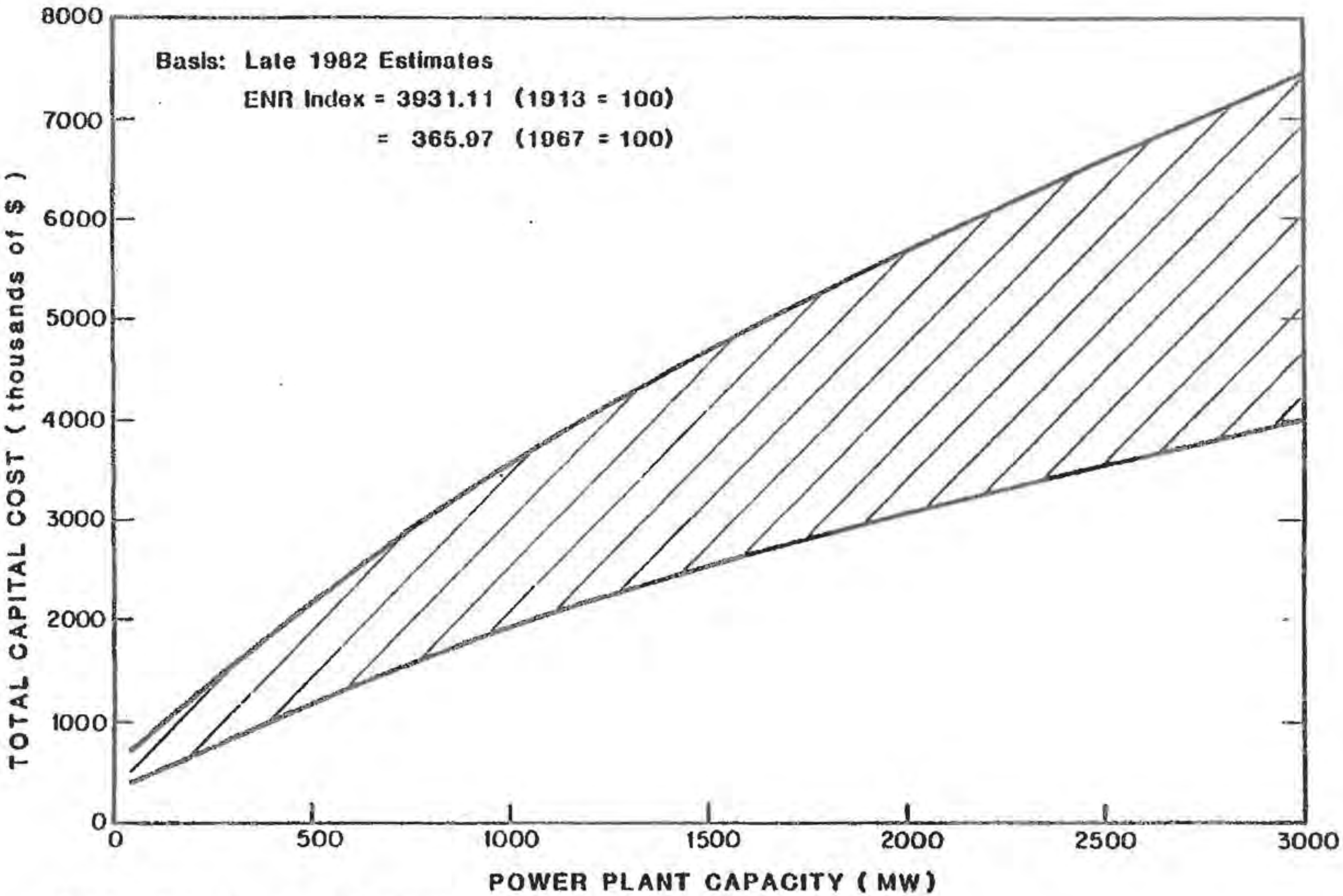
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.48 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH TRANSPORT (Wet Sluicing)



Source: Arthur D. Little, Inc. Estimates

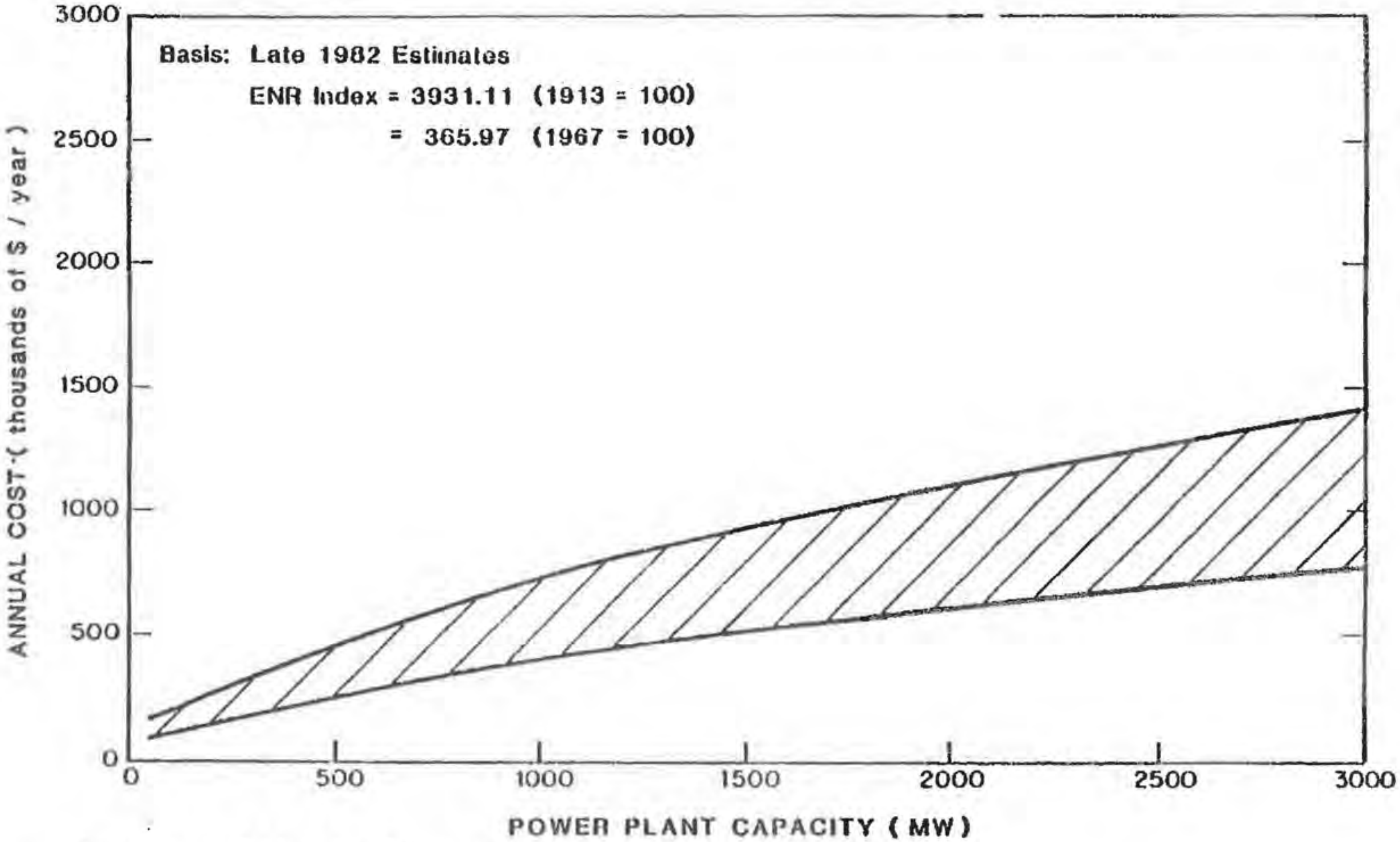
FIGURE 6.49 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH TRANSPORT (Wet Sluicing)



Source: Arthur D. Little, Inc. Estimates

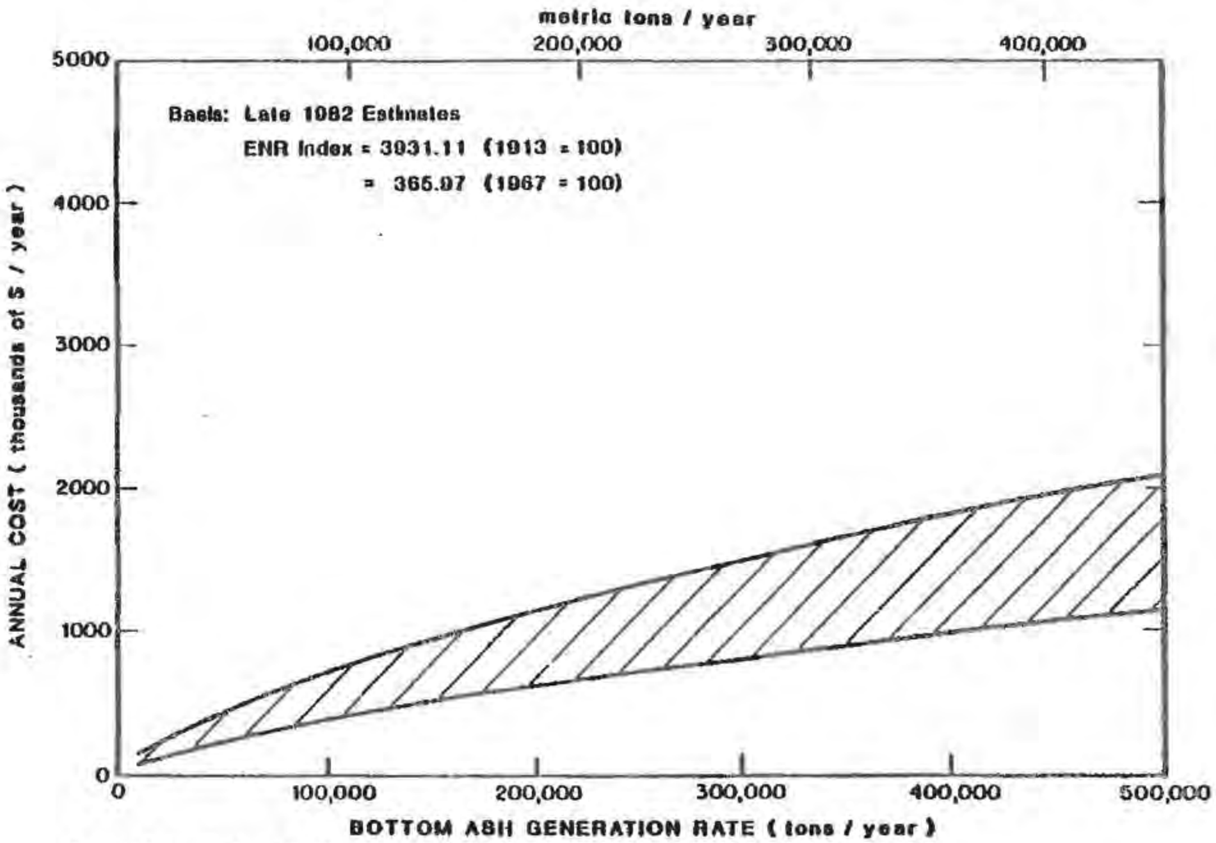
6-101

FIGURE 6.50 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH TRANSPORT (Wet Sluicing)



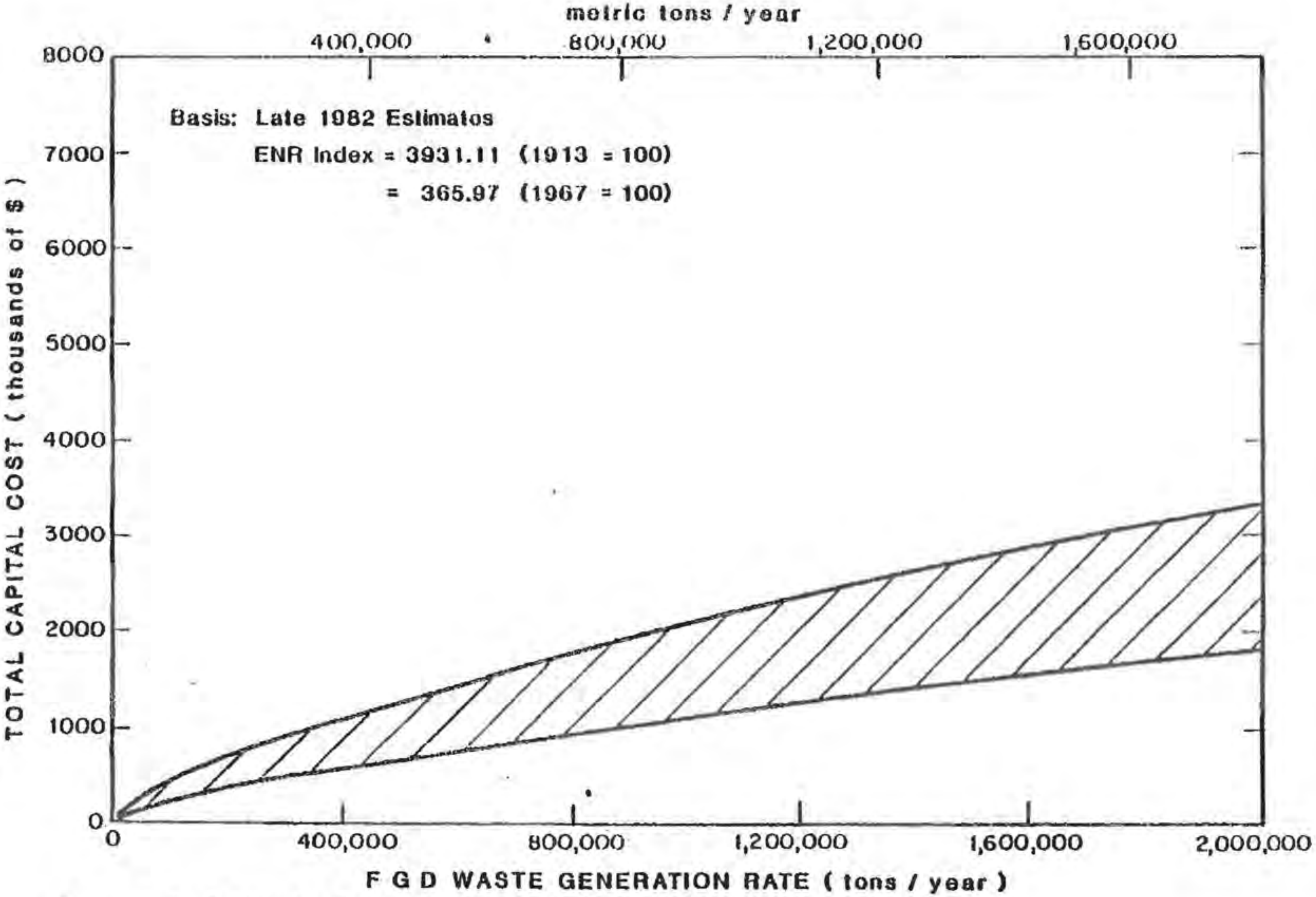
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.51 ANNUAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH TRANSPORT (Wet Sluicing)



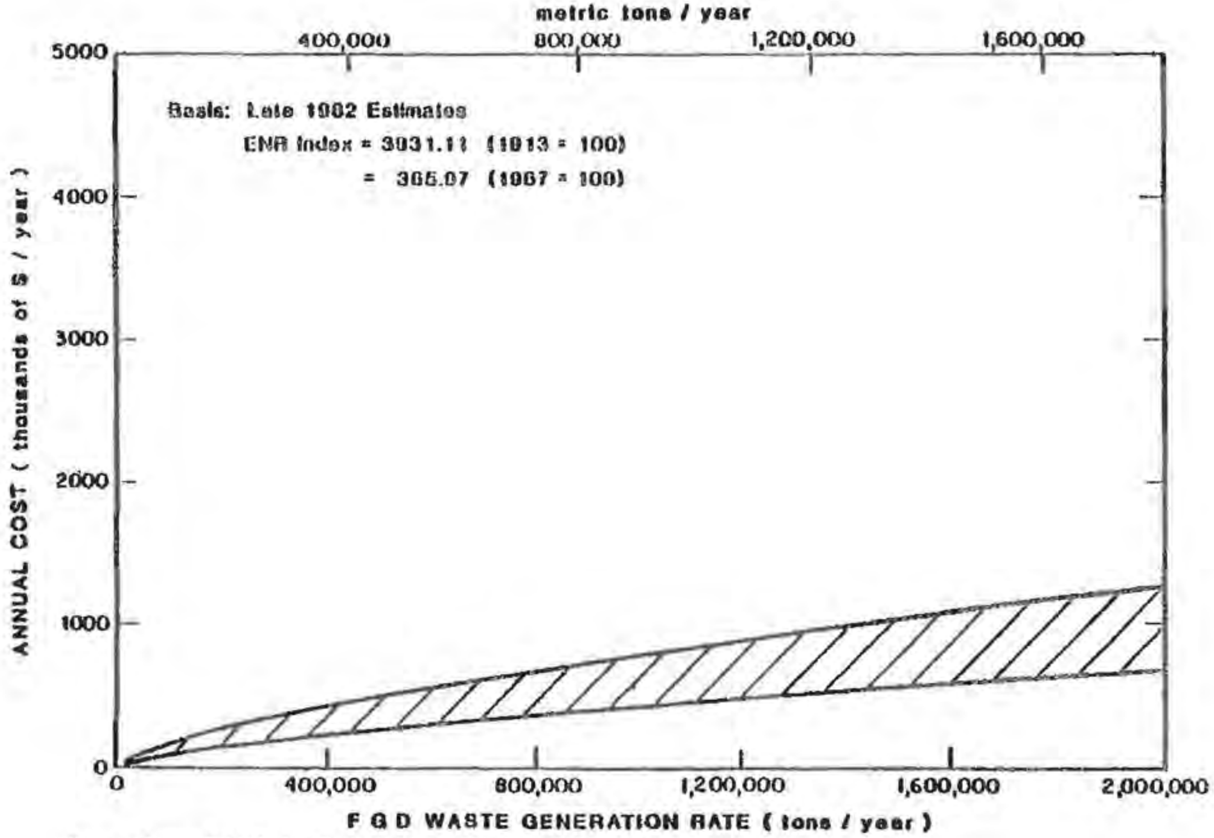
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.52 ANNUAL COST VERSUS BOTTOM ASH GENERATION RATE
BOTTOM ASH TRANSPORT (Wet Sluicing)



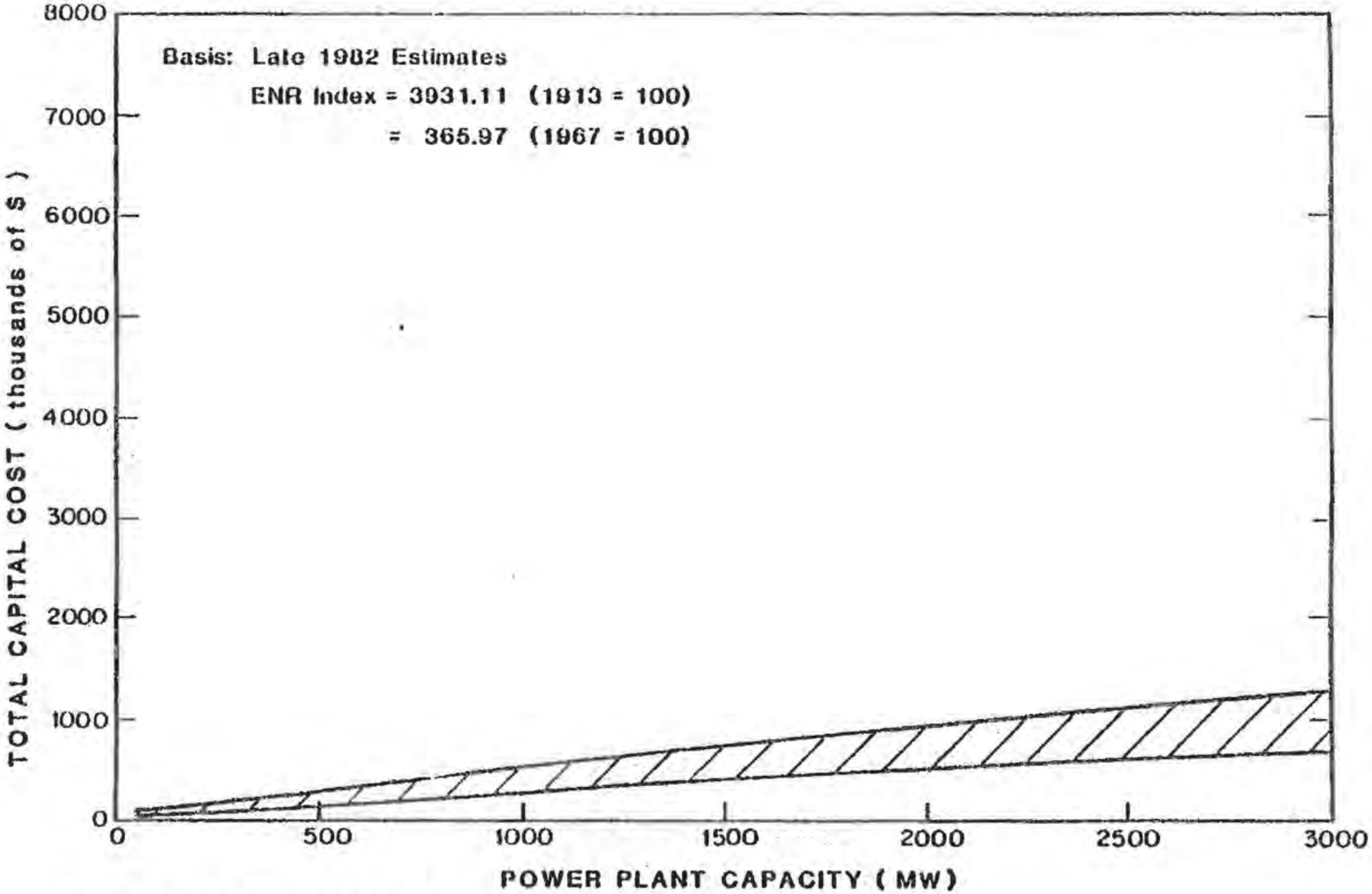
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.53 TOTAL CAPITAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE TRANSPORT (Wet Sluicing)



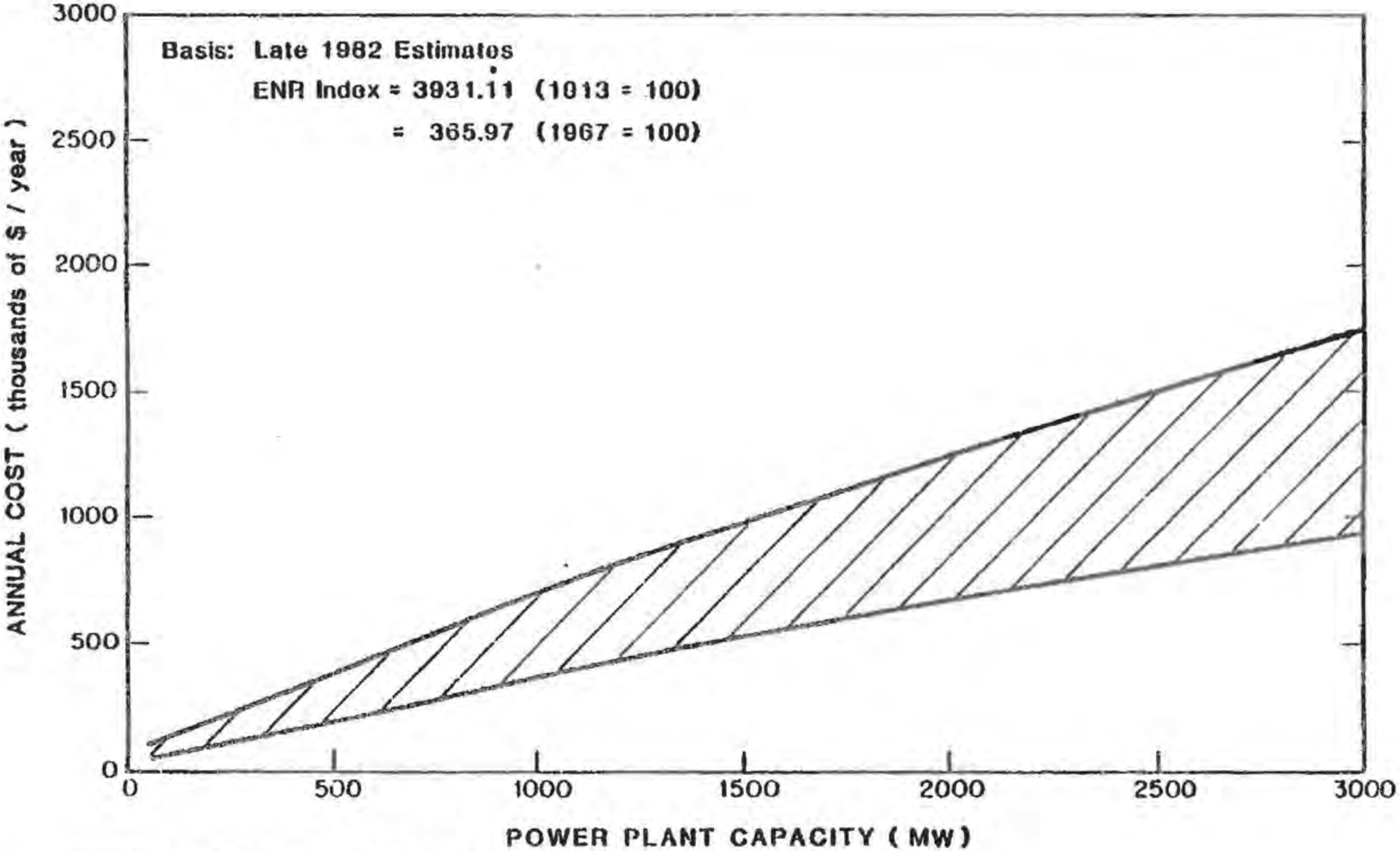
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.54 ANNUAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE TRANSPORT (Wet Sluicing)



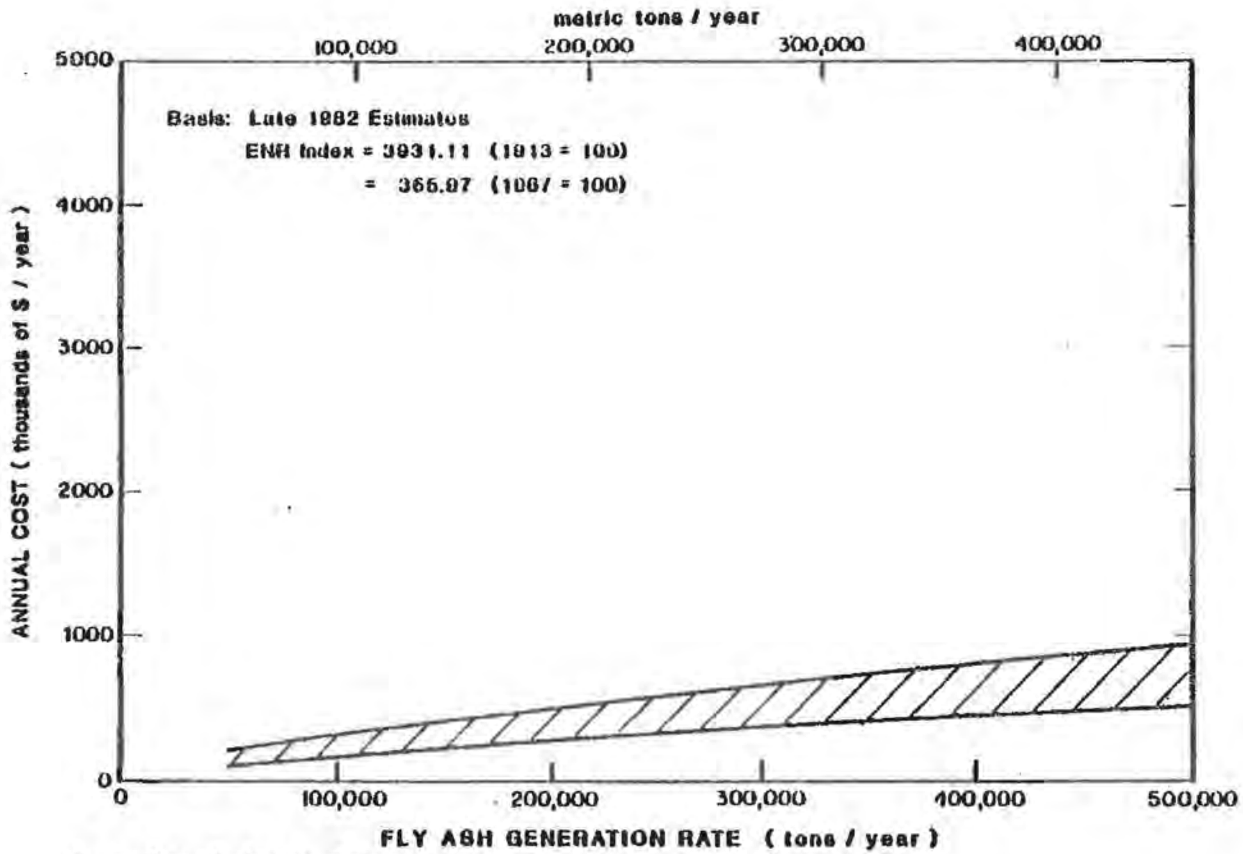
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.55 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH TRANSPORT (Trucking)



Source: Arthur D. Little, Inc. Estimates

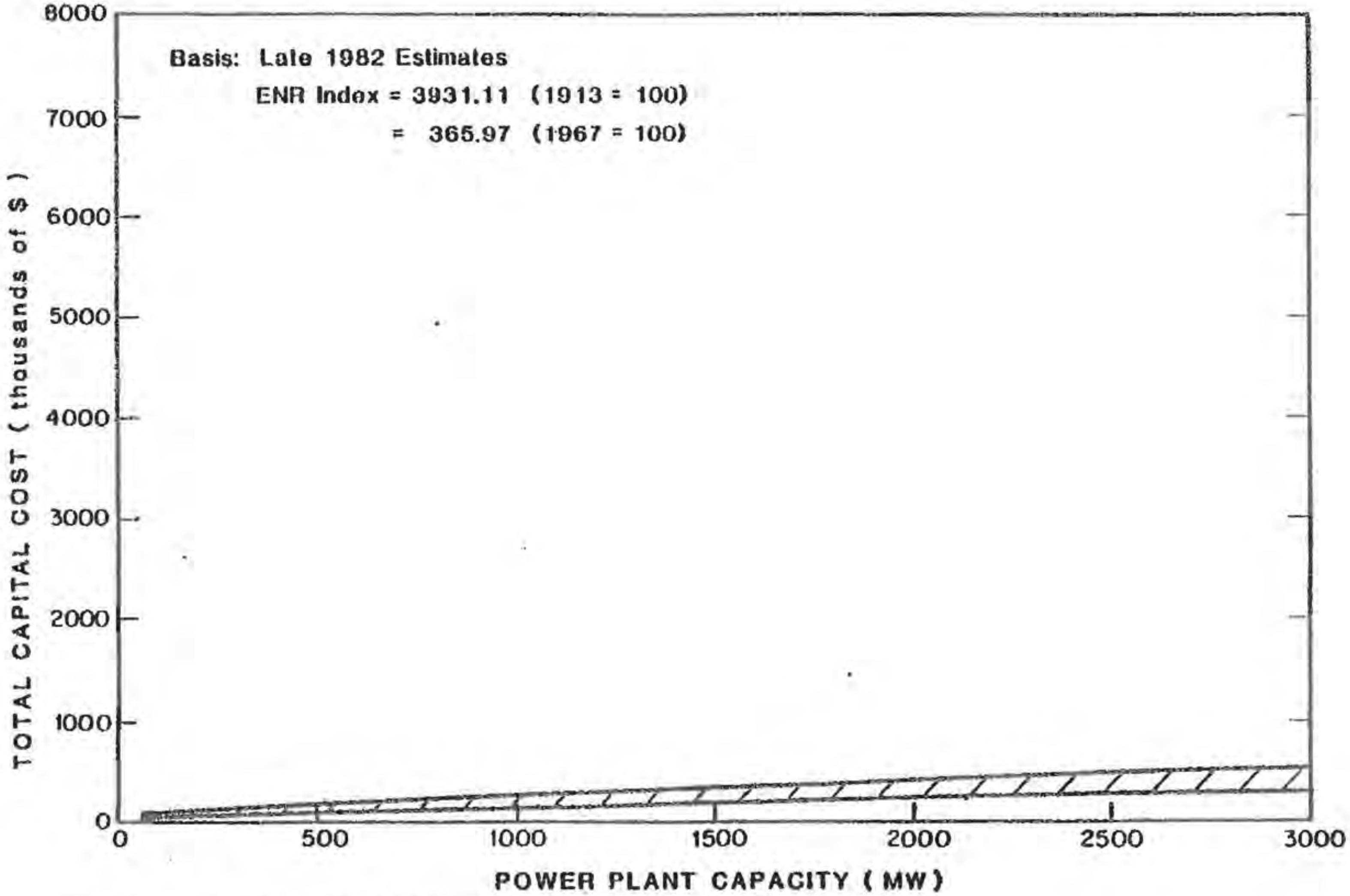
FIGURE 6.56 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH TRANSPORT (Trucking)



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.57 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH TRANSPORT (Trucking)

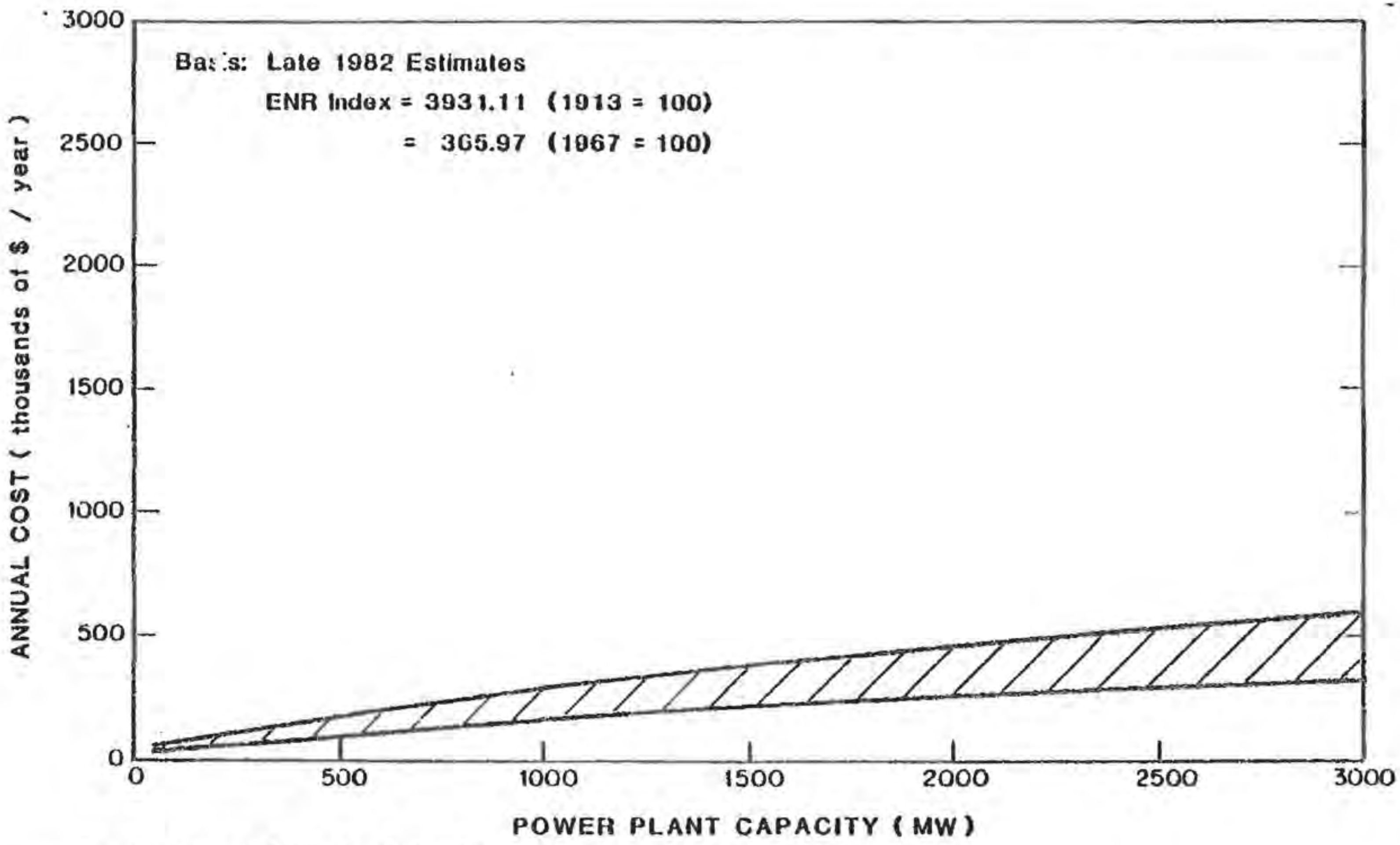
6-109



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.58 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH TRANSPORT (Trucking)

6-110



Source · Arthur D. Little, Inc. Estimates

FIGURE 6.59 ANNUAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH TRANSPORT (Trucking)

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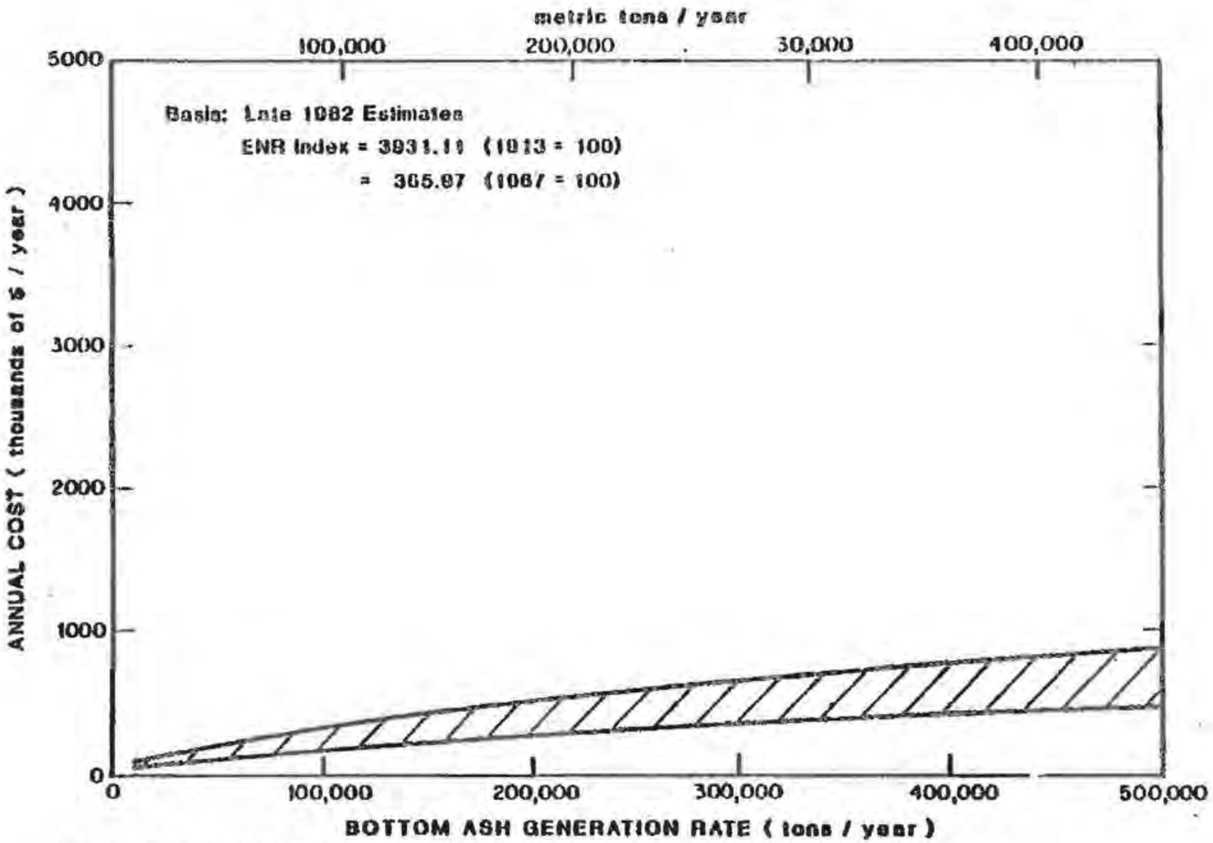


Source: Arthur D. Little, Inc. Estimates

FIGURE 6.60 ANNUAL COST VERSUS BOTTOM ASH GENERATION RATE
BOTTOM ASH TRANSPORT (Trucking)

for annual costs) and FGD wastes (Figures 6.61 and 6.62 for capital and annual costs, respectively). Variations in these costs arise as a result of transport distance and transport vehicle type. For the purpose of constructing these cost curves, a transport distance of 1.6 km (1 mile) was assumed.

The effect of varying transport distance on truck transport costs was not determined (see Section 6.3). In general, increased transport distances require additional vehicles with accompanying purchase and operating cost increases. Such cost increases, however, would not be directly proportional to the amount of additional capacity required.

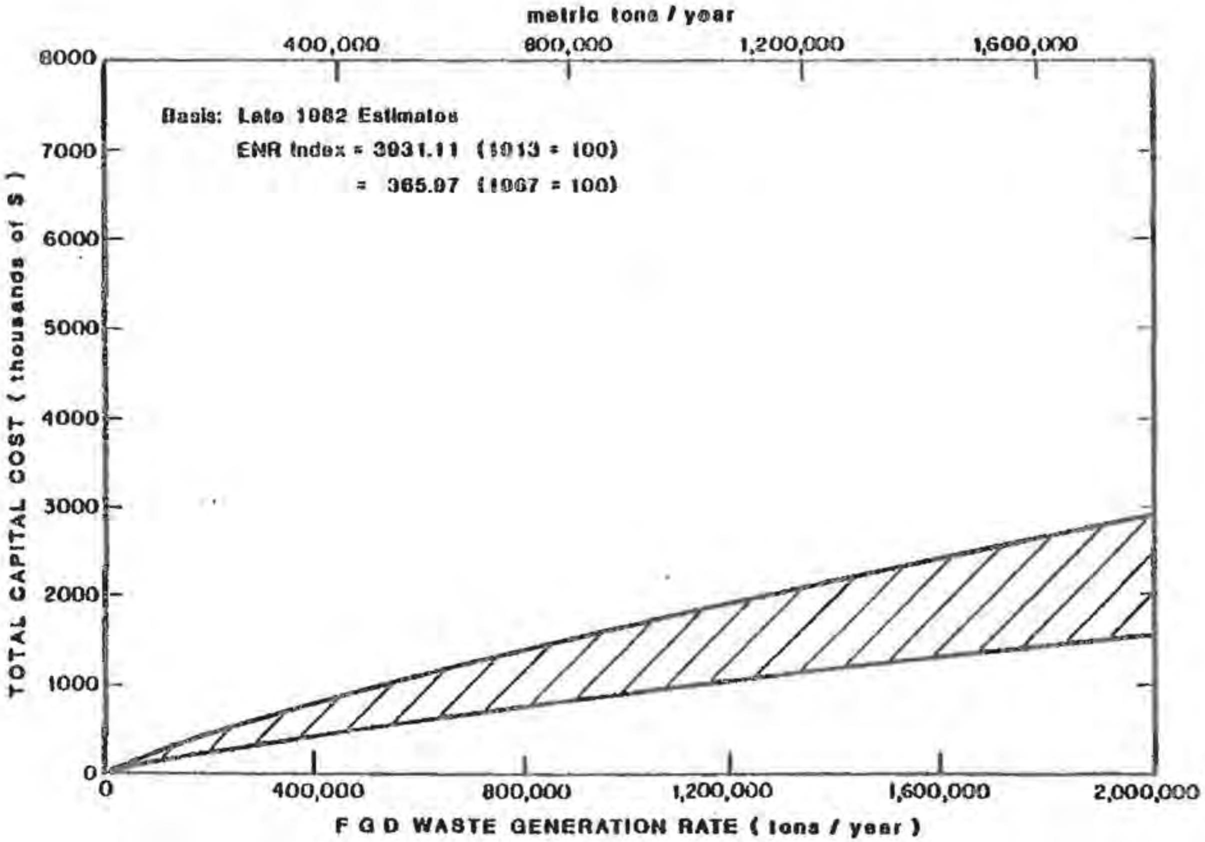
Coal-fired utility wastes can be transported in on-highway or off-the-road trucks. Off-the-road truck transport would result in higher capital but potentially lower annual costs. The curves are based on the use of on-highway trucks.

Coal Ash and FGD Waste Placement and Disposal -- There is very little difference among the three types of wastes with respect to disposal practices. In fact, codisposal of wastes is common practice. Thus, the following discussion of disposal capital and operating costs pertains to all of the three wastes under consideration.

Two types of disposal were considered with respect to capital and annual costs, ponding and landfilling. Mine disposal was not evaluated due to a paucity of data; ocean disposal, which is not currently practiced commercially, was similarly not considered.

Pond disposal costs for fly ash are provided in Figures 6.63 (capital costs), 6.64 and 6.65 (annual costs). Similar graphs are provided for bottom ash ponding, Figures 6.66 (capital costs), 6.67 and 6.68 (annual costs), as well as for pond disposal of FGD wastes, Figures 6.69 and 6.70 (capital and annual costs, respectively). Cost curves for landfill disposal are presented in Figures 6.71 (capital costs), 6.72 and 6.73 (annual costs) for fly ash; in Figures 6.74 (capital costs), 6.75 and 6.76 (annual costs) for bottom ash; and in Figures 6.77 and 6.78 (capital and annual costs, respectively) for FGD wastes.

Disposal site capital costs are primarily attributed to site preparation, excavation, and containment structure construction. With ponds, the costs of dike construction (for diked ponds) or excavation (for incised ponds) contribute significantly to overall capital costs. Sites which can be converted to ponds with minimal construction activities (e.g., valleys, abandoned pits, etc.) will have lower capital and annual costs than those which require significant earthwork. In the case of landfills, sites requiring minimal excavation to be suitable impoundment areas will have relatively lower costs than those requiring excessive earthwork. Thus, in disposal operations, the higher ranges of the capital cost curves reflect sites which require significant earthwork, while the lower cost band ranges pertain to disposal facilities where little earthwork was undertaken.



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.61 TOTAL CAPITAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE TRANSPORT (Trucking)

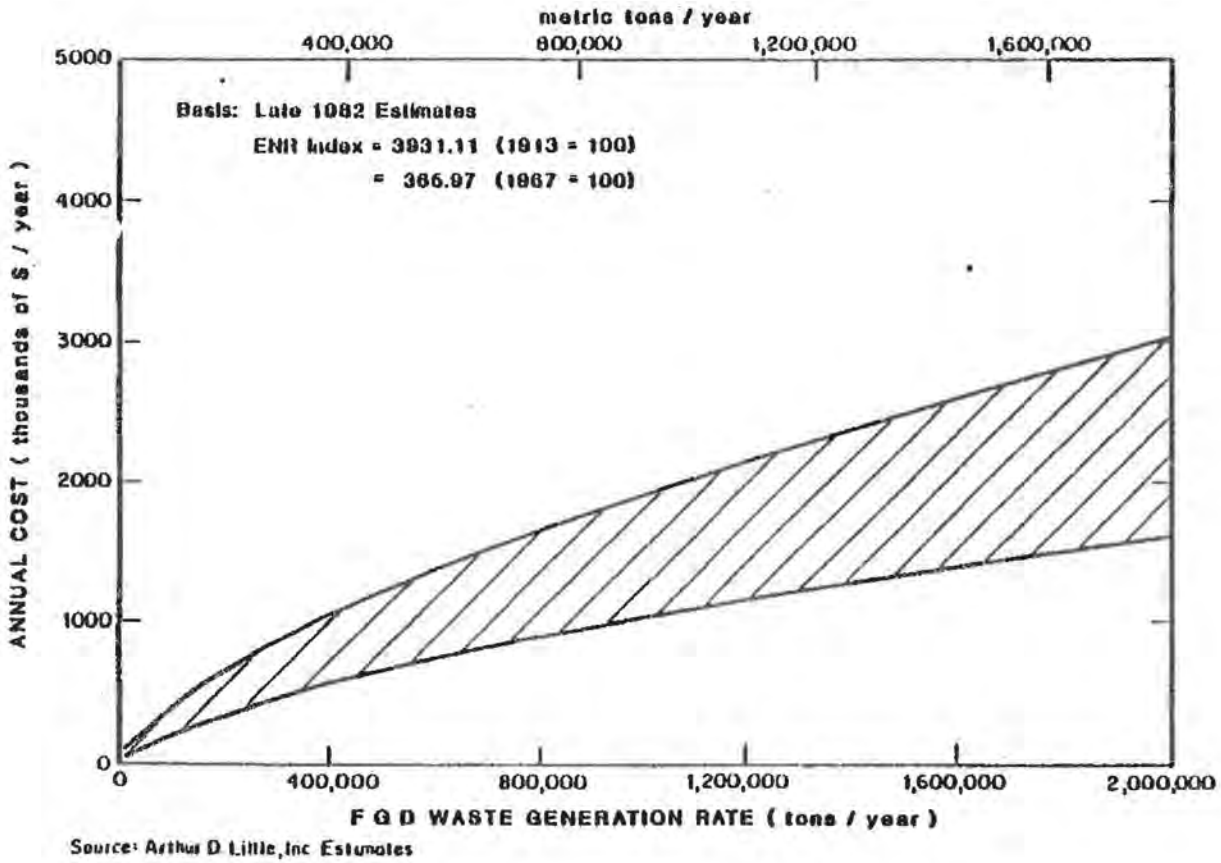
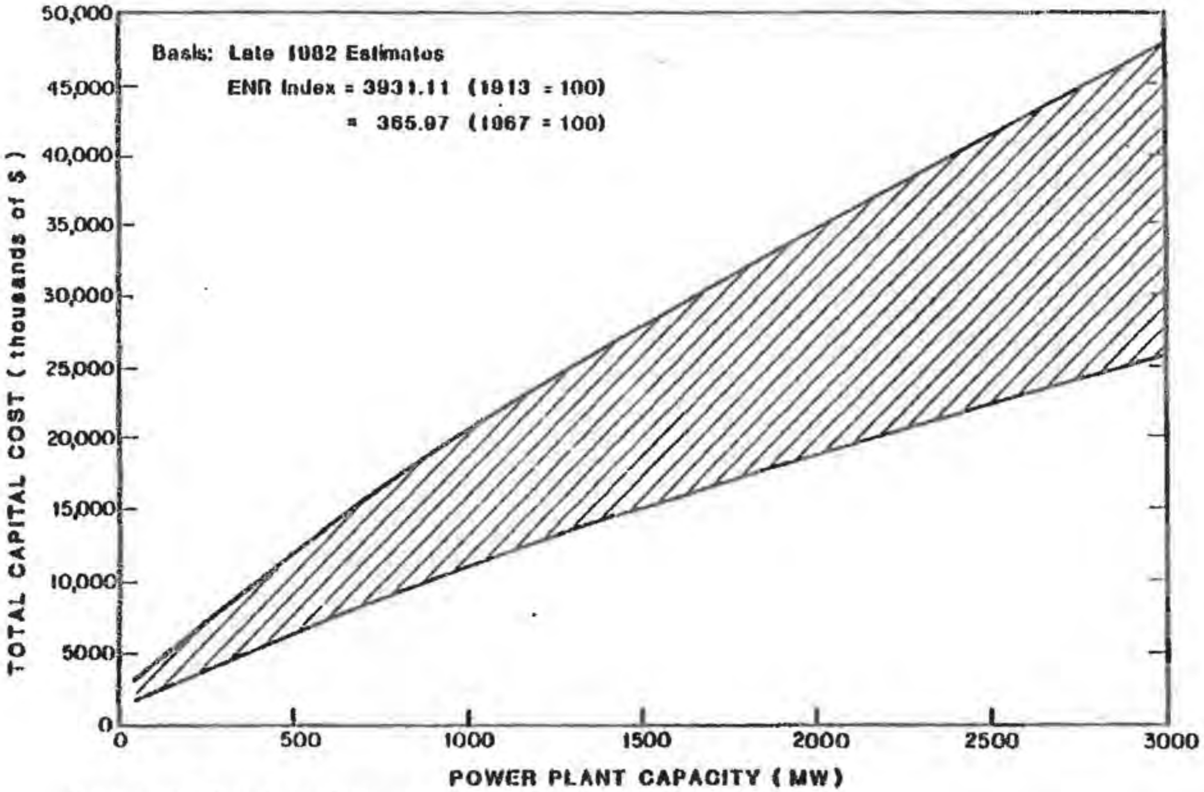
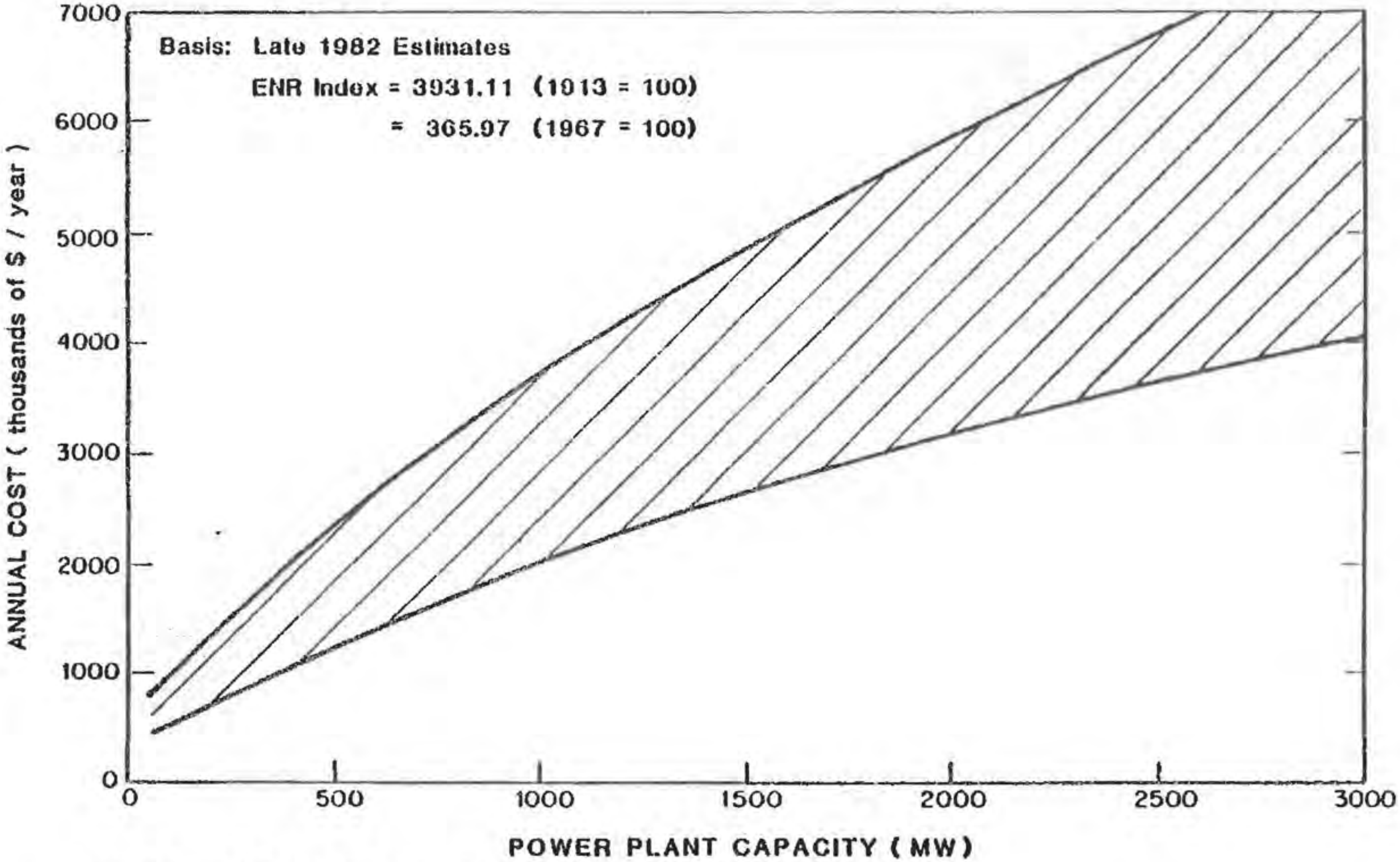


FIGURE 6.62 ANNUAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE TRANSPORT (Trucking)



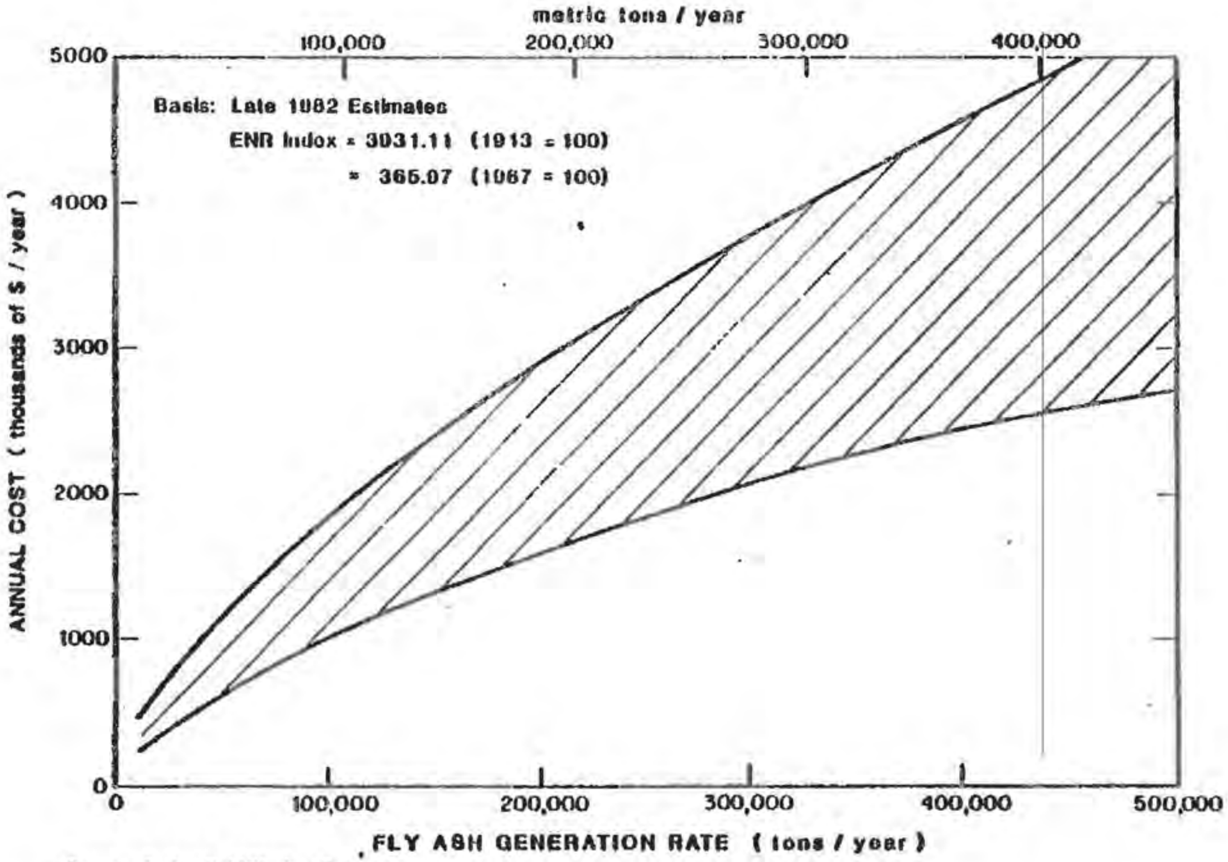
Source: Arthur D Little, Inc. Estimates

FIGURE 6.63 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding – Unlined Ponds)



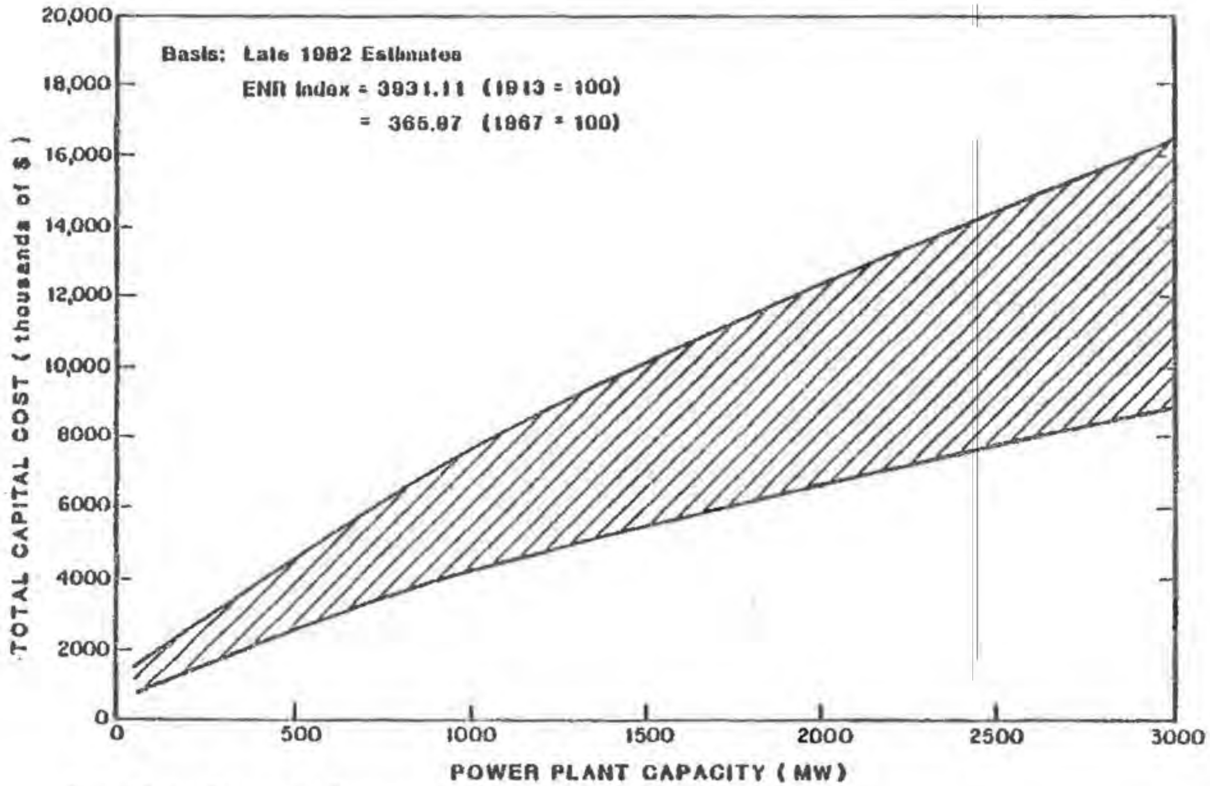
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.64 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding – Unlined Ponds)



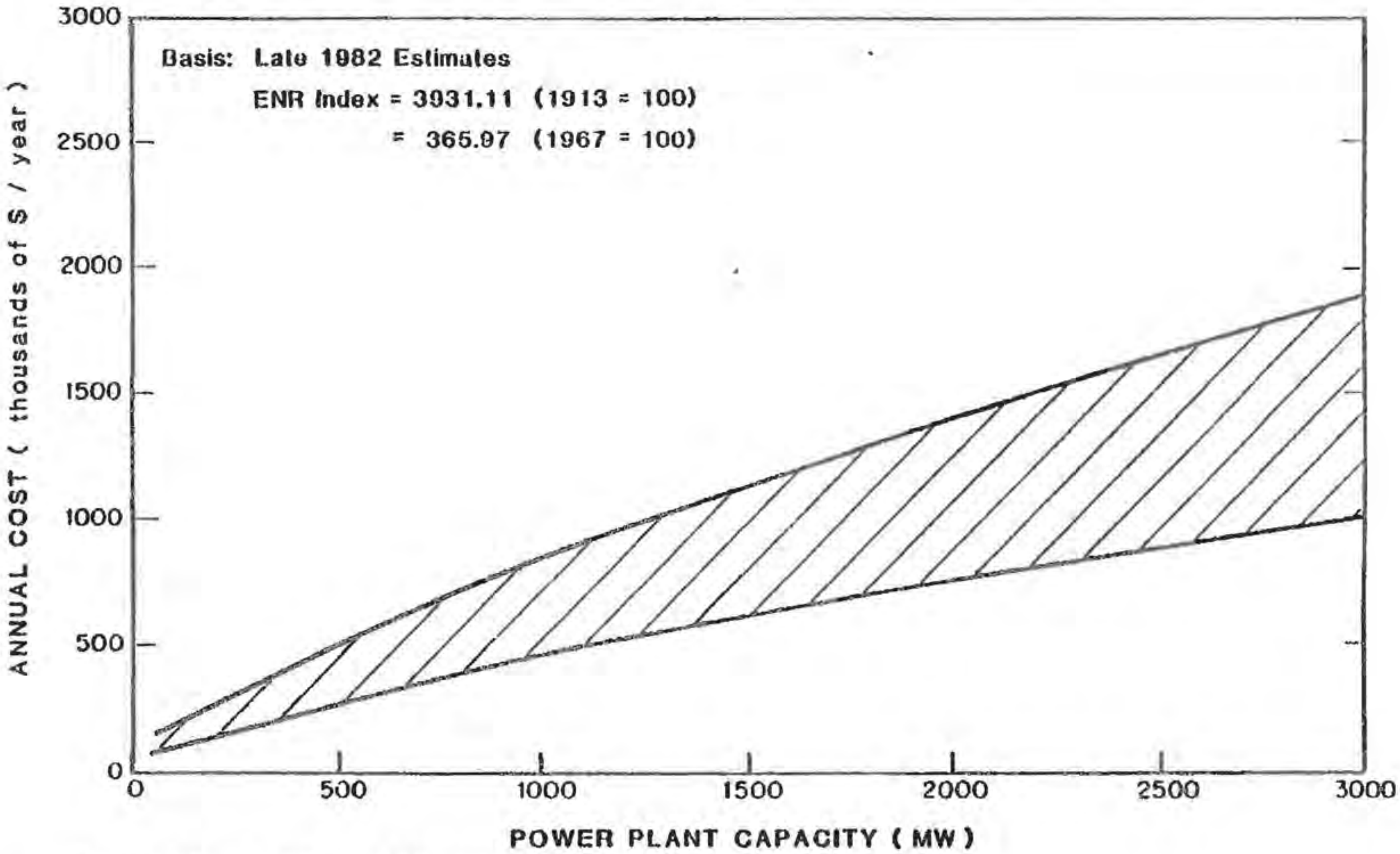
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.65 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH PLACEMENT and DISPOSAL
(includes site monitoring and reclamation)
(Ponding - Unlined Ponds)



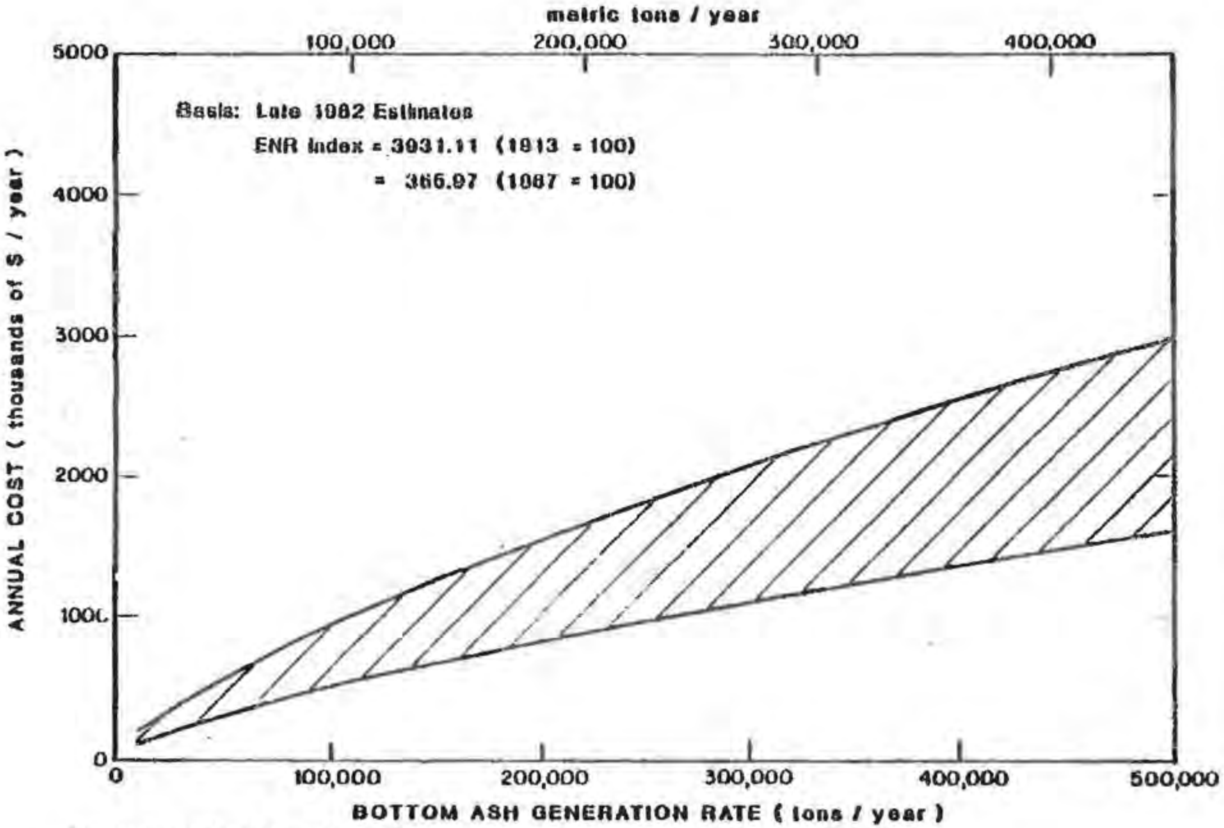
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.66 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding – Unlined Ponds)



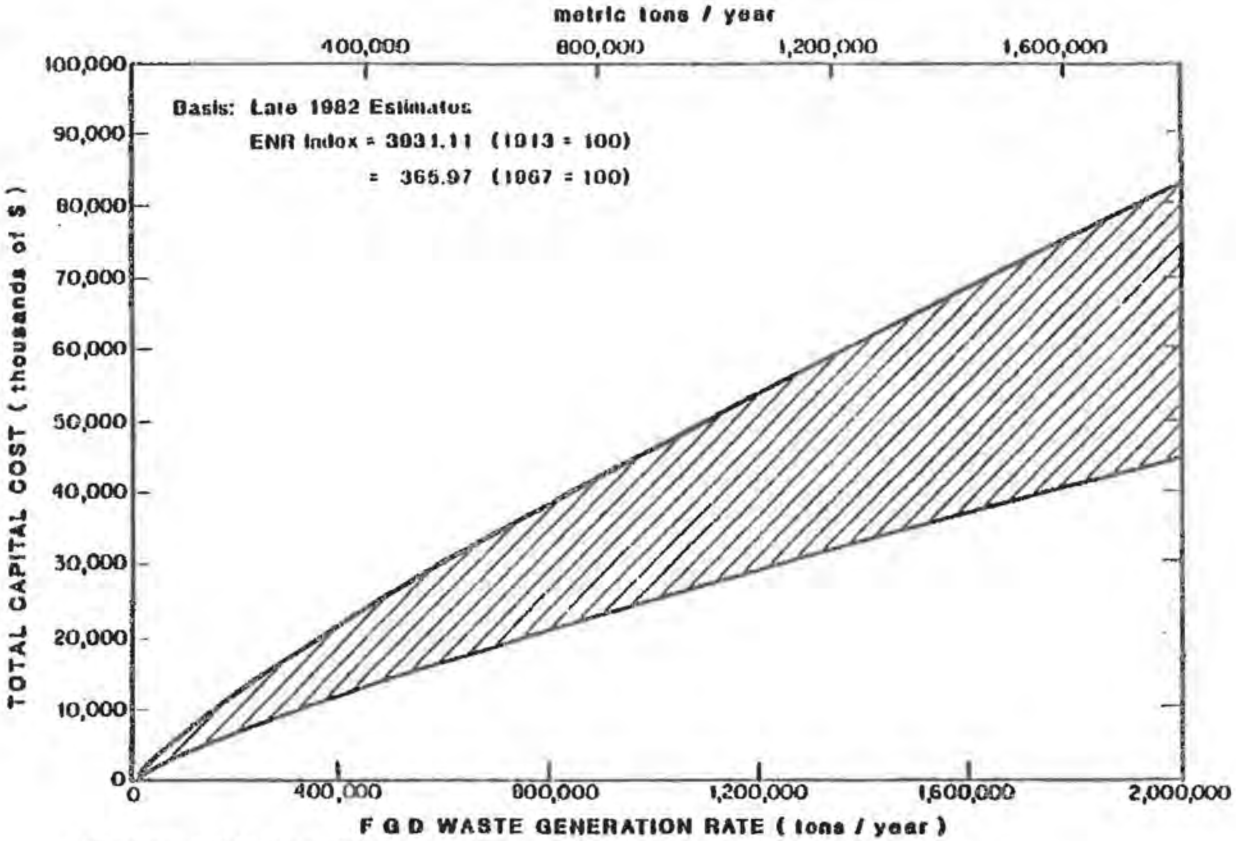
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.67 ANNUAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding – Unlined Ponds)



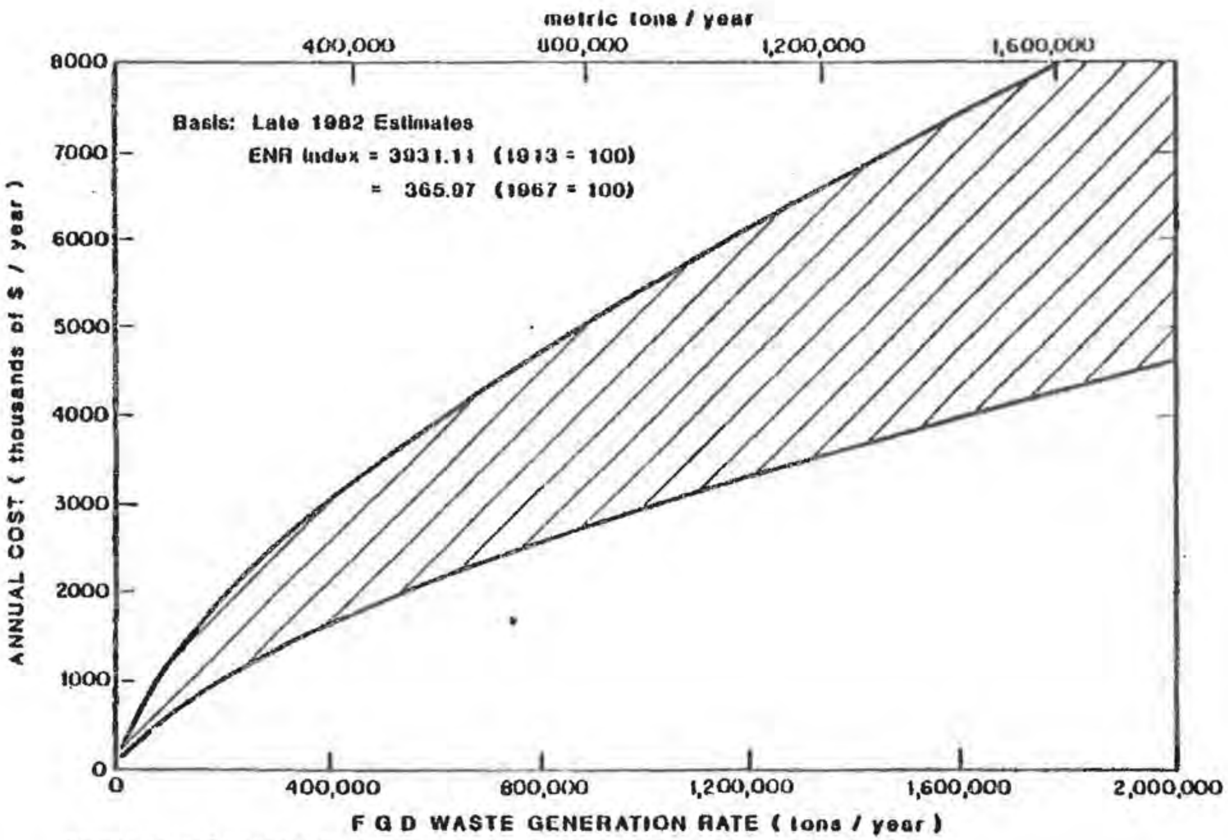
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.68 ANNUAL COST VERSUS BOTTOM ASH GENERATION RATE
BOTTOM ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding - Unlined Ponds)



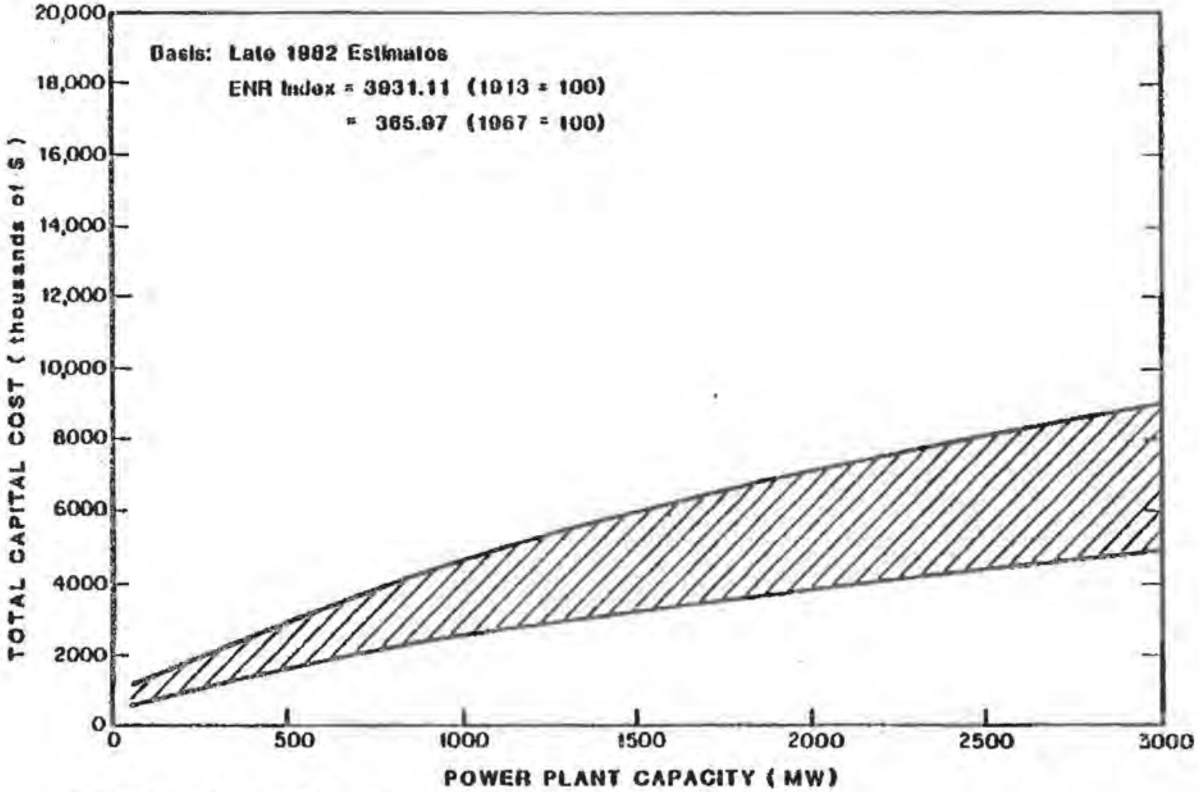
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.69 TOTAL CAPITAL COST VERSUS F G D WASTE GENERATION RATE
FGD WASTE PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding – Unlined Ponds)



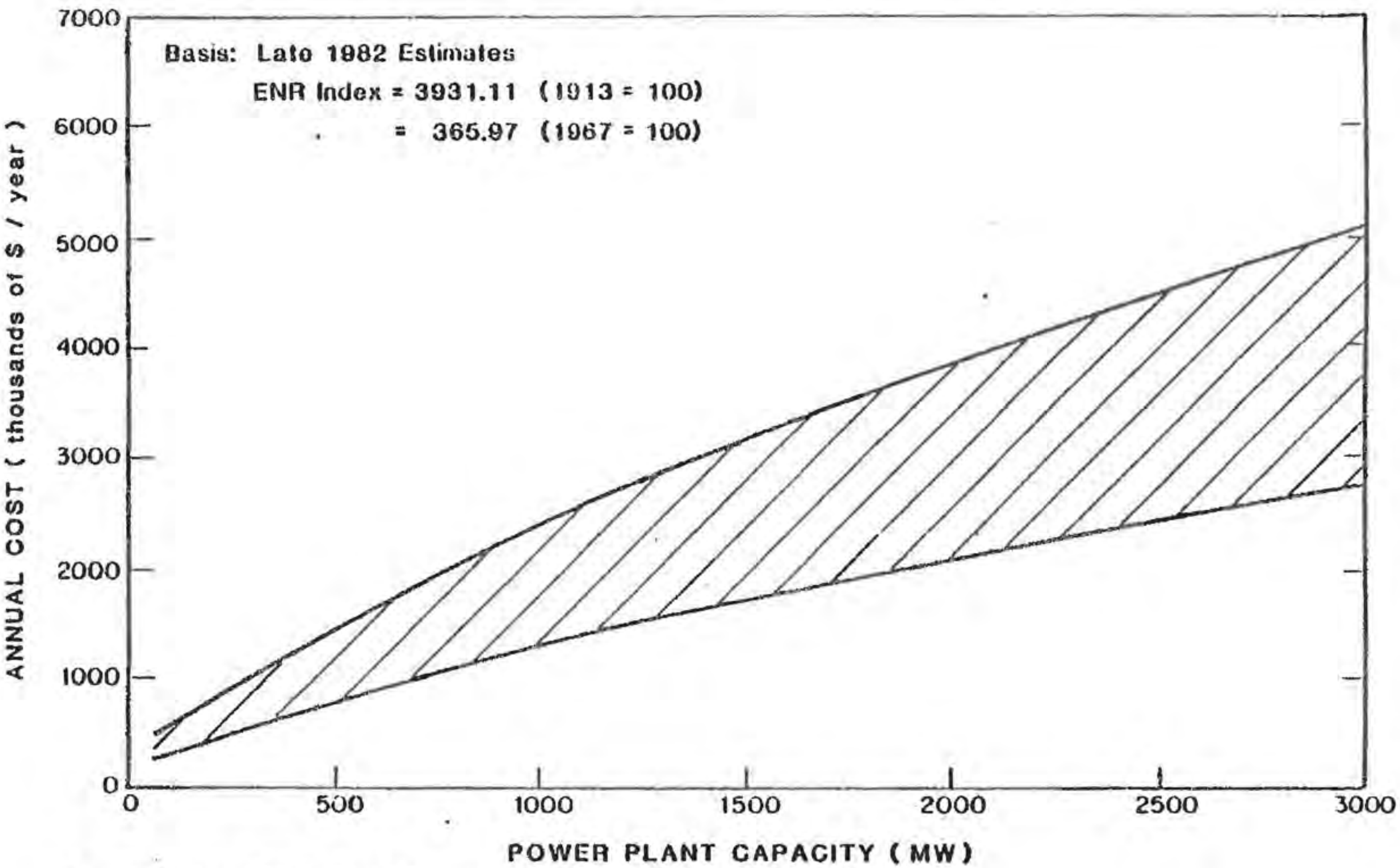
Source: Arthur D Little, Inc. Estimates

FIGURE 6.70 ANNUAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Ponding – Unlined Ponds)



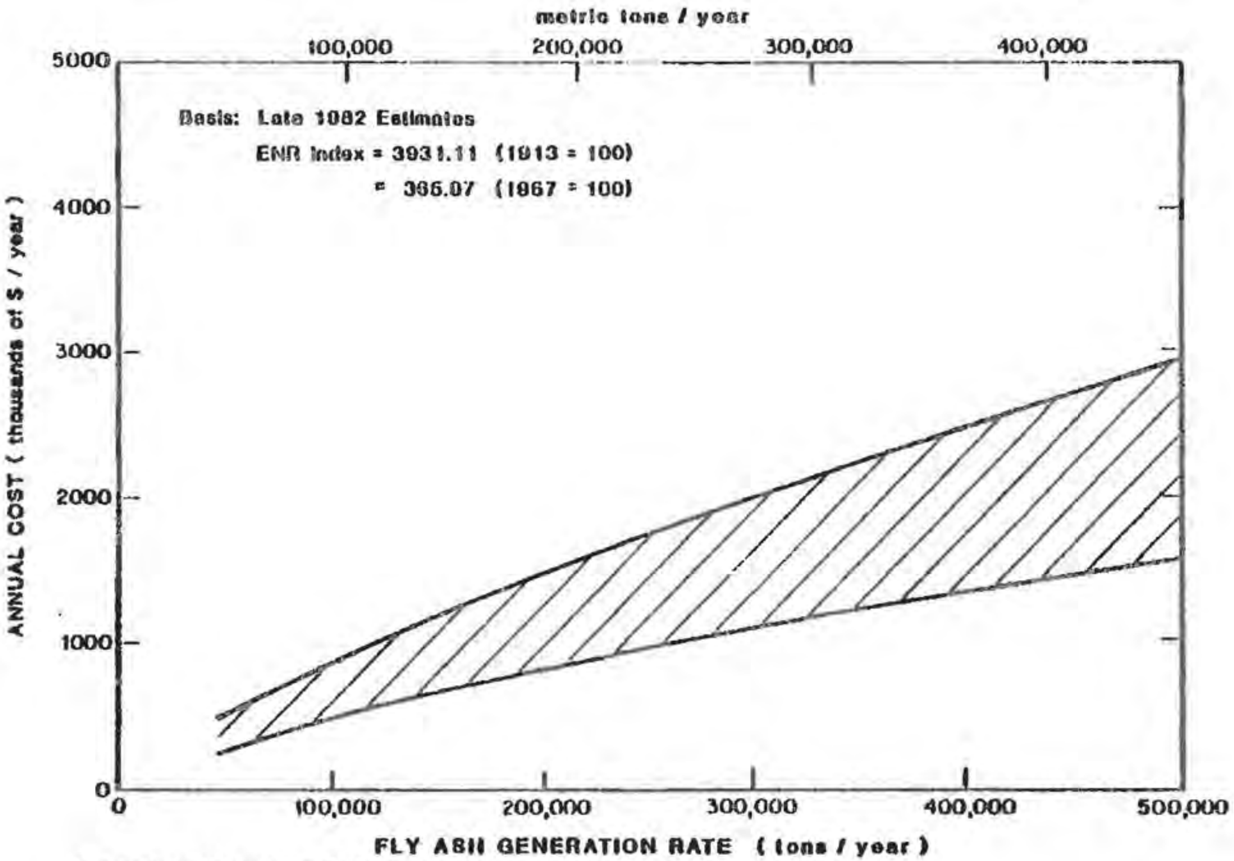
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.71 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
FLY ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Landfilling)



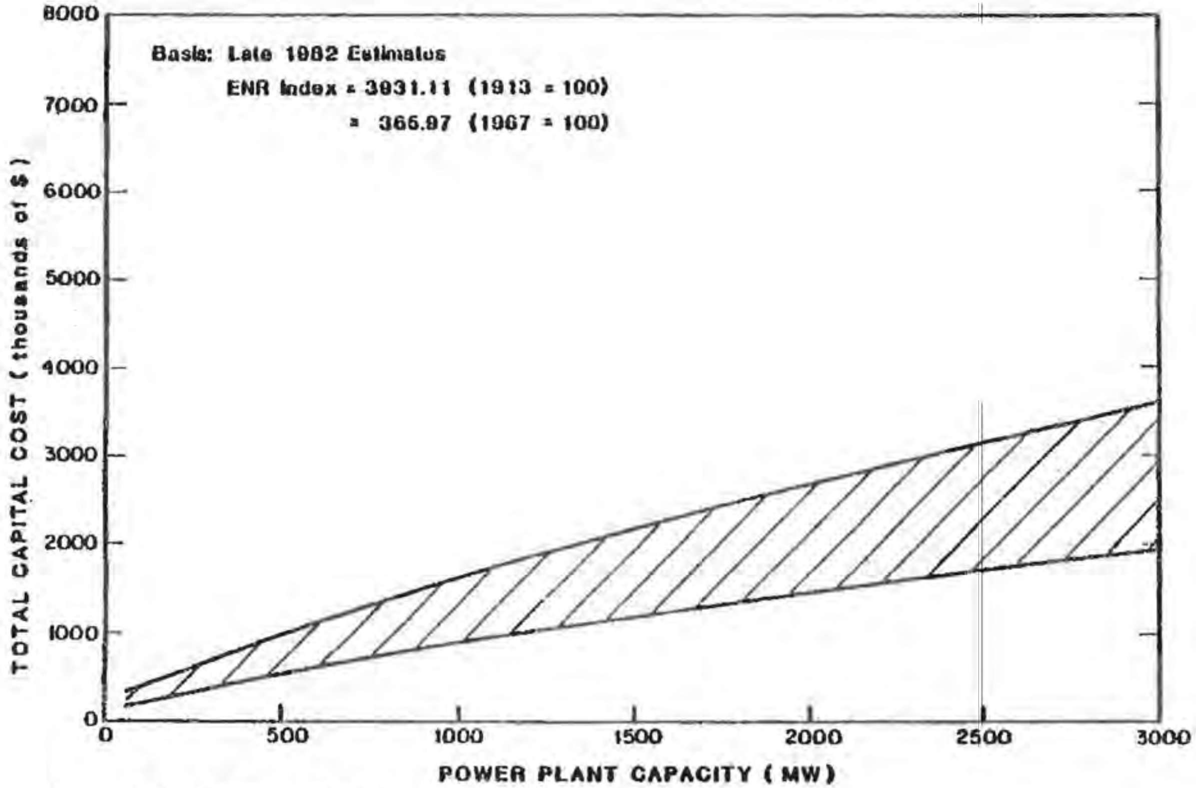
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.72 ANNUAL COST VERSUS POWER PLANT CAPACITY
FLY ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Landfilling)



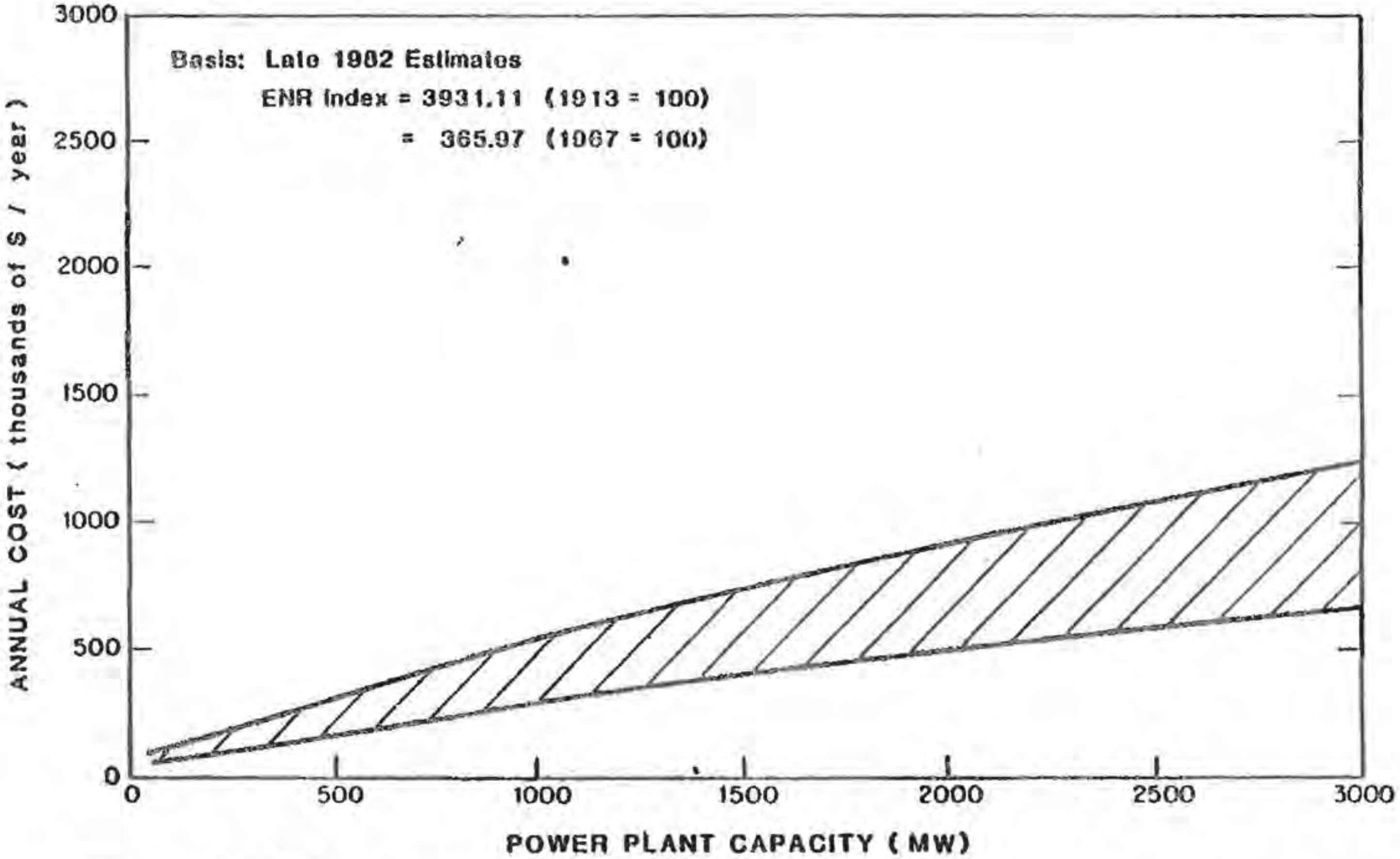
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.73 ANNUAL COST VERSUS FLY ASH GENERATION RATE
FLY ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Landfilling)



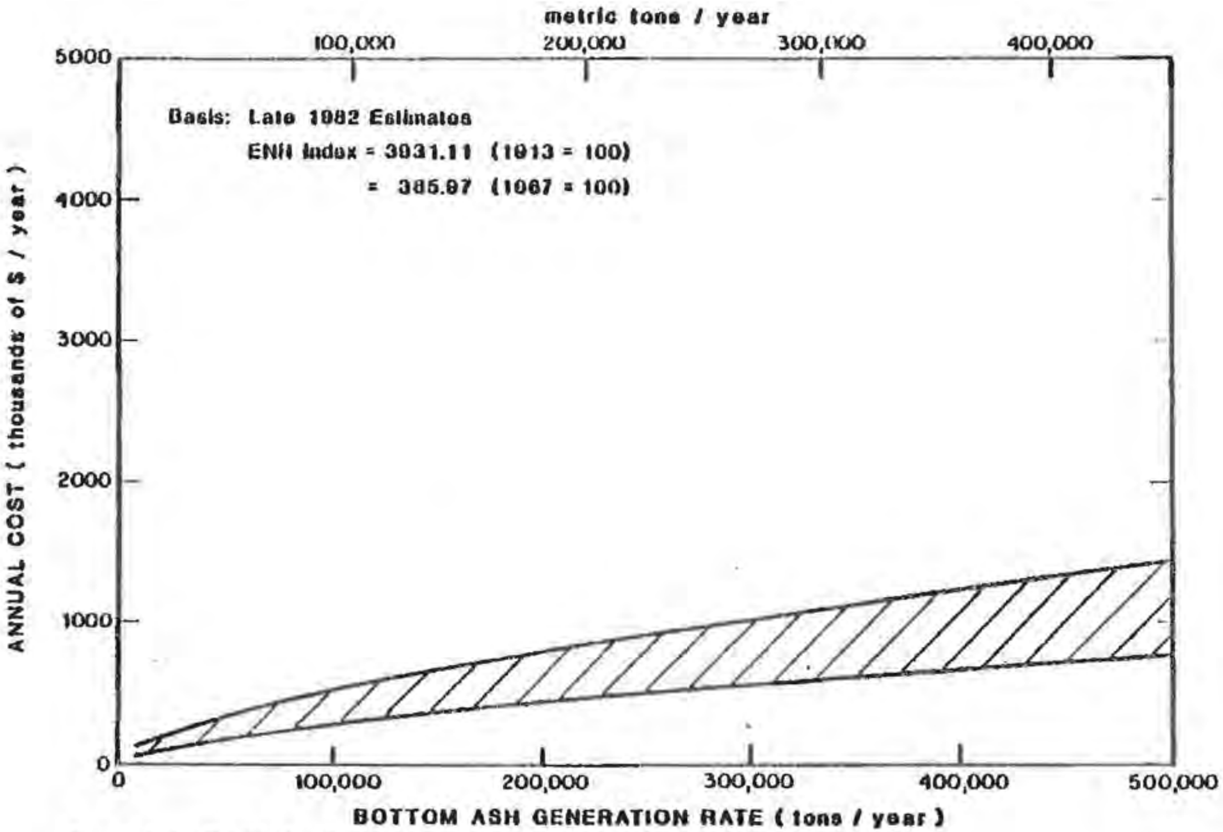
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.74 TOTAL CAPITAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Landfilling)



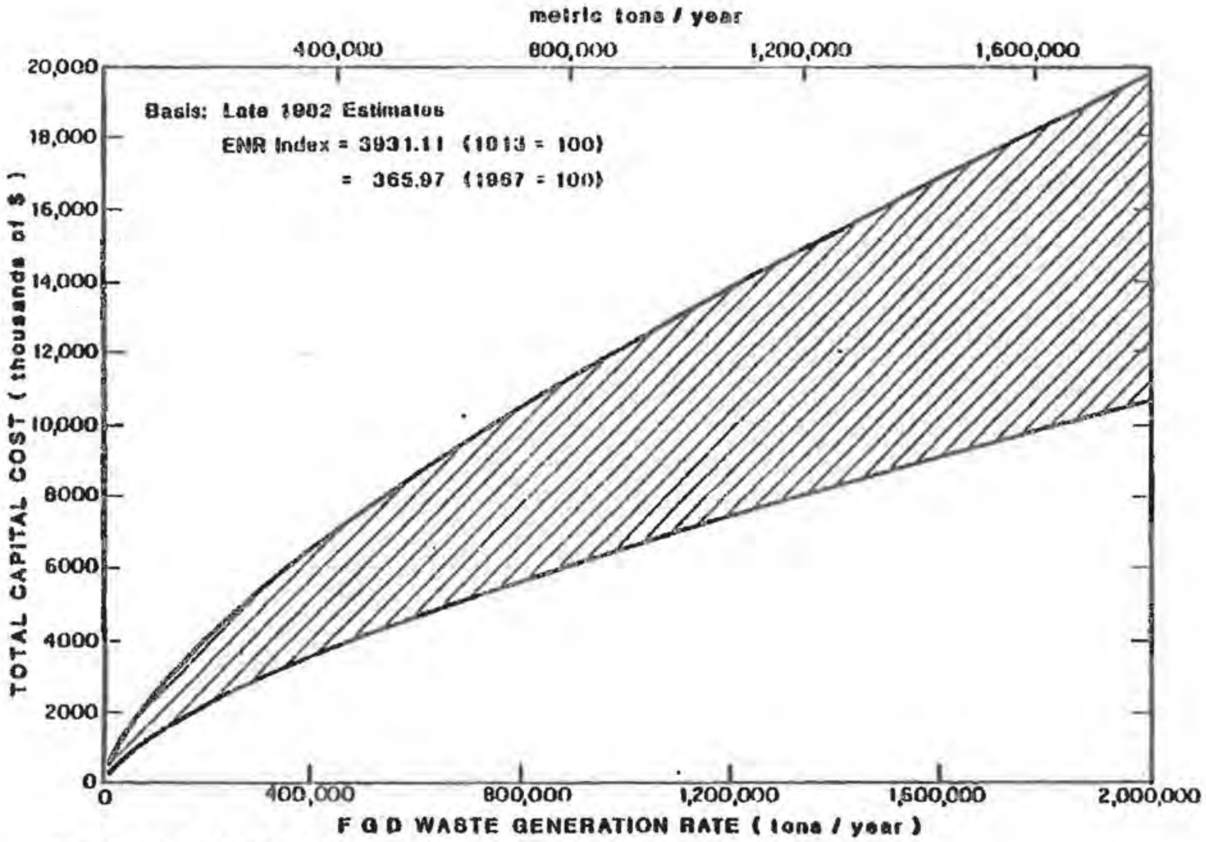
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.75 ANNUAL COST VERSUS POWER PLANT CAPACITY
BOTTOM ASH PLACEMENT and DISPOSAL
(includes site monitoring and reclamation)
(Landfilling)



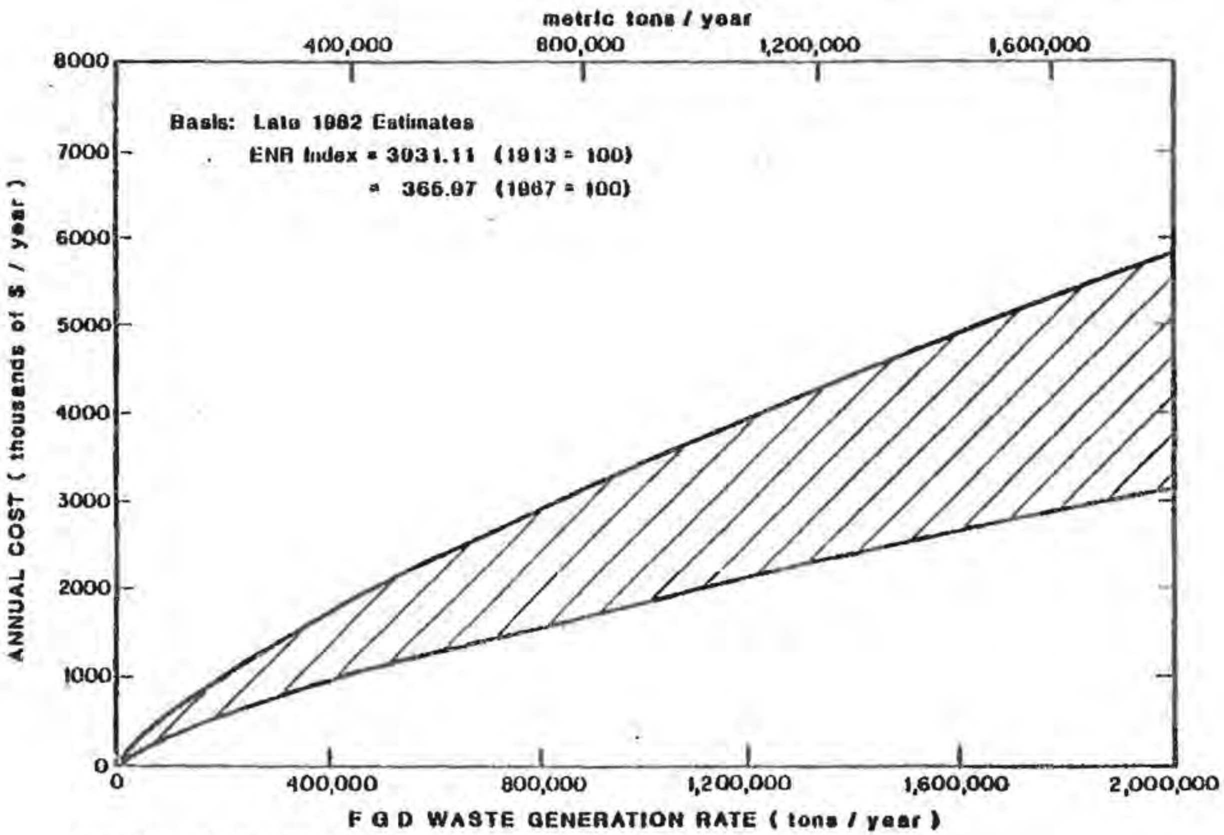
Source: Arthur D. Little, Inc. Estimates

FIGURE 6.76 ANNUAL COST VERSUS BOTTOM ASH GENERATION RATE
BOTTOM ASH PLACEMENT and DISPOSAL
(includes site monitoring and reclamation)
(Landfilling)



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.77 TOTAL CAPITAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Landfilling)



Source: Arthur D. Little, Inc. Estimates

FIGURE 6.78 ANNUAL COST VERSUS F G D WASTE GENERATION RATE
F G D WASTE PLACEMENT and DISPOSAL
(Includes site monitoring and reclamation)
(Landfilling)

Another issue with respect to landfill disposal is posed by operating requirements. In some cases, wastes are dumped with moderate or minimal compaction, while in other cases, significant effort is expended to place the waste in a specific manner. For example, the wastes from CSI chemical fixation processes are routinely compacted and graded at the landfill site. Thus, landfill annual costs are highly dependent upon placement requirements as well as on the capital charges contribution. In cases where the landfill requires significant construction and placement of the waste involves compaction, the annual costs will fall in the upper ranges of the cost band. Where no significant capital charges or compaction requirements are involved, annual costs will be much lower.

The most significant annual cost for pond disposal is for capital charges. Thus, pond configurations which give rise to high capital costs (i.e., those which require significant site preparation and earthwork) would be likely to have high annual costs.

All disposal cost curves pertain to sites which do not have natural (i.e., clay) or synthetic liners. Liner costs are highly site specific depending on:

- the liner material employed;
- the availability of a good source of liner material within a reasonable proximity, in the case of natural liners;
- the desired thickness of the liner; and
- the area to be lined.

Due to this site-specificity, and the fact that a very large number of design options exist for disposal site liners, it was not possible to develop generic cost curves which adequately included all such site conditions and options. Instead, some general insights into liner costs and factors influencing variations in such costs are presented below.

A variety of lining materials are available for disposal operations. Clays, polymeric membranes, admixtures, chemical sealants, and other materials have been used. (A more detailed discussion of liner characteristics is presented in Section 6.1.6.2) The most common liners for utility waste disposal applications include clays, polymeric materials and stabilized utility wastes. This study considers only those three liner types.

Clay Liner materials include a variety of clay soils. However, the most well-known clay liner material is bentonite. The most important cost consideration with respect to clay liners is the availability of the liner material; transportation is a major cost element if the clay must be imported. Compacted indigenous clays are low-cost liner options. Permeability can vary, depending on the nature of the clay and degree of compaction. Thus, proper installation is essential to optimum performance. Imported bentonite is higher in cost than native soil liners, although the use of this liner may, in some cases, be more economical than polymeric liner options. Of course, this is a site-specific issue relating to the cost of transporting the bentonite from its source to the disposal site. The installed cost (1982 dollars) of clay liners ranges from \$5.10 to \$18.00/m^3 (\$3.90 to \$13.80/yd^3) (59). Assuming a liner thickness of 0.46 m (18 in), this corresponds to a cost range of \$2.30 to \$8.20/m^2 (\$9,400 to \$33,000/acre). Transportation of imported clays, if such is necessary, can influence cost trends significantly. Assuming a bentonite source in Wyoming, transportation costs to the West Coast, East Coast and the South could be in the ranges of \$55 to 65/metric ton (\$50 to 65/ton), \$130 to 140/metric ton (\$120 to 130/ton) and \$105 to 110/metric ton (\$95 to 100/ton) for each destination, respectively (60). The cited costs were adjusted to late-1982 dollars. The clay liner costs presented here are for placement of the liner only and do not include site preparation costs (e.g., clearing, grubbing, cutting, filling, etc.) which are attributed to disposal site construction. The liner costs are presented in late-1982 dollars and include the total incremental capital investment for liner placement. Items such as engineering and contractor's overhead and fees, as well as contingency, are included.

Stabilized utility waste materials have been used as liner materials. One material, Poz-O-Tec®, is a mixture of fly ash, FGD waste and lime; a second material which is a mixture of only coal ash (fly ash and slag) and lime is currently denoted Pozzolanic Aggregate Mixture (PAM), although it was previously referred to as Poz-O-Pac®.

The fixated waste may be an attractive liner for new disposal sites at existing utility plants, since the majority of the liner material is available captively as an undesired by-product. For new plants, it may be necessary to import the liner materials, at least during the initial phases of plant construction.

Based on discussions with a supplier of Poz-O-Pac® liners, a fully installed cost of \$15.70/m^3 (\$12.00/yd^3) was estimated (M. Nowicki, American Fly Ash Company, personal communication, September 24, 1982). For hypothetical sites with 0.9 m (3 ft) and 1.5 m (5 ft) liner thicknesses, this corresponds to a cost of \$14.40/m^2 (\$58,000/acre) and \$24.00/m^2 (\$97,000/acre), respectively. The costs cited here were estimated with the underlying assumption that all required materials are locally available.

Polymeric membranes have been increasingly applied as waste disposal site liner materials. Two types of polymeric membranes are in use, exposable (i.e., membranes which are resistant to exposure to the elements without being covered) and unexposable (i.e., membranes which do not retain their integrity if left exposed). Of the four common polymeric membrane liner materials, three fall into the exposable category (i.e., hypalon , chlorinated polyethylene, and high density polyethylene), while one, polyvinyl chloride (PVC) is an unexposable material. The installed costs (late-1982 dollars) for the listed types of exposable membrane liners range from \$9.40 to \$24.50/m^2 (\$38,000 to \$99,000/acre), and those for unexposable membranes range from \$12.80 to \$26.70/m^2 (\$52,000 to \$108,000/acre) (60). The above costs include soil sterilization, subgrade preparation, underliner materials and installation, liner materials and installation, contractor's profit and overhead, engineering fees/overhead and contingency. The ranges provided reflect differences in the cost of varying materials, differences in cost related to liner thickness, and a contribution for minimal site specific requirements. The cost of site preparation (e.g., clearing, grubbing, filling and compaction) is not included, since these have been attributed to disposal site construction. As such, the costs presented are incremental costs for liner placement only.

The costs associated with site monitoring and reclamation are included in the waste placement and disposal module costs. Site monitoring capital costs, based on the assumption that six groundwater monitoring wells are installed for any one disposal site, would typically range in the vicinity of \$15,000 to 20,000. As one would expect, site monitoring costs contribute very little to the overall waste placement and disposal module capital costs. The same holds true for the annual cost associated with site monitoring (sampling and analysis activities, which generally fall in the range of \$8,500 to 12,000/year for the first year (assuming four sampling trips per year). In contrast, site reclamation costs are highly site-specific, depending on the surface area to be reclaimed, the availability of top soil, and the need for dewatering of the waste in the case of ponding operations. Site reclamation activities covered by the waste placement and disposal module costs in this project consist of covering the disposal site with 0.45 m (1.5 ft) of cover soil along with 0.15 m (6 in) of top soil (not available on site), followed by seeding. The capital cost for such reclamation would typically be on the order of \$1.50 to 2.20/m^2 (\$6000 to 9000/acre).

Related Environmental Systems (Air Pollution Control) -- As noted in Section 6.1.2, in developing engineering and cost data on solid waste handling and disposal systems at utilities, it is difficult to divorce oneself entirely from other aspects of a plant's environmental control system. One such example is the air pollution control system, which consists of particulate control, and in some cases sulfur oxides control. Using broad capital and annual cost estimates for both the air pollution control and the waste handling and disposal sytems, one can better understand the cost contributions of each to the total environmental control system cost.

The cost of air pollution control systems sheds some light on the cost of coal-fired utility waste disposal by allowing for the assessment of integrated environmental control systems. However, detailed capital and operating cost estimates for air pollution control were not developed in this project. The focus was rather on developing broad unit cost data of particular usefulness for preliminary evaluation of waste disposal options.

Presently, two types of air pollution control systems are used by coal-fired utilities, sulfur dioxide control systems and particulate control systems. A variety of options are available with respect to each type of air pollution control system. The cost data in this study are limited to include only those systems most commonly employed by utilities. Thus, with respect to sulfur dioxide control, conventional lime and limestone scrubbing systems are considered. Electrostatic precipitation is considered with regard to particulate control.

The cost of sulfur dioxide emissions control is affected by a number of variables, including, but not limited to:

- Plant size - FGD systems are modular in nature. One would expect costs per module to decrease as more identical modules are used. Hence, FGD costs per unit electric power generating capacity are expected to increase with decreasing plant size. In other words, economies of scale can be realized with FGD systems.

- Coal sulfur content - For specific sulfur oxides emission control requirements, the use of coal with relatively lower sulfur contents would result in the need for relatively lower sulfur oxides scrubbing capacities. Lower capacities, likewise, are lower in cost.

- Reagent consumption and availability - There are certain trade-offs between reagent availability and stoichiometric requirements. However, in some cases the less efficient reagent may be the least costly, particularly when a more efficient reagent is not available locally at an economical price.

In light of these variables, a review of the literature indicates that capital costs (in late-1982 dollars) for new FGD installations, typically lime or limestone based, would range from $90 to 170/kW (61-63). For retrofit applications, the capital costs for similar FGD systems could be up to 30 percent higher. Operating costs for these same systems would range from $35 to 65/kW per year. It must be noted, however, that a wide variability exists among the reported costs in the literature. This is primarily because the capital and operating costs found in the literature, as presented here, are attempting to represent a range of plant sizes (200 to 2000 MW), coal sulfur contents, and reagent consumption and availability. In addition, the wide variability in reported costs from different sources stems from plant specific conditions, including:

- design requirements for meeting various emission standards;

- battery limits included in the engieering/cost estimate; and

- degree of design redundancy in the FGD system itself.

The capital cost range noted above for these FGD systems covers direct and indirect capital costs. Direct capital costs include purchased equipment costs and installation costs (materials and labor) for system battery limits including the following major process areas: raw material handling and storage; feed preparation; flue gas treatment; and flue gas reheat. Waste handling, processing and disposal are not included in these estimates.

However, indirect capital costs such as field supervision, construction and field expense, and engineering and contingency are included. The annual operating costs similarly include both direct and indirect annual costs. Direct annual costs are for such items as operating labor, materials (e.g., lime or limestone), supervision, maintenance (materials and labor) and utilities (e.g., power and water). Indirect costs would include such elements as overhead expenses (i.e., payroll and plant overhead), general and administration costs, taxes, insurance, and capital charges.

As with FGD systems, the cost of particulate control by electrostatic precipitation is affected by a number of variables, including:

- electrical resistivity of the fly ash;
- temperature of the flue gas; and
- flue gas composition.

Electrical resistivity of fly ash significantly influences its collection by ESPs. In general, fly ash with high resistivity is more difficult to collect (and hence, for similar ESPs exhibits lower collection efficiencies) than that with low resistivity. Flue gas temperature has significant influence on resistivity; higher temperatures tend to decrease resistivity, thereby increasing collection efficiency. This is the major design premise behind hot-side ESPs. Although collection efficiency and costs are reduced as a result of decreases in fly ash resistivity, equipment must be sized considerably larger to handle the increased volume (due to thermal expansion) of gas; the cost of such requirements must be taken into consideration. As noted in Section 6.1, fly ash resistivity is dependent upon coal sulfur content; in a similar manner, costs can be related to this parameter.

Flue gas composition can also affect collection efficiency and hence costs for electrostatic precipitation. Here too, the presence of certain species tends to influence resistivity. In general, fly ash resistivity is decreased with increasing coal alkali content, thereby increasing collection efficiency and costs.

Given these variables, a review of the literature indicates that capital costs (in late-1982 dollars) for new electrostatic precipitator installations (both cold and hot-side type) would range from \$30 to 36/kW (64-66). Annual costs for these same systems would range from \$9 to 12/kW per year. Again, wide variability exists among the reported costs in the literature. This is primarily because the capital and operating costs found in the literature, as presented here, attempt to represent a range of plant sizes (200 to 2000 MW), coal sulfur contents, and flue gas compositions.

The capital cost range noted previously for electrostatic precipitator systems consists of direct and indirect capital costs. Direct capital costs include purchased equipment and installation (materials and labor) costs for system battery limits including the basic collector, fans and associated ductwork. Indirect costs cover such items as field supervision, construction and field expense and engineering and contingency. The annual costs similarly include both direct and indirect costs. Direct operating costs are for items such as operating labor, supervision, maintenance (materials and labor) and required utilities (e.g., power). Indirect costs include such elements as overhead expenses (i.e., payroll and plant overhead), general and administrative costs, taxes, insurance, and capital charges.

The generic costs presented in Figures 6.25 through 6.78 generally agree with the cost estimates developed for the six study sites. Notable differences occur when the design premises for a specific site differ from the design premises that pertain to the generic estimates. Tables 6.7 and 6.8 provide the modular site-specific cost estimates (capital and first year annual costs, respectively) for each of the six study sites, as well as the generic cost estimates that apply to each site. The analysis of these cost data follows:

- Plant Allen - The generic cost estimates for Plant Allen were on the same order as the site-specific estimates, with the exception of costs for the waste transportation module. This is because basalt-lined cast iron and polybutylene slurry piping are used at Plant Allen, and these materials are more expensive than more common piping materials.

- Elrama Plant - The site-specific cost estimate for the processing and handling module was higher than the generic estimates; this is because the Elrama Plant utilizes interim pond dewatering for bottom ash, and the generic costs do not include this option. Since interim ponding is more expensive than other bottom ash processing options, the difference among the generic and site-specific costs is expected. The costs of the waste transport system at Elrama follow a similar trend; this is because the site-specific cost estimate is based on a transport distance of 19 km (12 miles), while the generic cost is based on a shorter distance 1.6 km (1.0 mile).

- Dave Johnston Plant - The Dave Johnston site-specific cost estimates do not agree well with the generic cost estimates. This is because this plant incorporates some expensive options. The fly ash handling system at the Dave Johnston Plant utilizes atypical, expensive Nuva Feeders to transfer ash from the electrostatic precipitator hoppers to the conveying lines. The fly ash is transported via off-the-road trucks that are more expensive than the more typical on-the-road trucks. Additionally, significant landfill excavation is undertaken at this plant. Most plants limited excavation to the quantity of fill needed for reclamation, while additional excavation was required at this plant.

- Sherburne County and Smith Plants - In general, the site-specific and generic costs agreed well for both these plants. Since in both cases, the distance between the plant and disposal area (0.4 km, 0.25 mile) is shorter than that used in the generic cost assessment (1.6 km, 1.0 mile), the waste transportation module costs differ.

TABLE 6.7

COMPARISON OF SITE SPECIFIC AND GENERIC CAPITAL COST ESTIMATES

		CAPITAL COST (thousand $)					
		Raw Materials Handling and Storage	Waste Processing and Handling	Waste Storage	Waste Transport	Waste Placement and Disposal	Comments[a]
Allen	Site Specific Cost Estimate	NA	5,204	NA	10,850	25,149	
	Generic Cost Estimate	NA	3,300-6,000	NA	4,800-8,900[b]	17,500-32,400	Adjustment - coal ash content
Elrama	Site Specific Cost Estimate	697	18,820	2,982	4,813	7,122	
	Generic Cost Estimate	500-900	10,300-19,100[c]	2,200-4,100	500-900[b]	4,200-7,400	Adjustment - coal ash content
Dave Johnston	Site Specific Cost Estimate	NA	6,912	2,512	689	4,596	
	Generic Cost Estimate	NA	770-1400[b]	1,800-3,400	140-260[b]	1,500-2,800[b]	
Sherburne County	Site Specific Cost Estimate	NA	21,003	NA	2,603	38,406[d]	
	Generic Cost Estimate	NA	12,100-22,500	NA	5,600-10,400[b]	25,329-49,615[d]	
Powerton	Site Specific Cost Estimate	NA	9,856	6,027	1,004	80,075[e]	
	Generic Cost Estimate	NA	6,600-11,900	3,300-6,200	664-1236	65,700-122,000[e]	Adjustment - Fly Ash/Bottom Ash Ratio
Smith	Site Specific Cost Estimate	NA	2,849	NA	2,442	10,528	
	Generic Cost Estimate	NA	1,700-3,200	NA	1,800-3,300	6,300-11,700	Adjustment - Fly Ash/Bottom Ash Ratio

[a] Only adjustments to generic costs are noted. Adjustments were made as noted on page 6-54.
[b] See text for discussion of differences among site specific and generic cost estimates.
[c] Excludes cost of interim bottom ash dewatering pond.
[d] Includes the cost of a 0.45 m (1.5 ft) thick clay liner.
[e] Includes the cost of a 3 m (10 ft) thick POZ-O-PAC® liner.

Source: Arthur D. Little, Inc. estimates.

TABLE 6.8

COMPARISON OF SITE SPECIFIC AND GENERIC FIRST YEAR ANNUAL COST ESTIMATES

		CAPITAL COST (thousand $)					
		Raw Materials Handling and Storage	Waste Processing and Handling	Waste Storage	Waste Transport	Waste Placement and Disposal	Comments[a]
Allen	Site Specific Cost Estimate	NA	2,103.7	NA	2,607.1	4,236.7	
	Generic Cost Estimate	NA	1,100-2,100	NA	1,400-2,700	2,600-5,200	Adjustment - coal ash content
Elrama	Site Specific Cost Estimate	1,647.2	6,326.3	689.7	2,723.6	1,666.6	
	Generic Cost Estimate	1,100-2,100	2,500-5,000[b]	450-1,100	600-1,400[b]	1,500-3,000	Adjustment - coal ash content
Dave Johnston	Site Specific Cost Estimate	NA	1,863.0	579.2	374.1	1,000.1	
	Generic Cost Estimate	NA	300-700[b]	400-900	200-500	700-1,400	
Sherburne County	Site Specific Cost Estimate	NA	5,237.2	NA	643.6	6,929.7[c]	
	Generic Cost Estimate	NA	2,905-5,769	NA	1,500-2,900[b]	3,600-8,000[c]	
Powerton	Site Specific Cost Estimate	NA	2,750.4	1,328.9	1,257.3	15,777.9[d]	
	Generic Cost Estimate	NA	2,400-5,100	700-1,500	800-1,600	10,100-20,600[d]	Adjustment - Fly Ash/ Bottom Ash Ratio
Smith	Site Specific Cost Estimate	NA	1,028.2	NA	420.8	1,594.7	
	Generic Cost Estimate	NA	500-1,000	NA	500-1,200[b]	1,200-2,300	Adjustment - Fly Ash/ Bottom Ash Ratio

[a] Only adjustments to generic costs are noted. Adjustments were made as noted on page 6-54.
[b] See text for discussion of differences among site specific and generic cost estimates.
[c] Includes capital charges for a 0.45 m (1.5 ft) thick clay liner.
[d] Includes capital charges for a 3 m (10 ft) thick POZ-O-PAC® liner.

Source: Arthur D. Little, Inc. estimates.

- Powerton Plant - The generic and site-specific cost estimates for the Powerton Plant agreed with each other.

The site-specific and generic cost estimates are thus fairly similar.

6.2.4 Capital and Operating Cost Estimation Methodology

As previously noted, it is not always necessary to prepare detailed cost estimates where conceptual estimates will suffice. This section explains a simplified method for quickly estimating capital and first year annual costs of both total utility solid waste handling and disposal systems as well as the individual process modules defined here. This method is intended to provide a conceptual cost estimate (with accuracy of plus 30 percent minus 10 percent) for preliminary planning purposes only, and should not be substituted for more detailed estimates prepared from detailed engineering or piping and instrumentation diagrams and site-specific information (e.g., type of terrain, soil conditions, etc.).

Methodology -- The method of estimating waste handling and disposal system costs for a set of specific waste types involves first determining both the capital and annual cost for each and every process module employed in the handling/processing and ultimate disposal of the various waste types (i.e., fly ash, bottom ash and/or FGD waste) generated at the proposed utility plant. This is accomplished with the aid of the appropriate capital and annual cost curves (Figures 6.25 through 6.78). After the costs of each and every individual process module have been estimated for each and every waste type of concern, one then simply adds all of the module costs to arrive at a total waste handling and disposal system cost for the particular plant under consideration. The following example illustrates the use of the cost curves.

Landfill Example: The hypothetical task consists of determining the total capital cost, first year annual cost, and cost per ton of dry waste (including fly ash, bottom ash and FGD waste) for a new 500 MW plant employing fixation of the FGD waste and landfilling of the fixated waste and dewatered bottom ash.

Step 1: Estimate or determine the basic engineering design premises.

- Plant size - 500 MW
- Plant life - 30 years
- Plant load factor - 70 percent
- Heat rate - 10.8 M joules/kWh (10,250 Btu/kWh)
- % S in coal - 2.0 percent
- % Ash in coal - 18.0 percent

- Coal heating value - 24.4 M joules/kg (10,500 Btu/lb)
- Waste quantities generated (dry)
  - fly ash: 195,000 metric tons/year (215,000 tons/yr), collected dry
  - bottom ash: 50,000 metric tons/year (55,000 tons/yr), dewatered in bins, with supernatant recycle
  - FGD waste: 122,000 metric tons/year (135,000 tons/yr)
- Distance to disposal site - 1.6 km (1 mile)
- Land availability - 100 percent
- Liner type - no liner

Step 2: Compare the above given or calculated engineering design premises for the newly proposed plant with those on which the cost curves were based (summarized in Table 6.5). Note any differences that exist between the engineering design premises for the proposed plant and those for which the cost curves are deemed applicable.

	Proposed Plant	Cost Curves
% S in coal	2.0	0.5 - 3.5
% Ash in coal	18.0	12.0 - 15.0

Proceed ahead to Step 3, with the understanding that the cost estimates determined from the curves will be somewhat less accurate for this proposed plant because it has a somewhat higher ash content than that on which the cost curves are based. (The sulfur content falls within the range for which capital and annual costs for process modules associated with FGD waste were developed.) One way to reconcile the difference in engineering design premises is to determine a correction factor for this difference in coal ash content and apply this factor to the costs determined from the cost curves. Unfortunately, at this time data are insufficient to determine such correction factors for each individual process module for which cost curves exist. However, correction factors which can be applied to the overall cost of a waste disposal system are available in the open literature (17). These correction factors exist for the following parameters: percent sulfur in coal; percent ash in coal; distance to disposal site; percent of optimum land available; and synthetic liner cost. These factors can be determined from graphs available in Reference 17.

Step 3: Determine the appropriate correction factor for the difference between the coal ash content pertaining to the desired system and the range specified for the cost curves. This factor can be applied to the capital cost estimate for the entire waste handling and disposal system only rather than for the individual process modules. The correction factor is 1.09. No correction factor is required for the annual cost since these system costs were estimated on the basis of the waste quantity which takes into account the ash content differences.

Step 4: Determine base capital and operating costs for all of the appropriate waste type/process module combinations (summarized in Table 6.9) from the appropriate cost curves.

For all modules, the higher range of the cost curves were taken to determine conservative estimates of both the capital and first-year annual costs (see Table 6.10), since the module options selected for the example in question are complex in nature and typically are represented by the upper regions of the cost curve bands.

Step 5: Calculate corrected capital and annual costs for the overall waste handling disposal system.

Total Corrected Capital Cost = Base Cost x Correction Factor(s)
= ($31,550,000)(1.09)
= $34,400,000

Total Corrected First-Year

Annual Cost = Base Cost x Correction Factor(s)
= ($10,600,000)(1.0)
= $10,600,000/yr

Unit Cost = Total Correct First Year Annual Cost ÷ Total Annual Waste Generation
= $10,600,000/yr ÷ 367,000 dry metric tons/yr
= $29/dry metric ton

6.3 Data Gaps

Data gaps related to the economics of coal-fired utility solid wastes (i.e., coal ash and FGD wastes) disposal include both cost information per se, as well as waste properties and disposal requirements that directly impact disposal costs. The most important of these (which may be addressed by government and/or industry initiatives) include the following:

- A general lack of uniformity exists in basic cost assumptions made in engineering cost studies to date. This makes attempts to compare and use such disposal cost estimates from different sources a difficult task, at best.

- A general lack of reliable cost information (capital and operating costs) exists from commercial operation of most types of FGC waste handling and disposal practices.

TABLE 6.9

SUMMARY OF REQUIRED MODULES FOR WHICH COSTS ARE ESTIMATED FOR THE LANDFILL EXAMPLE

WASTE TYPE/PROCESS MODULE	FIGURE NO. Capital Cost	FIGURE NO. Annual Cost
• Dry Fly Ash Handling and Processing	6.31	6.33
• Fly Ash Storage	6.42	6.44
• Fly Ash Transport		
- dry trucking	6.55	6.57
• Fly Ash Placement and Disposal		
- landfill	6.71	6.73
• Bottom Ash Handling and Processing		
- wet with recycle	6.37	6.39
• Bottom Ash Transport		
- dry trucking	6.58	6.60
• Bottom Ash Placement and Disposal		
- landfill	6.74	6.76
• Raw Materials Handling and Storage	6.45	6.46
• FGD Waste Handling and Processing	6.40	6.41
• FGD Waste Transport		
- dry trucking	6.61	6.62
• FGD Waste Placement and Disposal		
- landfill	6.77	6.78

Source: Arthur D. Little, Inc.

TABLE 6.10

SUMMARY OF CAPITAL AND OPERATING COSTS FOR FIXATED FGD WASTE/LANDFILL EXAMPLE

WASTE TYPE/PROCESS MODULE	Capital Cost ($1000)	Operating Cost ($1000/year)
• Fly Ash Handling/Processing (dry)	$ 1,700	$ 790
• Fly Ash Storage (dry, silo)	3,900	1,050
• Raw Materials Handling/Storage (fly ash & lime)	840	2,000
• FGD Waste Handling/Processing (thickening, filtration & mixing)	14,200	3,120
• Fly Ash Transport (dry, trucking)	300	530
• FGD Waste Transport (dry, trucking)	300	520
• Fly Ash Placement and Disposal (landfill)	3,100	1,650
• FGD Waste Placement and Disposal (landfill)	3,100	770
• Bottom Ash Handling/Processing (dewater, with recycle)	1,800	750
• Bottom Ash Transport (dry, trucking)	150	230
• Bottom Ash Placement and Disposal (landfill)	1,000	350
TOTAL:	$30,390	$11,760

Source: Arthur D. Little, Inc., estimates.

- Insufficient modular division (by process area) of waste disposal system capital and operating costs currently available in the open literature.

- Available capital and operating cost data on mine disposal (open pit and vee-notch) of FGC wastes is lacking, especially for plants with nameplate generating capacities greater than 500 MW.

- No definitive engineering or cost data are available (from conceptual studies or from actual operating systems) on the handling and disposal of FGC wastes from dry sorbent flue gas desulfurization systems.

- Existing physical and engineering properties data on some waste types are not adequate as a basis for developing design requirements needed to prepare reliable estimates of cost-effective disposal systems. Examples include: the disposal of untreated gypsum in dry impoundments; the optimum amount of ash and lime required for fixation of some sulfite-rich FGD wastes; and the potential use of some fixated wastes as liners for dry impoundments of FGC wastes.

- Engineering and cost data (from conceptual studies or from actual operating systems) for the waste handling and disposal of FGD wastes (treated and untreated) in ponds and landfills for all power plant sizes, especially those greater than 500 MW, are insufficient.

- Cost data are lacking concerning the use of interim ponds as a unit processing operation for dewatering coal ash or FGD waste prior to ultimate landfill disposal.

- Actual cost data are lacking regarding the installation of liners (clay, synthetic, etc.) for disposal ponds at various plant sizes.

To summarize, the most important data gap, which is a common thread throughout all of the data gaps, is the lack of detailed engineering/cost breakdown among the existing data (which are limited to begin with) for the disposal of FGC wastes. Consequently, it is very difficult to compare estimated costs with real costs (if they are documented) for a given disposal system or to compare either estimated or real costs for one system with those for another. With only limited cost breakdowns, it is difficult to make comparisons because of uncertainty about what is or is not included within each cost category that is reported. Without such comparisons, it is difficult to recognize which factors are most significant in introducing variations in costs. The result is that certain cost curves, presented here, were based on a limited quantity of data points with less than desired quality. This cost curves presented in Section 6.2 cover a band and, additionally, have an accuracy level of plus 30 percent, minus 10 percent. Another limitation of the cost curves (due to the lack of modularized cost data) is their limited applicability to plants and disposal sites with the same basic range of engineering design premises as those which the curves were based. In other words, for systems with variations from the base case engineering design premises, one would require correction factors which could be applied to the cost curves presented herein. Unfortunately, however, at this time there are insufficient data to determine such corrections for each individual process module for which cost curves exist. Corrections would be necessary for such case variations as: percentage ash or sulfur in coal, coal heating value, boiler type, FGD system type, transportation distance, and liner costs.

SECTION 7.0

ENVIRONMENTAL ASSESSMENT OF COAL ASH AND FGD WASTE DISPOSAL

7.1 MATRIX OF DISPOSAL PRACTICES

The environmental impact of any solid waste disposal practice is determined by the interaction of three factors: waste type, disposal method, and environmental setting. In assessing present and future practices of coal ash and FGD waste disposal, one may identify four basic waste types, three principal disposal methods, and five types of environmental settings of major importance.

7.1.1 Waste Types

As explained in Section 3.3, the four major types of coal ash and FGD wastes are: fly ash or fly ash admixed with other materials, non-fly ash materials, chemically treated FGD wastes, and dry FGD wastes. The chemical and physical characteristics of each waste type were discussed in Section 3.4.

7.1.2 Disposal Methods

Currently, all FGC waste disposal options involve some form of land disposal: pond disposal, interim ponding followed by landfill disposal, and landfill disposal. (Utilization of these waste products is another waste management option. FGC waste utilization is not addressed in this section because it is not as widely practiced as the other options.)

Section 6.1.7 discusses these disposal methods in more detail. They are considered separately for environmental assessment purposes because each involves basically different water management practices, with corresponding implications for the amounts and rates of leachate generation and movement at disposal sites.

7.1.3 Environmental Settings

Three basic environmental settings for solid waste disposal were initially identified for this assessment, based on major differences in climate and geohydrology. These were:

- coastal areas, where surface water and groundwater are directly influenced by the ebb and flow of tides;

- arid areas, characteristic of most of the western U.S., where net evaporation significantly exceeds precipitation; and
- interior areas, characteristic of non-coastal portions of the eastern U.S., where precipitation and evaporation tend to be more balanced than in the west, and where permanent surface water bodies are so abundant that they are close to many waste disposal sites.

Evaluations during this project suggested that two additional types of settings would be useful because of their fundamentally different background water quality characteristics. These are:

- arid areas, highly mineralized, and
- interior areas subject to acid mine drainage.

Both these areas and the coastal setting area tend to have water quality characteristics that, in effect, mask the effects of coal ash and FGD waste leachates. This is because background waters tend to already have high concentrations of certain species that are usually considered contaminants in leachates. More information on all settings and their implications for environmental effects is presented in Section 7.2.

7.1.4 Matrix Combinations

Table 7.1 is a matrix of waste types, disposal methods, and environmental settings. For each setting, the table indicates which combinations of waste type and disposal method apply. For example, pond disposal methods are not applicable to dry FGD wastes, eliminating ten combinations from further consideration. Also, pond disposal of chemically treated FGD wastes is generally not suitable in arid western settings where water availability is a constraint, and in coastal settings where natural valleys that can be converted to impoundments by the disposal practice are lacking.

Table 7.1 also shows disposal/waste/setting combinations for which field-scale and other information is available. Sources other than this project included the Utilities Solid Waste Activity Group (USWAG), EPRI, and DOE. As indicated, some information is available for most of the combinations that are practiced today or likely in the future. For example, full-scale field studies have been conducted in each category of environmental settings except an arid western location that is not highly mineralized. Full-scale field studies have been also been carried out for each major type of disposal practice. The information from these field studies and the extensive data from laboratory and other studies collectively provide a reasonable technical basis for projecting the environmental implications of the other matrix combinations. The environmental implications of the various combinations and their importance in decision-making are discussed in Section 7.3 and in Appendix H.

TABLE 7.1

SUMMARY OF INFORMATION AVAILABLE FOR COMBINATIONS OF WASTE TYPES, DISPOSAL METHODS, AND ENVIRONMENTAL SETTINGS

	Ponding				Interim Ponding/Landfilling				Landfilling			
	Fly Ash[a]	Non-Fly Ash	Processed FGD	Dry FGD	Fly Ash[a]	Non-Fly Ash	Processed FGD	Dry FGD	Fly Ash[b]	Non-Fly Ash	Processed FGD	Dry FGD
COASTAL SETTING	X Smith[c]	P	NA	NA	X/PD Chisman Cr. (USWAG)	P	P	NA	P	P	P	P[e]
ARID WESTERN SETTING - Not Highly Mineralized	P	P	NA	NA	P	P	P	NA	X	P	P	P[e]
ARID WESTERN SETTING - Highly Mineralized	P	P	NA	NA	P	P	P	NA	X Dave Johnston Milton Young (DOE/EPA)	P	P	P[e]
INTERIOR SETTING - Not Highly Acidic	X Allen, Sherburne County, Michigan City (USWAG), Wallingford (USWAG)	P	X Bruce Mansfield	NA	X/Pd Bailly (USWAG)	P	P	NA	X Powerton, Zuellinger (USWAG), Hunts Brook (USWAG) Dunkirk (DOE)	P	X Conesville (EPRI/USWAG)	P[e]
INTERIOR SETTING - Highly Acidic (mine drainage)	P	P	P	NA	P	P	P	NA	P	P	X Elrama	P[d]

Notes:
a. Includes co-disposal of fly ash with other wastes.
b. Includes FGD wastes without fly ash and bottom ash.
c. Plants for which data and information are obtained are listed in their appropriate positions.
d. Either the interim pond of landfill aspect of operation studies at field scale, but not both.
e. Laboratory data only.

Key:
X = Data available from full-scale field studies.
P = Data available from laboratory and/or limited-scale field studies for projection purposes.
NA = Matrix combination not applicable due to lack of present and future practices.

7.2 ENVIRONMENTAL SETTINGS

7.2.1 Overview

In any solid waste disposal situation, features of the environmental setting can influence the impact of the disposal practice. Such features are climate, geohydrology, surface water hydrology, and background water quality. Different combinations of these typify each environmental setting considered in this assessment. The environmental settings and their major features are:

- Coastal, typified by influence of tides on groundwater and surface water movement and quality, generally heavy precipitation, and local prevalence of highly pervious soils. This setting prevails along the U.S. Atlantic and Gulf Coasts.

- Arid (not highly mineralized), characterized by little rainfall, high net evaporation, relative absence of aquifers, and various soil types. This setting occurs at isolated locations in the western U.S., much of which is highly mineralized.

- Arid (highly mineralized), with the same climatic and hydrologic features as the previous setting. Other features include alkaline soils, and background water that is relatively high in dissolved chemical species. This setting prevails at many locations in the West.

- Interior (typical), distinguished by: modest rainfall with little difference in net precipitation/evaporation; numerous permanent surface water bodies of varying sizes at most locations, high-quality drinking water supplies in near-surface aquifers; and various soil types. This setting occurs over much of the eastern half of the U.S.

- Interior (acid mine drainage), typified by: same climatic and hydrologic features as the previous setting; water quality and water uses limited by high concentrations of chemical species in mine drainage. This setting is found in the central Appalachian Mountain Region, and at other more scattered locations in the eastern half of the U.S.

The rest of this section discusses the features of these various settings in more detail, with emphasis on the environmental effects of coal ash and FGD waste disposal.

7.2.2 Climate and Geohydrology

7.2.2.1 Coastal Environments--
Coastal environments are characterized by low-lying topography, marshes and coastal streams, and nearby salt water bodies with tidal fluctuation of water levels. Waste disposal facilities in coastal environments often act as local groundwater recharge areas, with groundwater and leachate moving in all directions away from the facility. Groundwater and leachate eventually

discharge to the salt water body or to nearby marshes and streams which drain to the salt water body. Leachate flowing through the fresh water aquifer toward the open salt water body is forced upward along the salt water-fresh water interface to discharge at or near the edge of the salt water body.

Rates of leachate movement may be influenced by tidal fluctuations of the nearby salt water body, which change the base levels for groundwater flow and hydraulic gradients away from the waste disposal facility. However, these fluctuations are short-term, and mean-tide conditions will approximate the long-term average leachate movement from the site.

Coastal environments usually experience year-round precipitation and thus year-round leachate movement. But, especially in the Gulf Coast and southeastern Atlantic Coastal Plain, these settings are characterized by intermittent, irregular storm events where substantial precipitation may occur in short periods of time. During such storms, leachate movement may increase due to greater runoff and infiltration in landfills, rising water levels and increased driving forces in ponds, and possible filling of ponds and overtopping of confinement dikes. The storm events and increased leachate movement are short-lived and usually recur once in several years. The probability of a storm occuring at any coastal location can be determined by analyzing historical climatologic data.

7.2.2.2 Arid Western Environments--

In arid environments, potential evapotranspiration exceeds precipitation. Most water losses from a landfill or pond will be to the atmosphere. This may minimize or eliminate percolation or seepage of leachate to groundwater. Precipitation does happen as intense, intermittent events, during which groundwater recharge and leachate movement may occur. But such events may happen only once every several years.

Depth to groundwater and thickness of unsaturated zones are large for waste disposal facilities in upland areas and moderate to small for facilities located on terrace deposits or in alluvial valleys. Directions of groundwater flow are structurally controlled and are towards discharge areas such as streams, where water is lost by runoff, or towards playa lakes, where water is lost by evaporation. Most of the groundwater movement is within alluvial fan complexes, stream terraces, and alluvial valleys.

7.2.2.3 Interior Environments--

Interior environments are usually characterized by humid climates where precipitation slightly exceeds evapotranspiration. Thus, percolation from landfills and seepage from ponds are likely. Although the environment experiences wet and dry periods, precipitation levels tend to be fairly constant, and leachate movement can occur throughout the year. In interior environments characterized by winter ground freezing, water may not infiltrate into a landfill. This will cause a seasonal decrease in percolation. Pond freezing similarly reduces losses to direct evaporation. Depth to groundwater and thickness of the unsaturated zone in interior environments are related to topographic and geologic conditions. Both deep and shallow water table conditions may be present. The direction of groundwater flow in surficial deposits may be controlled by topography, with groundwater flowing approximately perpendicular to topographic contours. Groundwater will flow to discharge areas such as rivers and streams.

7.2.3 Surface Water Hydrology

Most coal-fired power plants in the U.S. are located close to permanent surface water bodies (see Appendix A). This means that many disposal areas for coal ash and FGD wastes are also situated where they may influence or be influenced by a surface water body. These influences can affect leachate generation, leachate movement, and admixing. Surface water hydrology characteristics and their environmental implications for the major settings are summarized below.

7.2.3.1 Surface Water Hydrology - Coastal Settings--
Coastal settings for utility waste disposal represent only those areas subject to tidal influence. Three major types of surface water bodies exist in direct proximity to disposal sites on the U.S. East and Gulf Coasts: estuarine bays, estuarine rivers, and tidal creeks.

The estuarine bays and rivers are usually large water bodies with regular (diurnal), significant, horizontal flows during all seasons. As such, they represent an excellent ultimate mixing, dilution, and dispersion medium for most dissolved species in coal ash and FGD waste leachates. Tidal creeks are also subject to diurnal water exchanges, but their flow volumes are much less than those of the estuarine bays and rivers. Results of several field studies of coal ash landfill leachate dilution in small freshwater streams suggest that flows in even small tidal creeks could have major mixing and dilution impacts on landfill leachates. (See the Powerton site results for this project in Section 5.2 and also References 13 and 67.)

7.2.3.2 Surface Water Hydrology - Arid Settings--
In arid settings, the physical hydrologic characteristics of surface waters in both highly mineralized and less mineralized water bodies are similar. Permanent, natural, surface water bodies are often not present close to disposal sites. Small, flashy temporary streams with seasonal (snow-melt) and event-related flood flows are common, but are of only isolated importance in leachate admixing. A few western disposal sites are located in the alluvial floodplains of the larger permanent rivers. This circumstance can contribute to local water table elevations that affect leachate generation and movement and provide significant ultimate leachate admixing, dispersion, and dilution.

7.2.3.3 Surface Water Hydrology - Interior Settings--
Similar physical hydrologic conditions occur in both the surface waters of the central Appalachian region (where acid mine drainage is most common) and in the other non-tidal interior settings of the Eastern U.S. In the vicinity of any given interior coal ash or FGD waste disposal site, one or more permanent surface water bodies of varying size are likely. These range from very small streams to large lakes and rivers. Field studies in this and other projects strongly suggest that flows in even small, permanent streams

(0.3 to 30 m^3/s [10 to 100 ft^3/s) can have a very significant dilution impact upon admixing with coal ash landfill leachates (see Section 5 and References 13 and 67). Comparable data for small streams are not available for pond leachates, but a major dilution potential is again likely.

7.2.4 Water Quality

Typical water quality conditions vary considerably from one environmental setting to another. In three categories (coastal, arid-highly mineralized, and interior-acid mine drainage), many of the major dissolved species concentrations in background waters can be comparable to those in coal ash and FGD waste leachate. The conditions in each setting are discussed below.

7.2.4.1 Water Quality - Coastal Settings--

In background waters of Atlantic and Gulf Coast estuarine settings, concentrations of most major species and some important minor species (i.e., boron) are elevated to levels comparable to those in coal ash and FGD waste leachates. For example, concentrations in bays and rivers of intermediate salinity where coastal disposal sites are located are generally in the same range as that measured at the estuarine (Smith) site studied in this project:

Cl^{-1} - 35000 to 15000 mg/l
SO_4^{-2} - 700 to 2500 mg/l
B - 1 to 3 mg/l

However, background water concentrations of various trace metals, including As and Se, are typically quite low compared to the upper end of the range reported for coal ash and FGD waste leachates. For example, As and Se background ranges at the estuarine (Smith) site in this project were:

As - 0.6 to 1.2 μg/l
Se - less than 0.1 to less than 0.3 μg/l

(See Section 5.2 for more information on results from the Smith site.)

Typical water quality conditions in bays and estuaries are also often reflected in near-surface coastal aquifers subject to saline intrusion. This intrusion can cause violation of secondary drinking water standards (i.e., SO_4^{-2} and Cl^{-1} >250 mg/l) and so constrains the use of these aquifers for drinking water. Thus, typical water quality conditions in the coastal setting imply that the incremental water quality impacts of the major dissolved species in coal ash and FGD waste leachates may be of little or no concern. For this reason, an assessment of potential adverse effects may have to focus instead on trace metals, such as As and Se, and on non-drinking water standards (i.e., those established to protect aquatic life).

7.2.4.2 Water Quality - Arid Setting, Not Highly Mineralized--

The arid and generally alkaline nature of much of the western U.S. makes much of the surface and groundwater quality of the area "highly-mineralized," as discussed below. But even in these highly-mineralized settings, surface water and groundwater quality is relatively free from elevated concentrations of dissolved species. For example, the results of this project for the Johnston site, which is generally highly-mineralized, also showed some quite low concentrations of dissolved species at isolated sampling locations:

SO_4^{-2} - 38 to 144 mg/l
Cl^- - 2 to 8 mg/l
B - 0.01 to 0.06 mg/l

Such levels are well below applicable secondary drinking water standards (see Section 7.2.4.1) and other potential constraints on use (i.e., B in water for agricultural use: 0.750 mg/l). Trace metal concentrations in these background waters are also typically below drinking water standards. Ranges at the Johnston site were:

As - less than 0.5 µg/l (standard = 50 µg/l)
Se - 1.3 to 5.7 µg/l (standard = 10 µg/l)

(See Section 5.2 for more results on the Johnston site.)

The surface and groundwater quality of arid western settings that are not highly mineralized can usually support a full range of uses, including drinking water. Thus, the potential for incremental impacts by both major and trace dissolved species in coal ash and FGD waste leachates should be considered.

7.2.4.3 Water Quality - Arid Setting, Highly Mineralized--
Like the coastal settings discussed above, concentrations of at least some major dissolved species in the background surface and groundwaters of highly-mineralized arid western settings are often higher than secondary drinking water standards. Such background waters have been studied as part of this and other projects (see results on the Johnston site in Section 5.2 and also Reference 68). Measured ranges include:

SO_4^{-2} - 600 to 1300 mg/l (standard = 250 mg/l)
B - 0.7 to 5.1 mg/l (criterion = .750 mg/l)

Also like the coastal setting, concentrations of major trace metals tend to be below applicable drinking water standards. Measured ranges of As and Se in background groundwaters from the same two projects (see Reference 68 and Section 5.2) were:

As - 1.0 to 8.1 µg/l (standard = 50 µg/l)
Se - less than 0.8 to 2.5 µg/l (standard = 10 µg/l)

Because of high levels of major species, water in arid, highly mineralized settings may not be suitable for drinking water. This places primary focus on potential trace metal impacts for other than drinking water uses (i.e., aquatic life, agriculture).

7.2.4.4 Water Quality - Interior Settings (Typical)--

As in the not highly mineralized arid setting, background surface water and groundwater in interior settings free from major contamination generally have both major and trace species concentrations that allow the full range of water uses, including drinking water. For example, concentrations of selected species in background surface and groundwater samples from the typical interior settings sampled in this project (Powerton, Allen and Sherburne County) were:

SO_4^{-2} - 0.5 to 84 mg/l (standard = 250 mg/l)
B - less than 0.005 to 0.63 mg/l (criterion = .750 mg/l)

Ranges of selected trace metals (As, Se) in background waters at the same sites were:

As - less than 0.2 to 0.6 μg/l (standard = 50 μg/l)
Se - less than 0.3 μg/l (standard = 10 μg/l)

(See Section 5.2 for further results from the Powerton, Allen and Sherburne County sites.)

Because these waters have low background concentrations and can support a full range of uses, the initial focus for assessing impacts on water quality in interior settings is on both the major and trace dissolved species in coal ash and FGD waste leachates.

7.2.4.5 Water Quality - Interior Setting (Acid Mine Drainage)--

The poor quality of waters affected by acid mine drainage causes more potential use constraints than those experienced by other settings. Water bodies so affected are limited in their ability to support recreational fisheries as well as drinking water needs. For example, the ranges of selected species concentrations measured in groundwater believed to be affected only by acid mine drainage at the representative site (Elrama) were:

SO_4^{-2} - 85 to 1900 mg/l (standard =250 mg/l)
B - 0.015 to 0.407 mg/l (criterion = .750 mg/l)
pH - 4.5 to 6.1 (standard = 6.5 - 9.5)

Ranges of the two important trace metals in the same groundwaters were:

As - 0.4 to 8.6 μg/l (standard = 50 μg/l)
Se - less than 0.3 μg/l (standard = 10 μg/l)

(See Section 5.2 for more information on the Elrama site.)

As in other settings where background water shows elevated concentrations of species important in coal ash and FGD waste leachates, the implication for assessments here is that drinking water uses may already be precluded and that only the limited number of species affecting other uses should be considered.

7.3 MECHANISMS OF ENVIRONMENTAL EFFECTS

7.3.1 Overview

The environmental (water quality) factors discussed in Section 7.2 were assessed for each combination of waste type, disposal method and environmental setting, as shown in Table 7.1. Results are documented in Appendix H. The environmental findings at each of the six field sites were presented in Section 5.2. Results from both efforts are summarized below in terms of their implications for environmental (water quality) assessment and decision-making for prospective coal ash or FGD waste disposal practices.

Sections 7.3.3 through 7.3.8 summarize the effects and decision-making implications of six categories of the potential combinations shown in Table 7.1. These categories were selected because each shows fairly unique environmental effects and decision-making implications. The categories are:

1. Coastal setting, various waste types and disposal methods;
2. Arid setting - highly mineralized, various waste types and disposal methods;
3. Arid setting - not highly mineralized, pond disposal;
4. Arid setting - not highly mineralized, landfill disposal;
5. Interior setting - typical, various waste types and disposal methods; and
6. Interior setting - acid mine drainage, various waste types and disposal methods.

In three categories (1, 2 and 6), typical background water quality requires less emphasis on the impact of major dissolved species (i.e., sulfate) on water quality. Initial focus instead should be on the less frequently problematic trace metals in the waste leachate. In Category 2, potentially adverse effects are mitigated by the likely lack of physical proximity between the disposal site and usable receiving waters, and by the general minimization of leachate generation and movement in arid settings. Categories 3 and 4 share some of these advantages, although greater water movement generally accompanies the pond versus landfill disposal method. Finally, in Category 5, few, if any, potential assessment considerations can be ruled out *a priori*, and the decision process can regularly require in-depth analysis of each major mechanism of environmental (water quality) effects - leachate generation, movement, admixing, and attenuation.

7.3.2 Implications of Waste Type

Despite the differences in chemical and physical properties of coal ash and FGD wastes (see Section 3.4), there are also some basic similarities that result in common major effects and decision-making implications. Specifically, all four major waste categories (fly ash, bottom ash/FGD waste, chemically treated FGD wastes, and dry FGD wastes) share three characteristics:

- Despite variations in physical properties such as permeability, all these wastes are expected to release measurable leachates into the adjacent environment within a few years of placement by any prevalent unlined disposal method. (The quantity of measurable leachate release can vary significantly from one site to another.)

- Leachate from each waste type is expected to exceed Secondary Drinking Water Standards for at least one major dissolved species (sulfate). Fewer wastes have concentrations of multiple species in excess of these standards. For example, excess levels of chloride tend to be restricted to FGD wastes.

- Leachates sampled under actual or simulated field conditions from each waste type are highly variable in trace metal concentrations, but a minority of cases have exhibited concentrations in excess of the Primary Drinking Water Standards.

7.3.2.1 Fly Ash Wastes--

Fly ash wastes, including separately disposed fly ash and fly ash co-disposed with bottom ash or FGD waste, have been studied at field scale in each major environmental setting, as placed by several major disposal methods. The ability of these wastes to release measurable leachate into the adjacent environment has been documented under at least the following circumstances:

- pond disposal of fly ash and bottom ash, coastal setting (Smith site studied during this project; see Section 5.2);

- landfill disposal of fly ash following interim ponding, coastal setting (Chisman Creek site results reported in Reference 13);

- pond disposal of fly ash and bottom ash, interior settings (Allen site studied during this project, as described in Section 5.2; and Wallingford site results reported in Reference 13);

- pond disposal of fly ash and FGD waste, interior setting (Sherburne County site studied during this project; see Section 5.2);

- interim pond disposal of fly ash, interior setting (Bailly site results reported in Reference 13);

- landfill disposal of fly ash and bottom ash, western setting (Johnston site studied during this project; see Section 5.2);

- landfill disposal of fly ash and FGD waste, western setting (Reference 5);

- landfill disposal of fly ash and bottom ash, interior setting (Powerton site studied during this project, as described in Section 5.2; and Zuellinger and Hunts Brook sites described in Reference 13).

Given this wide range of conditions, it is reasonable to anticipate that these wastes will release measurable leachate into adjacent surroundings in the absence of additional physical barriers (i.e., site liners).

In this project, sulfate concentrations in the in-situ samples of fly ash waste interstitial liquids exceeded the secondary drinking water standard of 250 mg/l at all sites where fly ash wastes were disposed of (Smith, Johnston, Powerton, Allen and Sherburne County). Concentrations measured ranged from 320 to 1780 mg/l (Secondary Drinking Water Standard = 250 mg/l). At three sites (Smith, Johnston and Sherburne County), sulfate concentrations greater than 1000 mg/l were measured in the in-situ, interstitial waste liquors. Other major dissolved species in fly ash waste leachates may be expected to exceed Secondary Drinking Water Standards in a minority of cases. Such species includes chloride (especially where co-disposal with FGD wastes is involved--see Sherburne County site results for this project and also References 2 and 3) and manganese (67). The Water Quality Criterion for boron of .750 mg/l, is based on certain crop sensitivities to levels in irrigation water (6), is regularly exceeded by fly ash waste interstitial waters, as demonstrated at all five fly ash waste sites in this project.

Trace metal species that receive primary emphasis in assessments of coal ash and FGD waste leachates include arsenic and selenium, because of their potential to exceed applicable National Interim Primary Drinking Water Standards (50 µg/l for As and 10 µg/l for Se) (2,3). Results of this project support previous indications that fly ash waste leachates contain concentrations of these species that exceed the Standards in a minority of cases. At the four fly ash waste sites where Se analyses of waste interstitial waters were performed (Powerton, Smith, Allen and Sherburne County), the range of measured values was less than 0.1 to 6.6 µg/l, all below the 10 µg/l Standard, although at one site (Sherburne County), pond supernatant contained ~250 µg/l of Se. Arsenic values measured in the same waste interstitial waters were below the 50 µg/l Standard at three of the four sites, ranging from 0.7 to 11 µg/l, but exceeded the Standard at the fourth site (Allen), ranging from 1550 to 2425 µg/l.

7.3.2.2 Non-Fly Ash Wastes (Bottom Ash, FGD Wastes)--

Disposal of bottom ash and/or FGD waste separately from fly ash is fairly uncommon, and data from full-scale studies on leachate generation and chemical quality are lacking. The effects of these wastes must be estimated based on available laboratory and pilot scale field work.

Data indicate that the in-situ permeability of bottom ash alone is generally greater than or equal to that of fly ash (2,3). This means that bottom ash disposal areas will physically release leachate to the adjacent environment if additional physical barriers, such as liners or leachate collection systems, are not present. However, leachates from bottom ash usually do not have trace elements of concern in such concentration as do fly ash leachates. Unstabilized FGD wastes also release leachate, based on limited data comparing them to stabilized FGD wastes which release leachate in field applications (2,3,5; Conesville site results reported in Reference 1, and Elrama site results in this project).

Like fly ash, bottom ash liquors at field-scale have been shown in at least one case (Sherburne County site) to contain sulfate and boron levels that exceed the Secondary Drinking Water Standards and water quality criteria. The separate bottom ash disposal area characterized at Sherburne County showed sulfate levels of 2200 to 2300 mg 1 and boron at about 20 mg/1. Although this data base is small, more extensive laboratory and limited field-scale studies of unstabilized FGD wastes indicate that the same species, in addition to chloride, would likely exceed the secondary drinking water standards and water quality criteria in full-scale applications (2,3,6,15).

Data suggest that As and Se concentrations in ash-free, unstabilized FGD waste and bottom ash liquor may exceed the Interim Primary Drinking Water Standards, but in an even smaller minority of cases, (and perhaps not at all for bottom ash) (2,3,15,16,69,70). Water leaching of Se concentrations higher than 10 μg/1 from ash-free FGD wastes has been documented in at least two laboratory studies of wastes produced by different scrubbing techniques (15,16,70).

7.3.2.3 Chemically Treated FGD Wastes--

Results of this project at the Elrama site and from other limited field-scale studies (15,16,69) indicate that chemical treated wastes generally have similar leaching potential as those in the preceding two categories. The chemically treated FGD waste landfill studied at the Elrama site showed leachate release to the adjacent environment, as did other treated FGD wastes in limited field-scale pond disposal studies (2,15). Sulfate concentrations in the <u>in-situ</u> waste interstitial waters at Elrama ranged from 700 to 2020 mg/1, and some chloride values exceeded the 250 mg/1 secondary drinking water standard, generally by about a factor of two. Similar results (with higher chloride levels) were reported for the limited field-scale studies (15,16,69). Se levels at Elrama were less than 4 μg/1, but As levels measured in the <u>in-situ</u> waste site interstitial waters ranged from 5.9 to 266 μg/1; the upper end of this range is roughly five times the Interim Primary Drinking Water Standard. As and/or Se values greater than limits set by standards have also been reported for some treated FGD wastes, but the number of wastes tested seems too small to determine whether such concentrations could be expected in most field situations (15,16,68,69,70).

7.3.2.4 Dry FGD Wastes--

Characterization data on dry FGD wastes are available only from laboratory-scale studies. These data suggest that such wastes should have similar characteristics as the other types of wastes discussed above (3,70).

In work sponsored by EPRI, laboratory permeability values for fourteen different dry scrubbing wastes produced at nine plants ranged from 1.6×10^{-4} cm/sec to 2.7×10^{-7} cm/sec, a range comparable to that for the other coal ash and FGD wastes shown to allow leachate release at full field scale (2,18).

Sulfate concentrations in water extracts of dry FGD wastes have been reported to range from 1100 to 4200 mg/l, placing these leachates in excess of the Secondary Drinking Water Standard (2).

One EPRI study reported that the Interim Primary Drinking Water Standard for As was exceeded in neutral extracts of wastes at two of the nine plants studied and for Se at four of the nine (18). Comparable standards for Cr and Ba were also exceeded (70). These very preliminary results again indicate that, in a minority of cases, selected trace metals may be leached in concentrations of potential concern.

7.3.3 Implications of Disposal in Coastal Settings - Various Waste Types and Disposal Methods

7.3.3.1 Practices in this Category--

As described in Section 7.2, the coastal setting includes those portions of the U.S. East and Gulf Coasts subject to the regular (diurnal) influences of tidal action on surface waters and near-surface aquifers. (Other non-tidal portions of the traditionally defined "coastal plain" are considered in this study as part of the interior setting.)

Of the possible combinations of waste types, disposal methods and environmental settings shown in Table 7.1, eight waste/disposal method combinations are applicable to the coastal setting and have similar decision-making implications. These combinations are (13):

- Fly ash waste, pond disposal - By far the predominant practice at U.S. East and Gulf Coast plants, and expected to remain important in the future.
- Bottom ash or ash-free FGD waste, pond disposal - Unlikely to prevail in the future.
- Fly ash waste, interim pond-landfill disposal - Not common, and unlikely to become so.
- Fly ash waste, landfill disposal - An uncommon practice that is expected to become more prevalent as additional coastal plants convert to coal for their primary fuel source.
- Bottom ash or ash-free FGD waste, landfill disposal - Not commonly applied and unlikely to become more prevalent.
- Chemically treated FGD waste, landfill disposal - Not now practiced but may be in the future.
- Chemically treated FGD waste, interim pond/landfill disposal - Not applied at full scale in the coastal setting and unlikely to prevail in the future.

- Dry FGD waste, landfill disposal   In the early stages of commercialization; may be applie in the future.

7.3.3.2 Status of Documentation--

Field studies of full-scale coal ash or FGD waste disposal in the coastal setting have been reported for at least three sites. During this project, a combined fly ash/bottom ash disposal pond in the Florida panhandle was evaluated at the Smith site. Results are summarized in Section 5.2.6. More limited studies of final land disposal of interim-ponded fly ash in coastal Virginia were reported recently by USWAG (13). At a site in coastal Maryland, initial investigation by the State led to a planned program of more detailed field studies (71).

7.3.3.3 Summary of Environmental Implications--

The various coal ash and FGD wastes should have the following generic environmental implications when disposed of by any of the major methods in a tidally-influenced coastal setting:

- Leachate quality should have concentrations of major species (i.e., sulfate, boron) comparable to those of tidally-influenced background surface waters and near-surface aquifers. This was apparent and expected in the circumstances encountered at the Smith site in this project, where estuarine water is used as a regular or periodic waste transport medium.

- In some cases, concentrations of certain trace metals (i.e., As, Se) in the leachate may be higher enough than that of the background waters to be of potential concern (see Sections 7.2 and 7.3.2 above). For example, results for the coastal Virginia site showed disposal-related elevated levels of Se and V (13), and vegetation analyses at the coastal site in Maryland prompted concern over As and Se levels (71).

- The prevalence of heavy precipitation and pervious soils in the coastal setting can promote rapid leachate generation and movement. Off-site leachate migration was observed at both of the pond and landfill coastal coal ash disposal sites that have been studied (see Reference 13 and results for Smith site in Section 5.6.5 of this report).

- Opportunities for extensive admixing with tidally-influenced surface waters and near-surface aquifers can eliminate or reduce substantially the possibility of adverse impacts from major dissolved leachate species. As noted in Section 7.2, concentrations of major dissolved species in coastal settings are generally such that surface water and near-surface aquifers are not available as untreated drinking water supplies. Secondary Drinking Water Standards often have little or no applicability, and the relevant criteria may be limited to those designed to protect aquatic life in surface waters. Major dissolved species in coal ash and FGD waste leachates are generally of little concern with respect to the marine aquatic life criteria, and would be of essentially no concern in a situation where admixing with tidally-influenced surface waters prevailed (6).

- Chemical attenuation of trace metals can be expected in some but not all of the prevalent situations. Among the many soil types found in coastal settings are coarse sands of relatively low organic content and exchange capacity and, by implication, less anticipated ability to attenuate trace metals (see Appendix A). Yet this setting also includes wetland and other areas where organically enriched soils and some silts and clays prevail. These latter soils should be able to attenuate significantly trace metals. While field-scale data are sparse, significant soil attenuation of at least one trace metal species (V) was observed at a Virginia coastal coal ash disposal site, (see Chisman Creek results reported in Reference 13) and some of the soils at the coastal (Smith) site in this project had significant, though pH-dependent, attenuation capacity (see Section 5.2.6 and Appendix F).

Thus, opportunities for adverse effects of various disposal methods for coal ash or FGD waste in the coastal setting seem restricted to those few cases where elevated leachate concentrations of one or more trace metals (i.e., As or Se) may prevail, and specifically to the even more unlikely situation where a relative absence of both physical admixing and chemical attenuation of the elevated leachate metals concentrations could cause concentrations in an ambient surface water body to reach threshold levels harmful to resident aquatic life. If the latter circumstance were expected, mitigation could be achieved by selecting an alternative disposal site, or by placing an appropriately impermeable and/or chemically attenuative soil as a site liner.

7.3.4 Implications of Disposal in Arid, Highly-Mineralized Settings - Various Waste Types and Disposal Methods

7.3.4.1 Practices in this Category--

As described in Section 7.2, the arid, highly-mineralized setting is typical of many locations in the western U.S. This setting is distinguished from other arid settings by high concentrations of dissolved minerals in surface waters and near-surface aquifers, generally in excess of one or more secondary drinking water standards.

Of the possible combinations of waste types, disposal methods and environmental settings shown in Table 7.1, nine waste/disposal method combinations are applicable to the arid, highly-mineralized setting and have similar decision-making implications. These combinations (1) are:

- Fly ash waste, pond disposal - A fairly common practice that is expected to become less prevalent as users turn to dry disposal.
- Fly ash waste, interim pond-landfill disposal - An uncommon method that is likely to remain so, especially as dry disposal becomes more widely used.

- Fly ash waste, landfill disposal - An important practice that should become even more popular, since it is the major applicable combination in the West.

- Bottom ash or ash-free FGD waste, pond disposal - A combination that is practiced but not expected to prevail in the future.

- Bottom ash or ash-free FGD waste, interim pond-landfill disposal - A fairly uncommon practice that is unlikely in the future.

- Bottom ash or ash-free FGD waste, landfill disposal - A relatively uncommon practice, expected to remain so because of the likelihood of co-disposal with fly ash.

- Dry FGD waste, landfill disposal - In the early stages of commercialization in the West and likely to become more prevalent.

- Chemically treated FGD waste, landfill disposal - Does not occur now but may be practiced at a few locations in future.

- Chemically treated FGD waste, interim pond-landfill disposal - Not practiced presently and unlikely in the future.

7.3.4.2 Status of Documentation--

Field studies of full-scale coal ash or FGD waste disposal in arid, highly-mineralized settings have been reported for at least two sites. As part of this project, a combined fly ash/bottom ash landfill in a Wyoming alluvial floodplain was evaluated in detail, and results are summarized in Section 5.2.3 (Dave Johnston site). A research/demonstfation (and later full-scale) operation involving disposal of fly ash and fly ash-scrubbed FGD waste by landfill in a North Dakota surface mine has also been evaluated (5). Measured background water quality conditions in both these areas generally fell into the category of "highly-mineralized," as described in Section 7.2.

7.3.4.3 Summary of Environmental Implications--

The various coal ash and FGD wastes, should have the following generic environmental implications when disposed of by any of the major methods in an arid, highly-mineralized setting:

- Both background waters and leachate are likely to have concentrations of major dissolved species (i.e., sulfate) well above limits set by Secondary Drinking Water Standards. This was apparent at both field study sites. At the Johnston site studied during this project, major species concentrations were extremely similar in waste and background waters. At the other site, the highly alkaline FGD wastes produced some leachates with measurably higher concentrations of certain major species than the high background levels (68,5).

- In some cases, leachate concentrations of certain trace metals (i.e., As, Se) may be higher enough than those of the background waters to approach or exceed applicable standards and thresholds. For example, at the North Dakota site, alkaline fly ash-related leachate concentrations of As and Se in groundwater were significantly higher than the concentrations in the highly mineralized background waters, and above limits set by the Interim Primary Drinking Water Standards (68,5).

- Minimal precipitation, high net evaporation, and the general absence of significant near-surface groundwater generally reduce opportunities for leachate generation and movement. In many arid settings, receiving waters are so removed that waste leaching is confined to the unsaturated zone near the waste deposit. Exceptions do occur, as at the western (Johnston) site studied in this project. In this case, the waste was deposited by excavation in an alluvial floodplain, and this caused contact between the waste and locally high groundwater. But even at this unusual type of western site, the generally arid setting minimizes and restricts leachate generation and movement to the immediate vicinity of the waste deposit, especially when dry disposal methods are practiced.

- Even if disposal conditions allow leachate to contact receiving waters, its admixing with the highly-mineralized background water would result in few, if any, incremental effects from major dissolved leachate species, such as sulfate. However, the highly mineralized receiving waters are often of limited importance as untreated drinking water supplies. On the other hand, they may continue to be valued for agricultural purposes and for support of aquatic life. The latter are uses for which the typical reported concentrations of leachate major species would have few, if any, negative implications upon admixing (6).

- Chemical attenuation of trace metals can be expected in some, but not all of the prevalent situations. The highly mineralized arid setting has a broad range of soils with varied physical and chemical attenuative capacities (see Section 7.2). At one field site, waste alkalinity together with a lack of attenuation may have contributed to the elevated As levels measured at some near-downgradient sampling locations (68). Some of the soils at the arid, highly mineralized Johnston site studied in this project showed minimal attenuation capacity for most trace metals of interest.

In summary, the adverse effects of coal ash or FGD waste disposal by various methods in arid high-mineralized settings should be minimal and restricted to those cases where wastes with elevated levels of one or more trace metals (i.e., As) are placed so close to useful receiving waters that elevated receiving water concentrations develop in spite of the aridity of the setting. If such conditions were expected, the problem could be avoided by choosing a better-situated alternative disposal sites (which should be available even within a very small geographic area). In the unlikely event that no alternative site was feasible, the effects could be mitigated by placing an appropriately impermeable and/or chemically attenuative soil as a site liner.

7.3.5 Implications of Pond Disposal in Arid, Not Highly-Mineralized Settings - Various Waste Types

7.3.5.1 Practices in this Category--

As described in Section 7.2, the arid, not highly-mineralized setting includes many isolated locations in the western U.S. It is distinguished from the highly-mineralized areas by the prevalence of superior water quality, adequate to support a broader spectrum of uses, including use as a potable water supply without further treatment.

Of the combinations of waste types, disposal methods and environmental settings shown in Table 7.1, five ponding and interim pond-landfill disposal methods can be practiced in the arid, not highly-mineralized setting and have similar decision-making implications. These combinations (13) are:

- Fly ash waste, pond disposal - Common practice at present but expected to become less prevalent as dry disposal gains acceptance.
- Fly ash waste, interim pond-landfill disposal - Uncommon and expected to remain so, especially as dry disposal becomes more prevalent.
- Bottom ash or ash-free FGD waste, pond disposal - An existing practice that is unlikely to become prevalent in the future.
- Bottom ash or ash-free FGD waste, interim pond-landfill disposal - Uncommon, and unlikely for the future.
- Chemically treated FGD waste, interim pond-landfill disposal - A combination that, while possible, does not occur and is unlikely in the future.

7.3.5.2 Status of Documentation--

Applicable data from full-scale field studies are not available. Useful data can be obtained from other studies of full-scale practices in arid settings (5,68), as well as results from the Johnston site in this project. This information, along with the extensive literature on laboratory and limited field-scale investigations of coal ash and FGD waste disposal (2,3), provides a basis for projecting the likely environmental implications for this setting.

7.3.5.3 Summary of Environmental Implications--

The various coal ash and FGD wastes should have the following generic environmental implications when disposed of by ponding (including interim ponding) in an arid, not highly-mineralized setting:

- Leachate concentrations of certain major chemical species (i.e., sulfate) can be higher enough than those of background waters to be of potential concern with respect to Secondary Drinking Water Standards. (See Sections 7.2 and 7.3.2.)

- In a few cases, leachate may have sufficiently higher concentrations of certain trace metals (i.e., As, Se) than those of the background waters to be problematic (see Sections 7.2 and 7.3.2).

- Pond head can promote leachate generation and movement. However, the combination of minimal precipitation, high net evaporation, and the general absence of significant near-surface groundwater generally reduce the extent of leachate plume movement. Based on results of full-scale pond studies in the less arid areas of the eastern U.S. (see summaries for the Smith, Allen, and Sherburne County sites in Section 5), measurable leachate will likely remain within the immediate vicinity (i.e., a few hundred meters maximum) of typical western disposal ponds during their operating lifetimes.

- Chemical attenuation of trace metals can be expected in some, but not all, of the prevalent situations (see Section 7.3.4.3).

The adverse effects of coal ash or FGD waste disposal by ponding or interim pond-landfill methods in arid, not highly-mineralized settings would occur only if elevated concentrations of major and (less likely) trace metal species could reach an immediately adjacent drinking water supply or small, usable surface water body. Such conditions are unlikely, but if they were expected, the problem could be avoided by selecting an alternative disposal site or using an impermeable and/or chemically attenuative soil as a site liner.

7.3.6 Environmental Implications of Landfill Disposal in Arid, Not Highly Mineralized Settings - Various Waste Types

7.3.6.1 Practices in this Category--

Landfill disposal in an arid, not highly mineralized setting is placed in a separate category than pond disposal because of the differences in water movement associated with each practice. Since a landfill disposal site experiences less water movement than a waste pond, the environmental effects of landfilling are generally more acceptable, as explained below.

Four types of waste are suitable for landfill disposal in the arid, not highly mineralized setting:

- Fly ash waste - A prevalent practice that is expected to become even more popular.

- Bottom ash or ash-free FGD waste - Fairly uncommon and likely to remain so since these wastes are usually co-disposed with fly ash.

- Dry FGD wastes - In the early stages of commercialization in the West and expected to become more prevalent.

- Chemically treated FGD waste - Not now practiced but may be in the future.

7.3.6.2 Status of Documentation--

Data from full-scale studies of landfill disposal in this setting are not available, although useful information can be obtained from other investigations of full-scale practices in arid settings (5,68), as well as results from the Johnston site in this project. This information, along with the extensive literature on smaller-scale studies of coal ash and FGD waste disposal (2,3), provides a basis for projecting the likely environmental implications for this setting.

7.3.6.3 Summary of Environmental Implications--

The environmental implications of disposal practices in this setting are similar to those described in Section 7.3.5.3, with one major difference. In the case of landfill disposal, the combination of dry disposal methods, minimal precipitation, high net evaporation, and the absence of significant, near-surface groundwater makes opportunities for leachate generation and movement even more unlikely.

7.3.7 Environmental Implications of Disposal in Typical Interior Settings - Various Waste Types and Disposal Methods

7.3.7.1 Practices in this Category--

The range of typical interior settings includes most of the eastern half of the U.S., excluding only those areas subject to tidal influence (coastal) and acid mine drainage. Ten of the waste/disposal method combinations listed in Table 7.1 apply to this setting and have essentially similar decision-making implications. These are:

- Fly ash waste, pond disposal - The most dominant practice in the eastern U.S. and expected to remain important, although many new facilities will use dry disposal.
- Fly ash waste, interim pond-landfill disposal - A common practice that will become less prevalent as users turn to simpler practices.
- Fly ash waste, landfill disposal - A frequent practice that should become even more important.
- Bottom ash or ash-free FGD wastes, pond disposal - A fairly popular practice for bottom ash that is also used for FGD wastes. It will remain important for bottom ash, but may decline for FGD wastes in favor of fly ash co-disposal methods.
- Bottom ash or ash-free FGD wastes, interim pond-landfill disposal - A prevalent practice for bottom ash, but rare for FGD wastes; expected to be less common in the future.
- Bottom ash or ash-free FGD wastes, landfill disposal - Uncommon and unlikely to become more important because of the greater likelihood of co-disposal with fly ash.

- Chemically treated FGD waste, pond disposal - Practiced at only two sites and likely to remain fairly rare.
- Chemically treated FGD waste, interim pond-landfill disposal - Not practiced at present; feasible, but unlikely for the future.
- Chemically treated FGD waste, landfill disposal - Recently initiated at several interior sites and likely to become much more prevalent.
- Dry FGD waste, landfill disposal - In the early stages of commercial application and expected to become more important.

7.3.7.2 Status of Documentation--

A substantial data base is available for this setting. Field studies of full-scale coal ash or FGD waste disposal in typical interior settings have been reported for at least eleven sites:

- Combined fly ash and bottom ash ponding in North Carolina, studied at the Allen site as part of this project.
- Combined fly ash and FGD waste ponding, and separate bottom ash ponding, in central Minnesota, studied at the Sherburne County site as part of this project.
- Combined fly ash and bottom ash landfill in west-central Illinois, studied at the Powerton site as part of this project.
- Coal ash ponding in the Indiana Lake Plain and in Connecticut (Michigan City site, Wallingford site results, respectively, reported in Reference 13).
- Ponding of chemically treated FGD waste on the Pennsylvania/West Virginia border (72).
- Ponding of interim pond-landfill disposal of coal ash in the Indiana Lake Plain (Bailly site results reported in Reference 13).
- Landfill disposal of coal ash in Pennsylvania, northern New York and Connecticut (Zuellinger site, Chisman Creek site, and Dunkirk site results, respectively, reported in Reference 13).
- Landfill disposal of chemically treated FGD wastes in Ohio (Conesville site results reported in Reference 13).

7.3.7.3 Summary of Environmental Implications--

The various coal ash and FGD wastes will likely have the following generic environmental implications when disposed of by any of the major methods in typical interior settings:

- Leachate concentrations of certain major chemical species (i.e., sulfate) will be higher enough than background levels to approach or exceed Secondary Drinking Water Standards (see Sections 7.2 and 7.3.2). The Secondary Drinking Water Standard for sulfate was exceeded in waste interstitial waters at all three typical interior sites in this project (Powerton, Allen, and Sherburne County), and major dissolved species were of concern at other sites (72; Zuellinger site and Hunts Brook site results reported in Reference 13).

- In some cases, leachate concentrations of certain trace metals (i.e., As, Se) in groundwater may be problematic (see Sections 7.2 and 7.3.2). Waste interstitial waters had As or Se concentrations in excess of the Interim Primary Drinking Water Standards at two of the three typical interior study sites in this program. Downgradient wells did not show similar concentrations (see trace metal attenuation discussion below). In other interior site field studies, trace metal concentrations in waste water violated Primary Drinking Water Standards at 3 of 5 sites (Chisman Creek, Wallingford, Bailly, Zuellinger and Hunts Brook sites; see Reference 13). At one site, selenium bioaccumulation in a combined treatment pond was reported to be responsible for changes in a fish population (73).

- The typical range of interior climatic and hydrogeologic conditions can result in enough leachate generation and movement from unlined disposal sites to have a measurable effect on downgradient groundwater quality. Unlined pond and landfill sites in typical interior settings in this project (Powerton and Allen sites) contributed measurable leachates to downgradient groundwater. This same phenomenon was observed in most other studies of interior sites, regardless of the method of disposal (Wallingford, Bailly, Hunts Brook and Zuellinger site results reported in Reference 13). At Sherburne County, the lined pond site in this project, leachate movement was significantly restricted, at least for the short term.

- Admixing of leachates with even small surface water bodies can have a major dilution effect that mitigates potential leachate impacts on surface water and groundwater quality. Results from this project indicate that adjacent small streams can achieve an almost instant, order-of-magnitude reduction in landfill leachate concentrations of major dissolved species (see Powerton site results in Section 5.2.5). Other interior site studies confirm this finding (see, for example, Hunts Brook site results reported in Reference 13).

- Field data are incomplete as to how much effective dilution may be achieved in surface waters with the larger leachate flows that may result downgradient of interior pond disposal areas. For instance, the large impoundments required for pond disposal of FGD wastes (with their high levels of major dissolved species such as Cl^-) would have more significant drainage effects on water quality in a small, adjacent surface water body than the other disposal methods would.

- Significant chemical attenuation of trace metals in soils can be a mitigating factor in some, but not all prevalent soil types.

Background soils with high clay, iron and manganese contents at one of the three typical interior sites studied in this project appeared to have substantially attenuated As in ash pond leachate (see Allen site results, Section 5.2.1). At another site (Powerton), such As attenuation was not apparent in at least one downgradient location. Selenium attenuation was possible in the liner at the third typical interior site (Sherburne County), but the sandy, inorganic background soils showed little attenuation potential. In two other field studies at sites in the Indiana Lake Plain, chemical attenuation of trace metals in soils was reported (see results for Bailly and Michigan City sites in Reference 13).

Adverse effects of coal ash or FGD waste disposal by various methods in typical interior settings seem limited to situations where unlined sites are developed so close to useful water supplies that elevated leachate concentrations of major and/or minor species can reach the water supply without being diluted by an intervening surface water body. In a few cases, leachates from a large disposal pond or from a site with unusually high trace metal concentrations and non-attenuative soils also may be of concern for a small, adjoining surface water body. If such conditions were expected, the problem could be alleviated by choosing an alternative disposal site, placing an impermeable and/or chemically attenuative soil as a site liner, or by managing the site water to prevent contaminated leachate from reaching the receiving waters.

7.3.8 Summary of Effects Implications of Disposal in Interior Settings Affected by Acid-Mine Drainage; Various Waste Types and Disposal Methods

7.3.8.1 Practices in this Category--

The interior setting affected by acid mine drainage is most frequently encountered in the Central Appalachian Mountains coal-mining region of the Eastern U.S. - in such states as Pennsylvania, West Virginia, Ohio and Kentucky. In some locations, many years of surface and subsurface mining have significantly affected background water quality in the smaller surface water bodies and in mine-associated groundwaters. In other respects (i.e., climate and geohydrology), these areas are similar to the typical interior setting discussed in Section 7.3.7.

Of the possible combinations of waste types, disposal methods and environmental settings shown in Table 7.1, the same waste/disposal combinations applicable to typical interior settings (Section 7.3.7) may also occur in this setting. (The prevalence of these combinations in Central Appalachia is essentially the same as that described in Section 7.3.7.1).

7.3.8.2 Status of Documentation--

A full-scale stabilized FGD waste landfill in an interior acid mine drainage setting in western Pennsylvania was studied as part of this project (see Elrama site results in Section 5.2.2). At least two of the "typical" interior sites studied by others are near documented or suspected mining activity (72; Conesville site results reported in Reference 13), but these investigations have not identified any acid drainage that may prevail.

Results from the many field studies of the generic effects of interior climate and geohydrology on coal ash and FGD waste disposal (see Section 7.3.7.2) can be combined with the findings of this project, which concerned, in addition to these issues, the unique chemistry of interaction between a highly alkaline, stabilized FGD waste and its acid mine drainage setting. This information provides an adequate basis for a discussion of the environmental implications.

7.3.8.3 Summary of Environmental Implications—
The various coal ash and FGD wastes are likely to have certain generic environmental implications when disposed of by any of the major methods in interior acid mine drainage settings:

- Leachate concentrations of major dissolved species, such as sulfate, have little, if any, potential to degrade significantly receiving waters that are already affected by acid mine drainage. As discussed in Section 7.2, the background water quality in areas subject to acid mine drainage is so poor that the Secondary Drinking Water Standards are chronically exceeded, and surface water bodies are unable to support the full range of aquatic life uses. An important issue to consider is whether the slight addition of leachate contaminants may preempt longer term uses. Results from this project indicate that such preemptions are unlikely.

- In some cases, certain trace metals in coal ash or FGD waste leachate (i.e., As, Se) may be of concern. At Elrama, the acid mine drainage site studied in this project, As concentrations at one leachate collection point immediately below the waste deposit were 3 to 5 times higher than the Interim Primary Drinking Water Standard of 50 µg/l. The highly acidic nature of the background mine drainage could, at some sites, promote leaching of some of the otherwise less available trace metal fractions of coal ash or FGD waste (i.e., Cu, Zn), especially from fly ash. But relevant field-scale data are lacking. It is also possible that leachate from some of the more highly-alkaline ash or FGD wastes can locally reduce (by attenuation) the availability of trace elements that would otherwise remain relatively free in the mine drainage. This may occur at Elrama, although the site has not been operated long enough to be certain.

- As in the typical interior setting, the climatic and hydrogeologic conditions in regions experiencing acid mine drainage can cause leachate generation and movement from unlined disposal sites, with a measurable effect on downgradient groundwater quality. These effects can be measured by following some of the more environmentally innocuous tracer species, such as Ca. But the likelihood of incremental degradation in these waters is far less than in the typical interior settings, where receiving water bodies are more likely to support a full range of actual and potential uses.

- As in typical interior settings, admixing of leachates with even small surface water bodies can have a major dilution effect that mitigates potential leachate impacts on surface water and groundwater quality. This is even more true in acid mine drainage settings, where background and leachate concentrations of most major species are similar.

- Significant chemical attenuation of trace metals in soils can be a mitigating factor be in some, but not all of the prevalent circumstances. The acidity of the mine drainage and the wide pH range of various coal ash and FGD waste leachates may also combine to create locally unusual metals attenuation (or release) phenomena. Field-scale documentation is lacking on attenuation phenomena. At the Elrama site studied in this project, the soil attenuation capacity for trace metals was in the high to intermediate range (Appendix F).

Adverse effects of coal ash or FGD waste disposal by various methods in interior acid mine drainage settings with contaminated backgrounds appear to be limited to those cases where leachates from a disposal area with extremely high, leachable trace metal levels could reach and remain undiluted in a small water body used for such purposes as drinking or fishing, in spite of the prevalent acid mine drainage. If these unlikely conditions were expected, a variety of mitigative measures could be taken (see Section 7.3.7.3).

7.4 DATA GAPS

For many of the important combinations of waste types, disposal methods and environmental settings described in Section 7.3, the existing information base provides a solid foundation for estimating the overall potential for adverse effects on water quality and for disposal-related decision-making. But in some areas, significant data gaps exist, as described below.

7.4.1 Characterization of Trace Metals in Waste Leachates.

Although much information has been developed in this area (see Section 3.4), an analytical framework is lacking for accurately anticipating leachate trace metal concentrations based on coal types, air pollution control systems, and disposal methods. The data base remains fairly incomplete for trace metal speciation in leachates, for wastes produced by dry sorbent FGD systems, and for coal ashes collected by bag filters that retain a greater percentage of the trace-metal-enriched fine particles than other particulate control systems. Since leachate trace metal composition is an important decisi^n point, this is a high priority area for research. EPRI is investigating this area now.

7.4.2 Soil Attenuation of Leachate Constituents

Data developed during this project confirm the basic premise that several major factors, including pH, soil organic content, soil particle size, and ion exchange tendencies, combine to make prospective soil attenuation of leachate trace metals a highly variable, site-specific phenomenon. Soil attenuation can significantly reduce the potential for adverse effects at a disposal site (see the results for the Allen site in Section 5.2.1), and a more complete data base would be valuable for projecting impacts. Such attenuation issues are being addressed in studies sponsored by EPRI.

7.4.3 Effects of Various Artificial Liners on Long-Term Leachate Movement and Composition

Some of the artificial liners (made of material imported from off-site) studied in this project (i.e., soils at Sherburne County) can greatly reduce the rate of leachate release from a disposal area (see Section 5.2.4). This ability to retain water can be readily predicted. But it is difficult to project the impact of such liners on subsequent long-term leachate movement and admixing in adjoining unsaturated zones. Chemically attenuative soils can be used as liner materials, and these may serve as a practical mitigative measure in certain settings. The development of a regional data base correlating the relative abilities of potential liner materials to retard water movement and attenuate selected trace metals would be of obvious value.

7.4.4 Pond Versus Landfill Disposal In Arid Settings

Field studies in arid settings have focused on landfill disposal operations. Although landfill disposal will likely be the dominant practice for new operations in the western U.S., pond disposal will also persist. A better field-scale data base is needed to clarify how the maintenance of hydraulic head by ponding affects leachate movement and the site environment. This information would be especially valuable in arid, non-highly mineralized settings, where waste leachate quality differs significantly from that of the receiving water bodies.

7.4.5 Impacts of Abnormal Events

The existing field-scale data base largely describes cumulative effects observed at various study sites. As such, it reflects normal operations versus abnormal events (storms, earthquakes, material/equipment failure, etc.). For some circumstances, the data suggest that abnormal events can have proportionately much greater short-term impacts on groundwater quality than the normal disposal operation (see Section 5.2.4). In certain combinations of waste, disposal method and setting, the likelihood of abnormal events may warrant inclusion in the disposal-related decision-making process. For example, the potential for major storm events could be an important design consideration in a coastal ponding operation.

7.4.6 Effects of Acid Mine Drainage and Waste Alkalinity on Trace Metal Release

Results of this project show how acid mine drainage conditions can interact with a highly-alkaline, processed FGD waste. The disposal of less alkaline (and even slightly acidic) coal ashes in acid mine drainage situations may possibly increase the release of trace metals in leachate. Very high waste alkalinity may mobilize some trace metals in some other disposal settings (68). Further field-scale data on such phenomena would greatly aid the waste disposal decision-making process.

7.4.7 Admixing of Pond Leachates with Small Surface Water Bodies

Field-scale data strongly suggest that even very small permanent surface water bodies can cause major mitigative dilution impacts upon admixing with leachates from coal ash or FGD waste landfills. But data are lacking as to how such interaction would occur with the significantly greater leachate volumes generated by pond disposal operations, especially those involving very large water volumes and relatively high concentrations of dissolved major species (i.e., FGD waste ponds). Field scale studies to clarify this area would be practical at existing disposal sites. Data from such studies would be valuable in waste disposal decision-making, where location relative to a surface water body is often a major consideration.

SECTION 8.0

DECISION METHODOLOGY

8.1 INTRODUCTION

This Section provides various tools to assist utility planners and permitting officials in evaluating waste management practices:

- A decision methodology that outlines a procedure to help answer questions about coal ash and FGD waste disposal.

- A list of information requirements for assessing the waste management potential alternatives, including recommended laboratory and field tests that may provide more detailed information on a specific site.

- An information base on environmental effects and engineering costs associated with various waste management options. This gives some initial guidance on how to evaluate waste characteristics, disposal methods, and environmental settings and select the proper waste management alternative.

These tools should serve as guidelines only. Ultimate environmental effects of coal ash and FGD waste disposal are highly site- and system-specific and cannot be generalized. Table 8.1 shows the general environmental impact issues associated with various disposal options. Appropriate control technology can be applied on a site-specific basis to mitigate adverse impacts. The significance of many potential impacts may be better quantified by additional laboratory or field-scale work.

8.2 WASTE MANAGEMENT ISSUES

A state or local permitting official or a utility planner may face several waste management issues related to coal ash and FGD wastes. Typical examples are:

- Various waste management options for new coal-fired power plants.

- Waste management options resulting from expansion of existing power plants or changes in disposal operations. A typical example would be adding an FGD system that will generate FGD waste. Another would be a change in the disposal site. One ash landfill might have been filled, and another must be brought into operation.

TABLE 3.1

POTENTIAL IMPACT ISSUES—COAL ASH AND FGD WASTE DISPOSAL

Setting	Disposal Practice: Ponding	Disposal Practice: Landfilling	Interim Pond/Landfill
Coastal	G-2, S-2,3, M-2	G-2,3, S-2,3, M-2	G-2, S-2,3, M-2
Interior	G-2, S-2, M-2	G-2, S-2, M-2	G-2, S-2, M-2
Interior—Acid Mine Drainage	G-2, S-2,3, M-2	G-2, S-2,3, M-2	G-2, S-2,3, M-2
Arid	G-2, S-2, M-2	G-2,3, S-2 to 3, M-2	G-2, S-2, M-2
Arid Mineralized	G-3, S-3, M-3	G-2,3, S-3, M-3	G-3, S-3, M-3

Type of Issue

G = Effects on groundwater quality.

S = Non-point effects on surface water quality.

M = Mitigative design, management or control practice

Level of Importance

1. Usually important.
2. Important in site-specific cases.
3. Usually of minor importance.

Note: For details on settings see Section 7.

- Waste management alternatives associated with power plant conversion to coal from some other form of fossil fuel.

- The affects of continuing existing operations over the next few years.

- Impact of abnormal events such as a hurricane or a flood on a waste disposal site.

Each issue requires a different perspective and approach in the initial evaluation of alternatives. Some may involve making projections into the future from an existing data base. But, whatever the various issues, the overall environmental effects of coal ash and FGD waste disposal can be determined, given information on waste characteristics disposal methods (including engineering and cost considerations), and environmental settings. (Naturally, the more complete the data base the more reliable the assessment will be.) This initial assessment will enable some preliminary alternatives to be identified. After additional refinement by laboratory and field tests, more suitable waste management options can be selected.

8.3 DECISION METHODOLOGY

This Section describes the generic decision methodology developed to help the decision maker arrive at proper waste management options. The steps involved in evaluating alternatives for coal ash and FGD waste disposal are briefly outlined in Figure 8.1. The sequence is:

- Step 1 - Gather Data and Information on Disposal Alternatives

  A starting point for evaluating the options is to develop a list of information requirements for the waste and the type of disposal that may be feasible. These information requirements are discussed in Section 8.4. At this stage in the decision-making process, the approach is to gather as much data as possible on the potential type of wastes and the various types of disposal options.

- Step 2 - Perform Preliminary Engineering Evaluation of Disposal Alternatives

  After the initial information requirements have been met, a preliminary list of the potentially applicable disposal options should be developed. This list should be as complete as possible, based on an evaluation of the detailed data base provided by this report (Section 6) and the references cited. The data base includes waste characteristics and disposal methods and associated capital and annual costs.

- Step 3 - Gather Data and Information on Environmental Settings

  This step involves defining the information requirements on the site-specific environmental setting, including geology, hydrogeologic conditions, surface water information, climatic conditions, and other

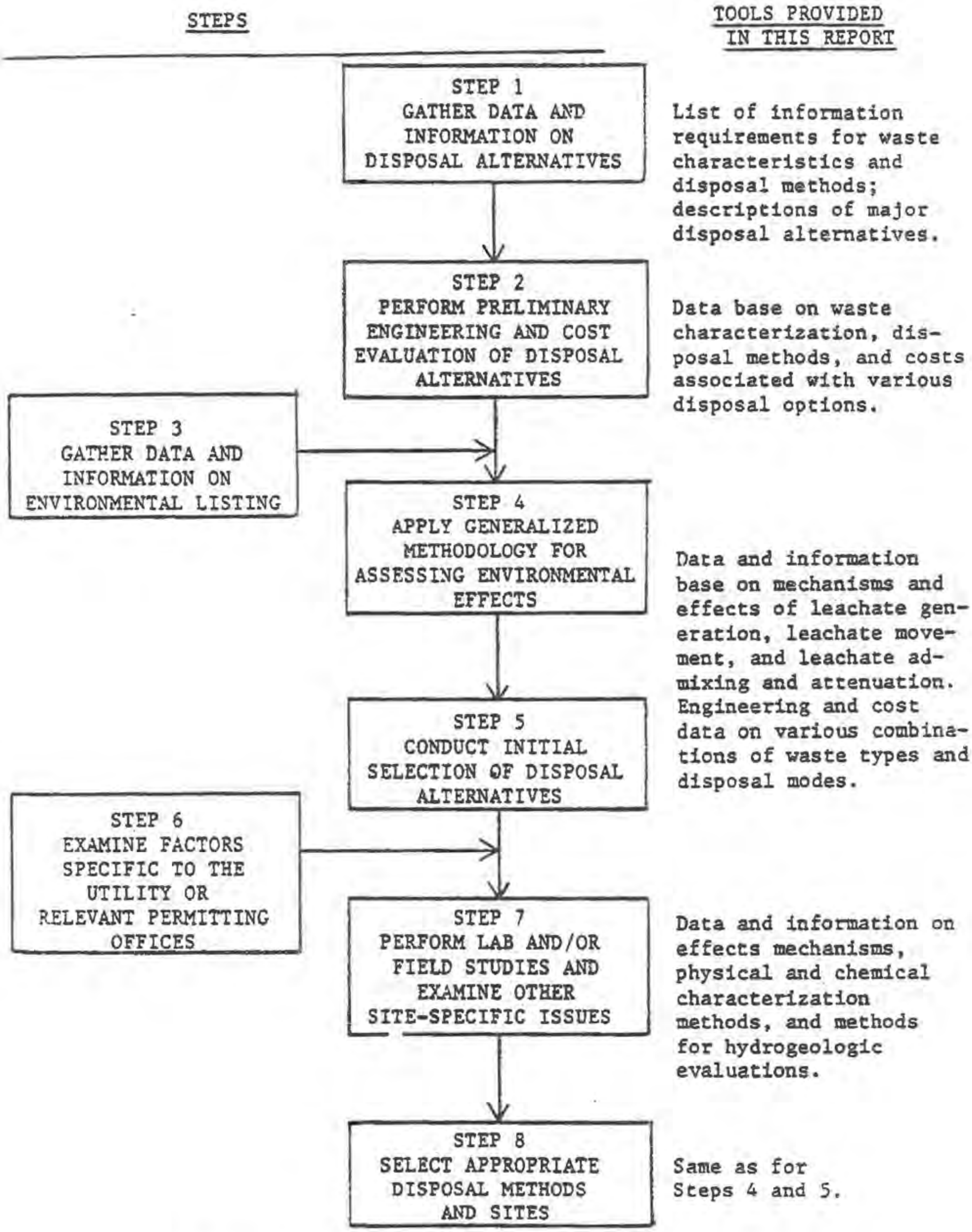


FIGURE 8.1 OVERALL DECISION-MAKING PROCESS

aspects of the environment. Section 8.4 describes the typical information requirements. Appendices to this report, together with the discussions in Section 5 and 6, provide the data base needed to compile this information.

- Step 4 - Apply Generalized Methodology for Assessing Environmental Effects

  Once information is available on waste characteristics, methods of disposal, and environmental settings, the next step is to evaluate the environmental effects. This can be best undertaken by studying the processes leading to leachate generation, leachate movement, leachate admixing with receiving water, and chemical attenuation by soils. Each of these four subjects is covered in detail in Section 8.6. The engineering and cost information on various combinations of different waste types and disposal modes, provided in Section 6 of this report and in the appendices, supplement the data base. This information allows both the environmental effects of each type of disposal and the associated conceptual costs to be evaluated.

- Step 5 - Make Initial Selection of Disposal Alternatives

  From a compilation of the environmental effects of various alternatives and the engineering costs associated with each, the decision-maker can perform a comparative assessment to arrive at an initial list of alternatives that may require the additional scrutiny described below.

- Step 6 - Examine Factors Specific to the Utility or Relevant Permitting Offices

  Each utility may have some historical practice in terms of waste management. Similarly, there may be very specific policy requirements that the permitting offices have to fulfill. These specific items are not covered in detail in this report. But the list of references provided cover the issues involved and provide an information base to assist the decision-maker.

- Step 7 - Perform Lab and/or Field Studies and Examine Other Site-Specific Issues

  Once a preliminary list of disposal options is available, laboratory or field tests may be necessary to obtain additional information on waste characteristics (both physical and chemical) or on the environmental settings. More site-specific engineering cost evaluations may also be in order. This report provides detailed information on physical and chemical characterization methods (see Appendix C), hydrogeologic evaluations (see Appendix B), and other procedures involved in determining environmental effects. Also, Section 6 provides engineering cost information for more site-specific disposal systems.

- Step 8 - Select Appropriate Disposal Methods and Sites

  From the information developed under Step 7 and the assessment from Step 5, the decision-maker can arrive at the most appropriate disposal-site and method for the specific situation.

These decision-making steps will vary from one situation to another. In some cases, substantial laboratory data and field effort may be required; in others, Step 5 may provide a clear enough indication of the waste management options to address the issues involved. The references given in Sections 6, 7, and 8 provide the additional information required for more detailed evaluation.

8.4 INFORMATION REQUIREMENTS

The information needed to consider environmental effects concerns waste type, disposal practice, and setting (see Figure 8.2). Specific requirements are listed in Tables 8.2 (waste type), 8.3 (environmental setting) and 4.11 (disposal method, see Section 4.6). The information requirements shown in these tables are quite complete. In many instances, all the information may not be available or may not be required. If necessary, data gaps should be filled. Laboratory or field efforts to obtain more specific data may be called for (see Appendixes B & C and References 2, 3, 17, 21, 60).

8.5 ENGINEERING/COST CONSIDERATIONS

The engineering data and cost estimation methodology provided in Section 6 of this report can be applied as described in Step 5 of the Decision Methodology to define and select appropriate waste handling/disposal scenarios for the new coal-fired power plant under consideration. Conceptual capital and annual cost estimates for the scenarios can then be selected. This process is described briefly below. See Section 6 for more detailed information.

Once the preliminary engineering design premises for the newly proposed plant have been established, they must be compared to those design premises on which the costs were based (see Table 6.5, Section 6). Any differences between the two must be noted so that appropriate correction factors can be determined. A list of the potentially applicable disposal options is then developed. This list should be as complete as possible, based on an evaluation of the detailed engineering data base provided in Section 6.1 and the numerous references cited.

Variations among waste types and in the collection, handling, processing, storage, transport and disposal of these wastes call for different approaches to waste management. Consequently, a matrix of waste types and waste management activities has been developed. For each type/waste management activity combination, one or more design option has been presented. The desired modular options can be combined to develop a preliminary engineering specification which is then used in determining a conceptual cost estimate for the desired integrated waste management system. An engineering description of

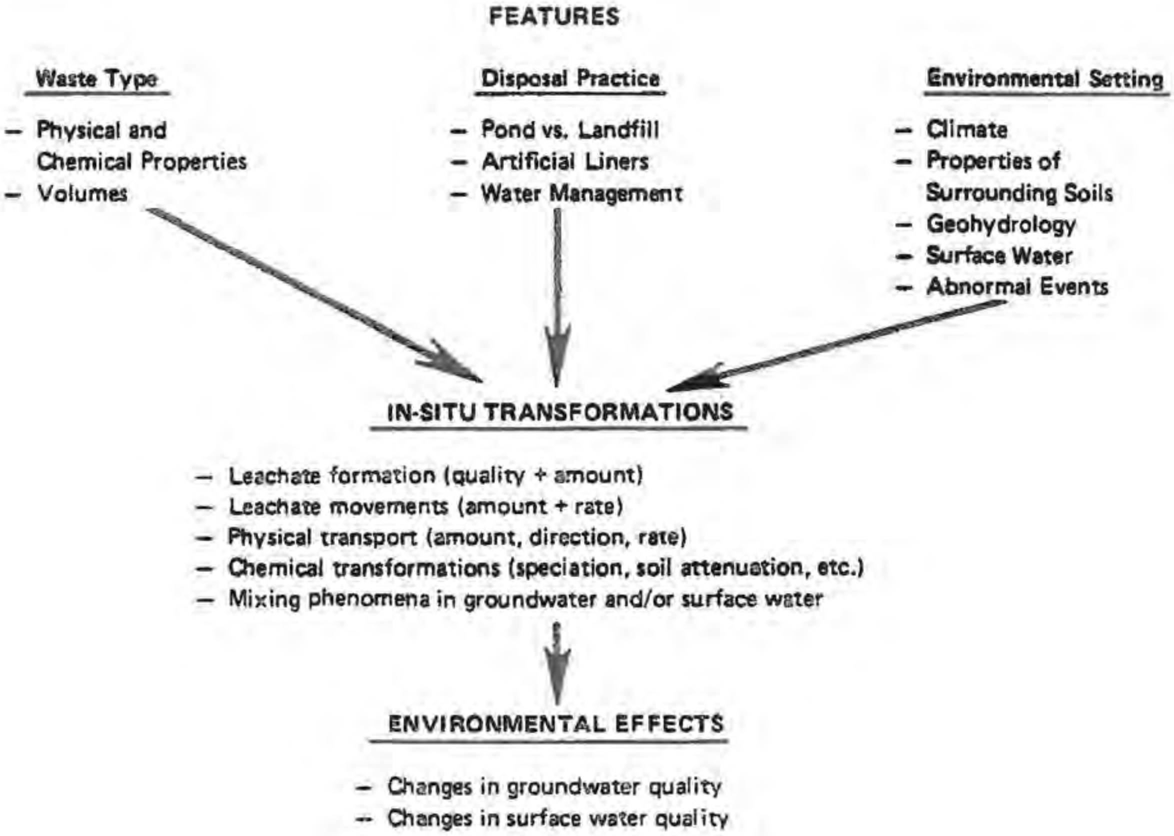


FIGURE 8.2 MAJOR FEATURES OF THE ENVIRONMENTAL EFFECTS PROCESS

TABLE 8.2

POTENTIAL INFORMATION REQUIREMENTS ON WASTE TYPE[a]

1. Power Plant Size and Location

2. Waste Type: Fly Ash
   Bottom Ash
   FGD, Waste, etc.

3. Volume: Annual Average
   Maximum in any Given Period
   Minimum in any Given Period

4. Physical Properties:

	Average	Maximum	Minimum
a. Coal Ash			
(1) Grain Properties			
Specific Gravity			
Grain Size			
Coefficient of Uniformity			
Atterburg Limits			
(2) Compaction Properties			
Bulk Dry Density			
Field Density			
Controlled Compacted Density			
(3) Permeability			
(4) Strength Parameters			
b. FGD Wastes			
(1) Grain Properties			
Specific Gravity			
Grain Size			
(2) Coefficient of Uniformity			
Atterburg Limits			

(continued)

TABLE 8.2

	Average	Maximum	Minimum
(3) Compaction Properties			
Maximum Dry Density			
Optimum Moisture Content			
Compressibility			
(4) Permeability			
(5) Strength Parameters			
Angle of Internal Friction			
Effective Cohesion			
5. Chemical Properties			
a. Coal Ash Wastes, Liquors and Elutriates			
(1) Major Constituents			
Silicon Dioxide			
Aluminum Oxide			
Iron Oxide			
Calcium Oxide			
Sodium Oxide			
Magnesium Oxide			
(2) Minor Constituents			
Titanium Oxide			
Sulfur Oxide			
Potassium Oxide			
Phosphorous Pentoxide			
(3) Trace Constituents			
Arsenic			
Beryllium			
Boron			
Cadmium			
Chromium			
Copper			
Lead			
Manganese			
Mercury			
Nickel			

(continued)

TABLE 8.2

	Average	Maximum	Minimum
(3) Trace Constituents (cont.)			
Selenium			
Strontium			
Vanadium			
Zinc			
b. FGD Wastes Liquors and Elutriates			
(1) Major Constituents			
Calcium			
Chloride			
Magnesium			
Potassium			
Sodium			
Sulfate			
Fluoride			
Total Dissolved Solids			
pH			
(2) Trace Constituents			
Antimony			
Arsenic			
Beryllium			
Boron			
Cadmium			
Chromium			
Cobalt			
Copper			
Iron			
Lead			
Manganese			
Mercury			
Nickel			
Selenium			
Strontium			
Vanadium			
Zinc			

Note: [a]List shown is comprehensive; all requirements may not be necessary in a given decision-making process.

Source: Arthur D. Little, Inc.

TABLE 8.3

TYPICAL INFORMATION REQUIREMENTS - ENVIRONMENTAL SETTING[a]

1. Power Plant and Location
2. Geotechnical Baseline
   a. Foundation Conditions Including Cross Sections and Evaluations
   b. Disposal Site Design and Construction (engineering details)
   c. Disposal Site Distress
3. Hydrogeologic Baseline
   a. Geologic Conditions

      Near-Region Geology
      Site Geology
      General Subsurface Profile

   b. Hydrogeologic Conditions

      Surface Water Regime
      Groundwater Regime
      Adjacent Water Usage
      Background Groundwater and Surface Water Quality

   c. Climatic Conditions

      Temperature
      Rainfall
      Evaporation

4. Other Information
   a. Area Studies
   b. Site Studies

      Land use and zoning information
      Other, as appropriate (e.g., critical habitat)

Note: [a]List shown is comprehensive; all requirements may not be necessary in a given decision-making process.

Source: Arthur D. Little, Inc.

the modules is presented in Section 6.1.2 to assist in determining which waste handling/disposal system might be best for the specific application.

After the waste handling and disposal alternatives have been selected, the generic cost estimation methodology provided in Section 6.2 can be used as a basis for developing conceptual cost estimates for these alternatives. A set of cost curves is provided as an easy and accurate method for developing capital and annual cost estimates for the waste handling and disposal system of a proposed new coal-fired utility plant. These cost curves are structured to allow estimates of both the capital and annular modular costs for the handling, processing, storage, transport and ultimate disposal of any or all of the three major wastes (i.e., fly ash, bottom ash, FGD waste) generated at coal-fired power plants. In this way, for a given combination of utility plant size (i.e., electric generating capacity) and waste types, the cost curves can be used to estimate the capital and annual operating costs (on a late-1982 basis) for the entire waste handling and disposal system or for any of the individual corresponding process modules comprising that system. Once base capital and annual costs for all of the appropriate waste type/process module combinations have been determined, corrected capital and annual costs (when required) can be calculated.

8.6 MECHANISMS OF ENVIRONMENTAL EFFECTS

8.6.1 Integration of Effects in Decision-Making

Figure 8.3 shows the type of decision logic that can be used to evaluate the main mechanisms of environmental effects discussed in the rest of Section 8.6. The first decision point is to determine whether the potential disposal site locations are known. If so, a fairly straightforward series of preliminary evaluations may allow the full range of disposal options to be considered without further major concern over environmental (water quality) effects. This series of evaluations would include:

1. Preliminary assessment of leachate formation, movement and admixing. Available information can be used to make a "first-cut" water balance analysis. This will give relatively gross estimates of potential leachate contributions to downgradient receiving water. If the preferred disposal method is known, it should be used for the estimate. If not, a "worst case" analysis should be taken, assuming the candidate method that allows the greatest amount of relatively unconfined water movement (i.e., disposal in an unlined pond). In the same manner, leachate and background water quality should be estimated based on the best available data. Where uncertainty is involved, the worst reasonably expected leachate quality and the best (least contaminated) reasonably expected background water quality should be assumed.

2. Initial judgement of the potential for adverse water quality effects. At this point it may be clear that the disposal operation will be acceptable. The site may be physically removed enough that dilution or attenuation by the soil can mitigate the potential for significant

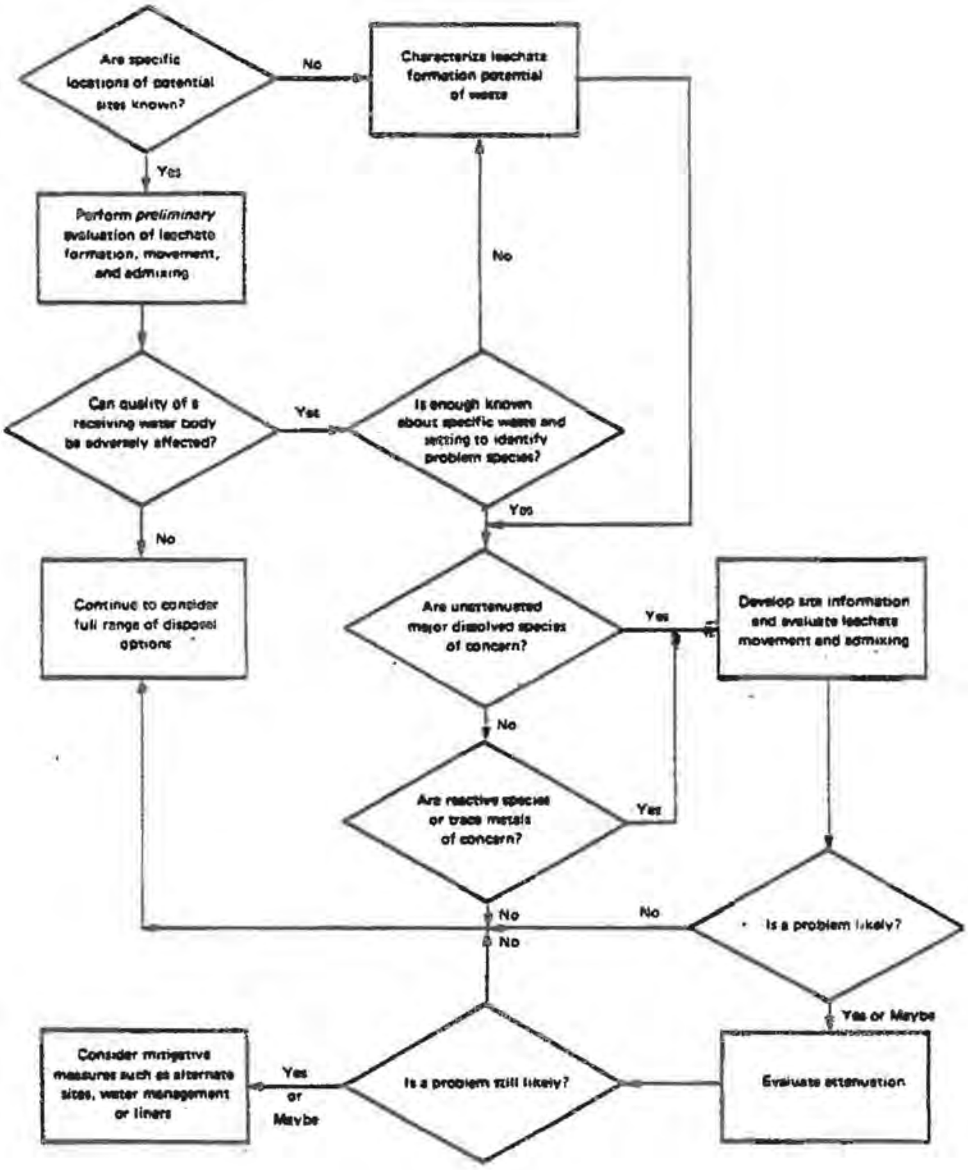


FIGURE 8.3 DECISION LOGIC FOR INTEGRATING EFFECTS

adverse effects. Alternatively, the background water quality may be so poor (i.e., unfit for human consumption) that the leachate would not have significant incremental adverse effects on downgradient water quality. Such conditions might be anticipated in some of the settings described in Section 7.3, especially where arid, coastal or acid mine drainage conditions exist.

If concern or uncertainty remains after these initial considerations, or if the prospective disposal sites are unknown, more detailed analysis is required:

3. Characterization of potentially problematic amounts and concentrations of chemical species in the waste leachate. Depending on how much information is available, this step may involve several of the methods to characterize leachate formation (described in Section 8.6.2). Subsequent decisions will depend on which species are of primary concern - the unattenuated, major dissolved species present in all types of coal ash or FGD waste leachates, or the less frequently problematic trace metal species. Leachate characterization may indicate that, after admixing with background waters, the potential for adverse effects is eliminated.

4. Development of site geohydrologic information and evaluation of leachate movement and admixing. Methods for evaluating leachate movement and admixing are discussed in Sections 8.6.2 and 8.6.3. These evaluations will indicate whether unacceptable downgradient concentrations of one or more leachate species are likely. If a reactive species or trace metals-related problem is indicated, the potential for soil attenuation should be assessed, as explained in Section 8.6.4.

5. Consideration of mitigative measures if the problem still seems likely. Potentially mitigative practices (alternate disposal sites, water management practices, and site liners) are discussed in Section 6. Details on engineering/cost considerations are presented in Section 6.2.

8.6.2 Leachate Generation: Movement and Chemical Composition

8.6.2.1 Leachate Movement--

Leachate movement is a complicated phenomenon affected by waste disposal method, climatological conditions and hydrogeology. The method of waste disposal may be either landfill, where the background water balance for the site is of primary concern, or ponding, where hydraulic head conditions in the pond and hydraulic conductivity of underlying materials are most important. Climatological conditions may range from arid, characterized by intense intermittent precipitation events and potential evapotranspiration (EVTS) exceeding precipitation, to humid, typified by year-round precipitation and potential EVTS less than precipitation. The regional hydrogeology of a waste disposal facility is defined by many parameters - the presence and stratigraphy of aquifers, depth to water table and thickness of the unsaturated zone, vertical and horizontal hydraulic conductivities and gradients, directions and rates of groundwater movement, presence and hydraulic properties of bedrock, groundwater-surface water interactions, and man-made groundwater discharges such as wells.

8.6.2.1.1 Disposal Method--

Landfill -- Determining leachate movement from a landfill involves estimating the quantity of water that infiltrates into and through the landfill. Figure 8.4 shows the flow of water in a landfill disposal site. The four primary sources of water in a landfill are:

- process water in the landfilled waste,
- percolation of direct precipitation,
- percolation of runoff onto the landfill, and
- groundwater movement through the landfill if it is below the water table.

The extent of water in the waste depends on waste handling and disposal processes. This water is usually in small amounts - insufficient to saturate the waste. Percolation of direct precipitation and surface water is related to the physical properties of the landfill (permeability, waste moisture capacity) and local climatological conditions. The amount of percolation can be estimated by the equation:

$$PERC = I - \Delta ST - AET \qquad (1)$$

where
PERC = percolation
I = infiltration
ΔST = change in waste moisture storage
AET = actual evapotranspiration

The amount of water which enters the landfill surface, or infiltration, is described by the equation:

$$I = P + R_I - Ro \qquad (2)$$

where
I = infiltration
P = precipitation
R_I = runoff onto landfill
Ro = runoff from landfill

This represents the maximum amount of water available to move through the landfill.

Precipitation varies with location. Historical records of precipitation are available from various state and federal agencies, most notably the

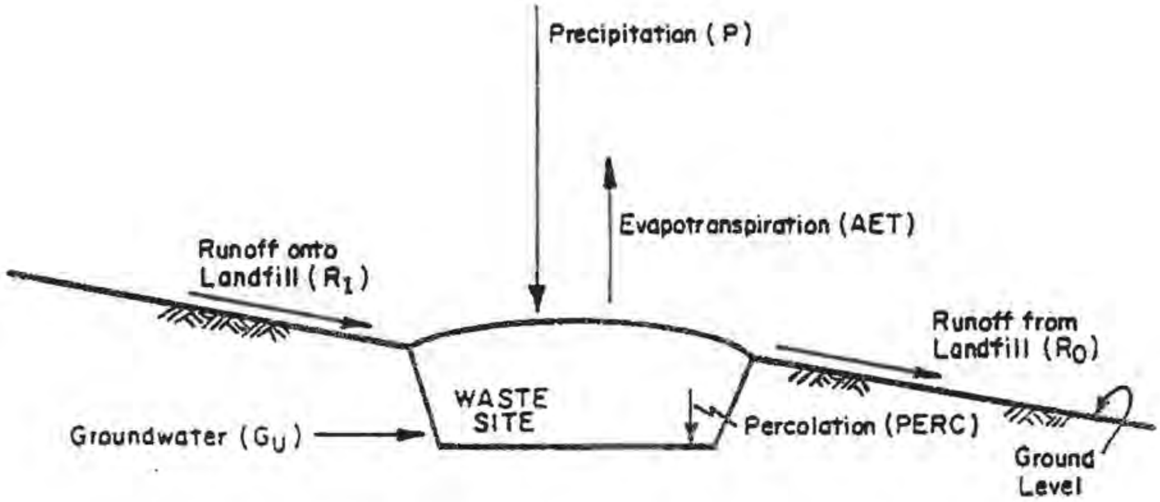


FIGURE 8-4 WATER FLOW IN A LANDFILL DISPOSAL SITE.

National Oceanic and Atmospheric Administration (NOAA). Runoff onto the landfill is a function of topographic and drainage conditions adjacent to the landfill. Runoff can be minimized by using diversion ditches around the site. The amount of infiltrating water is depleted by changes in soil moisture storage, direct evaporation to the atmosphere, and transpiration by plants. The remaining water moves through the surface layer, percolates through the landfill, and will eventually emerge as leachate.

An additional source of water in landfills is groundwater flow through the landfill, or underflow. This occurs if the base of the landfill is below the water table. In this case, the amount of leachate can be estimated by the equation:

$$L = PERC + G_u \qquad (3)$$

where
- L = amount of leachate
- $PERC$ = percolation through landfill
- G_u = groundwater underflow through landfill

The amount of groundwater underflow can be estimated from water table conditions in the vicinity of the landfill.

Ponds -- In a pond, standing water provides the driving force for moving leachate out of the pond and into adjacent materials. Since most of this movement is through the bottom of the pond, the predominant driving forces and direction of movement vertical. The vertical movement of leachate can be impeded by underlying man-made or natural less permeable materials. Figure 8.5 shows the flow of water in a pond disposal site.

The movement of leachate from a pond may be described in terms of hydraulic potential or mass balance. The hydraulic potential approach is described by a form of Darcy's Law, which considers the driving forces or hydraulic head in the pond, the hydraulic conductivity of waste and underlying materials, and the area of the pond:

$$Q = KiA \qquad (4)$$

where
- Q = water movement through pond bottom, or seepage
- K = hydraulic conductivity of underlying material
- i = hydraulic gradient across underlying material
- A = area of pond bottom

Equation 4 applies to ponds where the area of the bottom is much greater than the area of the sides, and where most of the seepage occurs through the pond bottom. The controlling terms in the equation are K and i. K is the hydraulic conductivity of the underlying material. This may be a man-made liner or a natural soil or rock unit. If waste material has settled on the pond bottom, it is considered part of the effective underlying material. The

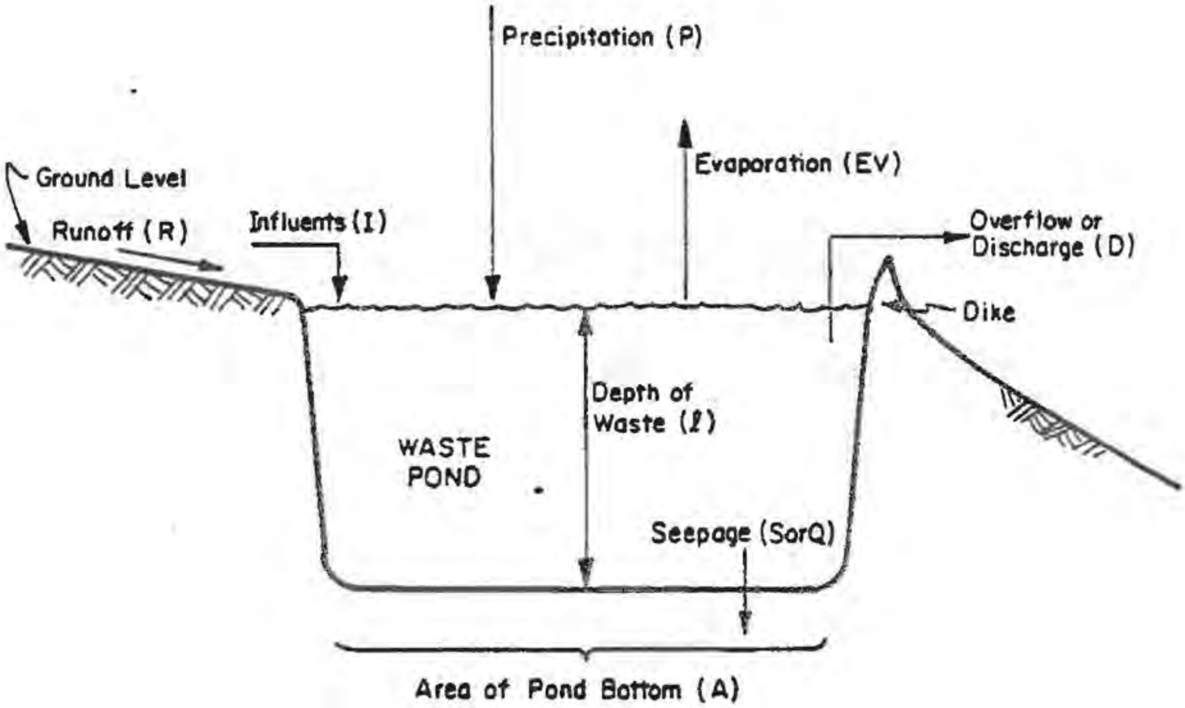


FIGURE 8-5 WATER FLOW IN A POND DISPOSAL SITE.

hydraulic gradient is a measure of the hydraulic head distribution across the underlying material and is given by the equation:

$$i = \Delta h/l \qquad (5)$$

where
Δh = head difference across the material
l = length or thickness of material

The head difference is equal to the difference between the hydraulic head at the bottom of the pond (usually the water level in the pond) and the hydraulic head at the base of the underlying material. This may be equal to or less than one atmosphere if the underlying soil or rock is unsaturated, or greater than one atmosphere if it is saturated.

The mass balance approach considers the balance of water inputs to and discharges from the pond:

$$S = P + R + I - EV - D \qquad (6)$$

where
S = seepage from pond bottom
P = direct precipitation into pond
R = runoff into pond
I = other water inputs to pond (for example, from a discharge line)
EV = direct evaporation from pond
D = other water discharges from the pond (for example, from a spillway or discharge pipe)

Precipitation into the pond may be determined from climatologic records, as may evaporation. More detailed information can be obtained from precipitation gauges and evaporation pans established at the pond site itself. Other water inputs and discharges can be determined from records of the pond operation.

8.6.2.1.2 Hydrogeology -- Once leachate enters the surrounding environment from landfills or ponds, its movement is controlled by hydrogeological conditions in the vicinity. Since leachate will generally move with the groundwater, the direction of its movement can be estimated by studying groundwater flow conditions. Three aspects of site hydrogeology control leachate movement: depth of water table and thickness of the unsaturated zone, hydraulic conductivity anisotropies, and regional groundwater movement.

Thickness of Unsaturated Zone -- Unless the water table is at the ground surface, an unsaturated zone will exist above groundwater. Deep water tables are characterized by thick unsaturated zones while shallow water tables are characterized by thin unsaturated zones. Construction of a pond or landfill will likely alter the geometry of the unsaturated zone unless a completely impermeable (synthetic) liner is placed under the site. Landfill construction may also affect the geometry of the unsaturated zone, as described below.

In a pond or landfill constructed above the water table, initial leachate movement will be vertically downward through the unsaturated zone (see Figure 8.6). If this movement is significant, the water table will mound to increase local hydraulic gradients and cause more movement of groundwater away from the mound (Figure 8.6a). The mound will reach equilibrium when the hydraulic gradients are sufficient to move all the water supplied by the waste disposal facility. If the unsaturated zone is thick, mounding should not raise the water table to the base of the pond or landfill. If the unsaturated zone is thin, mounding may cause direct contact between waste and groundwater and possibly increase rates of leachate generation. The amount of groundwater mounding can be calculated with the governing differential equations.

Under certain conditions, a wetting front may form beneath a pond or landfill and eventually reach the water table (Figure 8.6b). This happens when the saturated hydraulic conductivity of underlying material is less than the percolation or seepage rate. In this case, water is supplied to the underlying material faster than it can move through it. The seepage or percolation is "backed up," and a wetting front formed. The movement of a wetting front to the water table is halted by changes in hydraulic properties of underlying materials, and so would only be expected in very uniform deposits.

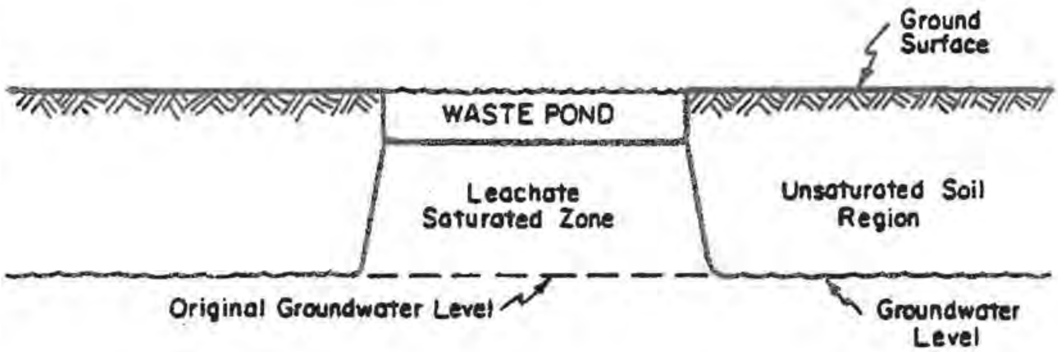
Hydraulic Conductivity Anisotropies -- Stratification of soils and sedimentary rock units and structural discontinuities in bedrock units will result in anisotropy of hydraulic properties, most notably hydraulic conductivity. In soils and sedimentary rocks, the horizontal hydraulic conductivity (K_h) is usually greater than the vertical hydraulic conductivity (K_v). In bedrock, hydraulic conductivity is largest in the directions of structural discontinuities such as joints, faults, and solution cavities.

In a stratified sequence of soil or rock, the equivalent vertical hydraulic conductivity of the section is given by the equation:

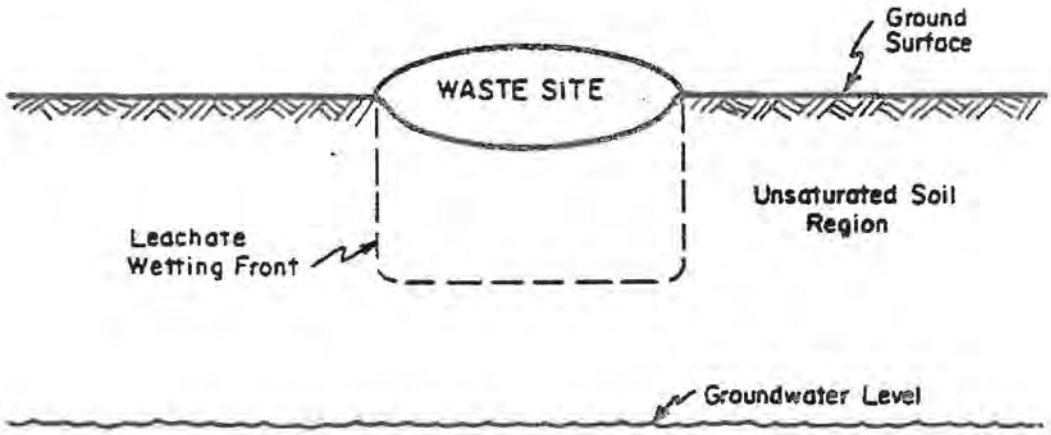
$$K_v = \sum_{i=1}^{n} \frac{d}{di/Kiv} \qquad (7)$$

where
K_v = equivalent vertical hydraulic conductivity
d = total section thickness
di = thickness of individual stratum
Kiv = vertical hydraulic conductivity of individual stratum

Equation 8.7 shows that layers with low vertical hydraulic conductivities have the greatest effect on the equivalent hydraulic conductivity of the section. One or two layers with very low hydraulic conductivity may be enough to make the equivalent vertical hydraulic conductivity very low.



(a) Thin unsaturated zone.



(b) Thick unsaturated zone.

FIGURE 8-6 LEACHATE MOVEMENT IN THE UNSATURATED SOIL REGION

The equivalent horizontal hydraulic conductivity of a stratified sequence is given by the equation:

$$K_h = \sum_{i=1}^{n} \frac{Kihdi}{d} \qquad (8)$$

where
K_h = equivalent horizontal hydraulic conductivity
d = total section thickness
di = thickness of individual stratum
Kih = horizontal hydraulic conductivity of individual stratum

The greatest influence on equivalent horizontal hydraulic conductivity will thus be from strata with high horizontal conductivities. One or two strata with high horizontal hydraulic conductivity may be enough to make the equivalent horizontal hydraulic conductivity high.

Comparison of equations 7 and 8 indicates that K_h is greater than K_v for all values of K_v. Ratios of K_h to K_v may be on the order of ten, one hundred, or greater.

In deep groundwater areas with large groundwater mounds beneath the waste disposal facility, leachate movement can be predominantly vertical. The rate of leachate movement controlled by the equivalent vertical hydraulic conductivities in the underlying strata. A clay liner may effectively retard leachate movement from the disposal facility. If the water table is shallow or the landfill or pond is constructed below the water table, the predominant direction of leachate movement is horizontal and controlled by the equivalent horizontal hydraulic conductivity. A permeable stratum between layers of much less permeable materials will facilitate horizontal movement of leachate.

Regional Groundwater Movement -- Groundwater generally flows from recharge areas to discharge areas. Recharge areas may consist of outcrops or subcrops of permeable bedrock units, permeable upland soil units and river valley alluvium in humid climates, and alluvial fans and terrace deposits in arid environments. Discharge areas may comprise springs, streams, rivers, ponds, lakes, bays, or pumping wells.

Depending on the rates of percolation and seepage, landfills and ponds may act as local recharge areas. Formation of a groundwater mound indicates significant groundwater recharge. Waste disposal facilities near streams, ponds, and lakes may be located in areas of groundwater discharge, in which case leachate may have a short pathway to the discharge point. Ponds and landfills in low-lying coastal areas may be recharge areas or may be located in discharge areas, depending on local topographic and hydrogeologic conditions.

Pumping wells act as groundwater discharge points which may enhance natural discharge or create new discharge. Groundwater in the area of influence of the well moves towards the well and, if the area intersects a pond or landfill, leachate also may move towards the well. Pumping from a well may be sufficient to reverse local groundwater flow directions.

8.6.2.1.3 Leachate Quantity Decision-Making Process — The leachate quantity decision-making process is shown in Figure 8.7. The goal is to estimate the quantity of leachate that may be produced over a certain period of time. This in turn can be related to the flow or leachate generation-per-unit time. Since the decision methodology is different for a pond versus a landfill disposal scenario, it has two separate branches. In the case of a landfill, leachate generation is produced by infiltration of water (precipitation, runoff on the site, or even intermittent disposal of liquid wastes) and contact of groundwater with the waste.

For the ponding disposal scenario, leachate volume may be calculated by: (1) using a mass balance around the pond (influents vs nonleachate effluents) and determining the leachate by difference and (2) using hydraulic conductivity and other site specific parameters to calculate the flow and thus quantity. The decision-making process in Figure 8.7 uses the mass balance approach and may require further calculations based on the second approach, depending on the available data and accuracy of desired result.

8.6.2.2 Leachate Chemical Composition--

8.6.2.2.1 Overview -- Leachate chemical composition depends on the chemical and physical properties of the waste and how they interact:

- displacement of interstitial liquor present in saturated waste;
- mixing of influent water with displaced interstitial liquor (for unsaturated waste);
- dissolution of readily available species in the waste;
- dissolution of bulk matrix species and associated trapped components;
- solubility and adsorption constraints on concentrations in the leachate;
- concentrations determined by total availability of material from the waste; and
- chemical speciation in wastes and leachates.

8.6.2.2.2 Displacement of Interstitial Liquor -- The chemical composition of leachates from saturated wastes is best estimated from the makeup of the interstitial liquid phase. Wells placed in the saturated waste near the bottom of the disposal areas show the composition of water likely to exit the disposal area. This composition may not only represent the waste present at that particular depth but may also reflect how the percolating liquid has contacted many layers of waste. Since waste layers tend to be inhomogenous (i.e., particle size segregation in a pond), different leaching behaviors are expected for various strata. Concentrations in interstitial

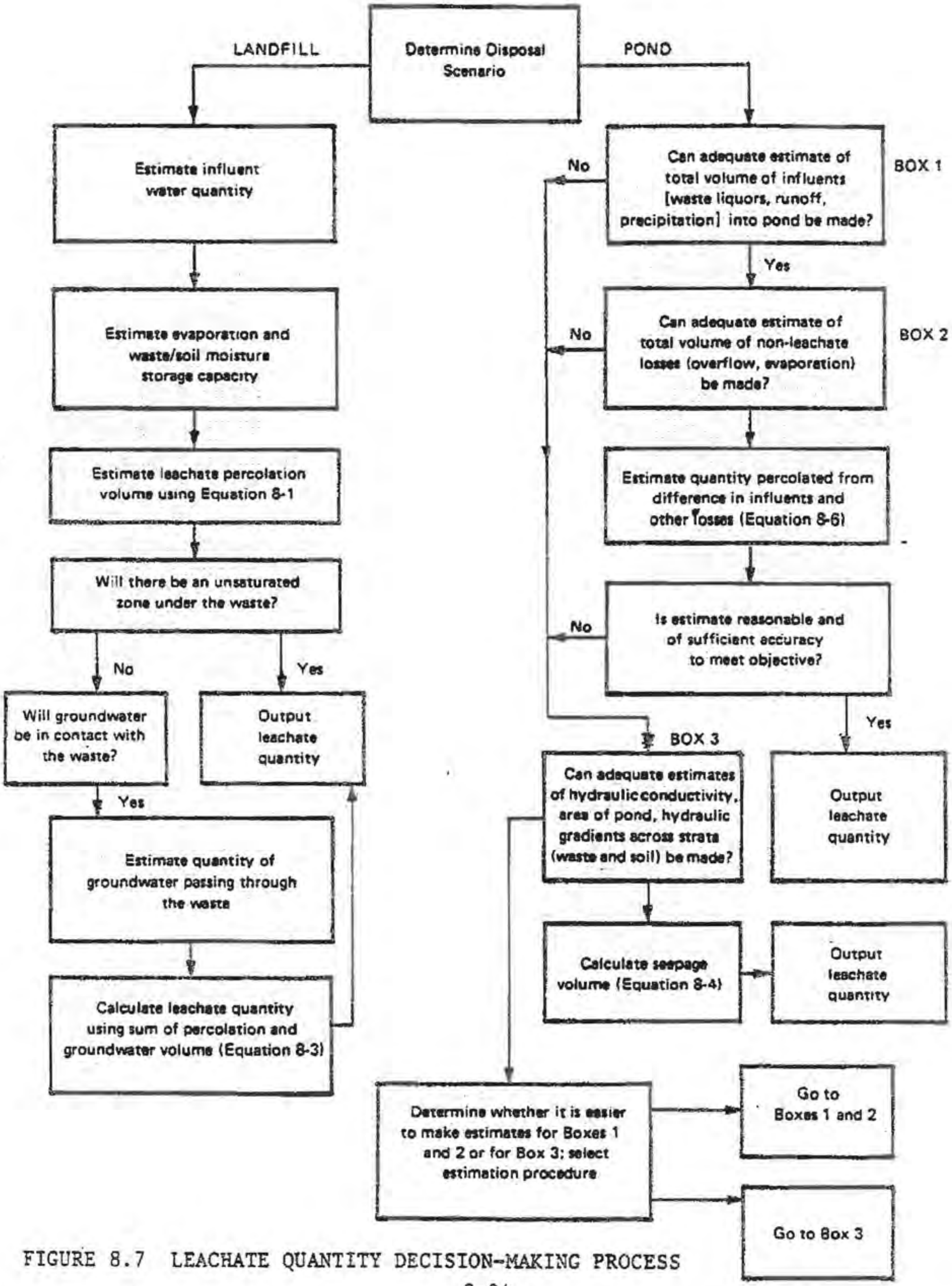


FIGURE 8.7 LEACHATE QUANTITY DECISION-MAKING PROCESS