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Project Summary

Full-Scale Field Evaluation of Waste Disposal from Coal-Fired Electric Generating Plants

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This project summary describes 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. Results of the study provide 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; 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 (based on climate and hydrogeology)—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 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.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in six separate volumes (see Project Report ordering information at back).

Introduction

This study—of current coal ash and flue gas desulfurization (FGD) waste disposal practices at coal-fired power plants—involved characterization of wastes, environmental data gathering, evaluation of environmental effects, and engineering/cost evaluations of disposal practices at six sites around the country. Results of the study provide the technical background data and information needed to help EPA determine the degree to which disposal of these wastes needs to be managed in order to protect human health and the environment. The study results will also assist EPA in preparing a report to Congress required under the 1980 Amendments to the Resource Conservation and Recovery Act (RCRA), and should provide useful technical information to federal, state, and local permitting officials and utility planners on methods for environmentally sound disposal of coal ash and FGD wastes.

Background on Waste Generation/Disposal Methods

Coal-fired power plants using conventional combustion technology generate two major categories of waste materials: coal ash (fly ash, bottom ash, or boiler slag) and FGD wastes are generated in large amounts relative to other wastes generated at these plants and, therefore, are usually referred to as "high volume wastes." Numerous other wastes, generated in smaller quantities, are associated with other processes or maintenance operations in a power plant; e.g., coal pile runoff, boiler and cooling tower blowdown, water treatment and 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, approximately 103,000 MW of coal-fired generating capacity—operational units, units under construction, and units at various stages of planning—had been committed to FGD systems. Flue gas can be desulfurized 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 becoming operational in 1982-1983. The principal 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.

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. are presented in Table 1. Most of the coal ash and all of the FGD wastes generated are sent to disposal. Considering the expected increase in coal consumption in the U.S., this is likely to be the case for many years. Utilization of FGC waste is expected to grow but at a slower rate than FGC waste generation. A significant fraction of the total coal ash generated is used for such purposes as soil stabilization, ice control, and as ingredients in cement, concrete, and blasting compounds; however, there is currently no utilization of FGD wastes in the U.S.

Table 1. Projections of FGC Waste Generation by Utility Plants in the United States (1980-1995)

	Waste Generation (10^6 Metric tons/yr)		
Waste Type	*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]	*158.6* *(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.*

On balance, disposal will continue to be the major option for FGC waste management in the U.S. for the foreseeable future.

Currently, 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. The principal methods of disposal on land are: ponding, landfilling (including disposal in surface mines), and interim ponding followed by landfilling. Table 2 presents data on current practices based on data obtained on 176 plants.

Ponding of FGC waste is more widely practiced than any other disposal method. Ponding can be employed 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 expensive. In the future, particularly if chemical treatment of FGD wastes is widely practiced, ponding will probably be limited to sites that would 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 and 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 prior to 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 also be dewatered via thickening, vacuum filtration, and, i necessary, blending with dry fly ash fo stabilization or other 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 as required 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.

In a landfill disposal site, the wastes are spread on the ground in 0.3 to 1 m (1 to 3 ft) lifts and compacted by wide-track dozers, heavy rollers, or other equipment. Layering proceeds in 0.3 to 1 m lifts in segments of the site. The ultimate height of a disposal fill is site specific, but can range from 10 m (30 ft) to as high as 76 m (250 ft). A properly designed and operating dry impoundment 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. Since the quantity (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 Plain States (e.g., North Dakota), have practiced this disposal method in recent years.

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

Site Selection and Test Plan Preparation

Candidate Site Selection Process

The overall objective of the candidate site selection process was to evaluate available data on coal-fired power plants and recommend a number of candidate and backup sites. The selection process consisted of two steps.

First, the contiguous 48 states were divided into 14 physiographic regions, and the plants in each region were screened to develop a list of plants that would be suitable for consideration as candidate and backup sites. A total 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 region was agreed upon. In screening selections, the investigators remained cognizant 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. A total of 26 plants in all the regions emerged from this filtration process.

Second, these 26 were then ranked in iterative group discussions leading to the nomination of 18 as candidate sites and the remainder as backup sites.

Table 2. *Current FGC Waste Disposal Methods Utilized at Utility Coal-Fired Power Plants in the U.S. (Data Base: 176 Plants ≥ 200 MW)[a]*

	Number of Plants		
Type of Waste	*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 ≥200 MW with the exception of four plants employing FGD systems. Figures represent the number of plants at which each waste type/disposal method is practiced. (Note: Many plants utilize more than one method.)*

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

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

Final Selection Process

The candidate and backup sites were then subjected to a more detailed evaluation. These evaluations included one or more detailed site visits by engineering, environmental, and hydrogeologic specialists assigned to the project. Their findings, together with mid-course evaluations that were continuously taking place, supported an iterative process that resulted in the selection of the final six sites. Table 3 provides overall information on the final six sites that were selected for evaluation under this project; Figure 1 indicates the site locations.

Test Plan Preparation

Detailed test plans providing background information on each of the sites, together with a description of the pro-

Table 3. *Waste Disposal Sites Selected for Evaluation*

	Location	Nameplate Generating Capacity (MW)	Startup Date (mo/yr)	Waste Site Under Study		High Priority Issues Under Study		
Plant (Utility)	*State (County)*		*Plant (FGD)*	*Waste Type*	*Disposal Method[a]*	*Ground Water Quality*	*Surface Water Quality*	*Employment of a Potentially Mitigative Practice*
Allen (Duke Power)	*N. Carolina (Gaston)*	1155	–/57	*Combined fly and bottom ash*	*Pond (UL)*	X	X	X
Elrama [Duquesne Light (waste disposal by Conversion Systems, Inc.)]	*Pennsylvania (Washington)*	310	6/52 (10/75)	*Stabilized FGD waste*	*Landfill (UL; offsite)*	X	X	X
				Combined fly and bottom ash	*Landfill (UL; offsite)*			
Dave Johnston (Pacific P&L)	*Wyoming (Converse)*	730	–/59	*Fly ash*	*Landfill (UL)*	X	—	X
Sherburne County (Northern States Power)	*Minnesota (Sherburne)*	1458	5/76 (5/76)	*Fly ash/FGD*	*Pond (CL)*	X	—	X
Powerton (Commonwealth Edison)	*Illinois (Tazewell)*	1786	–/72	*Combined fly and bottom ash*	*Landfill (AL)*	X	X	X
Smith (Gulf Power)	*Florida (Bay)*	340	6/65	*Combined fly and bottom ash*	*Pond (UL)*	X	X	X

[a] *UL = Unlined.*
CL = Clay-Lined.
AL = Artificially Lined (Poz-O-Tec).

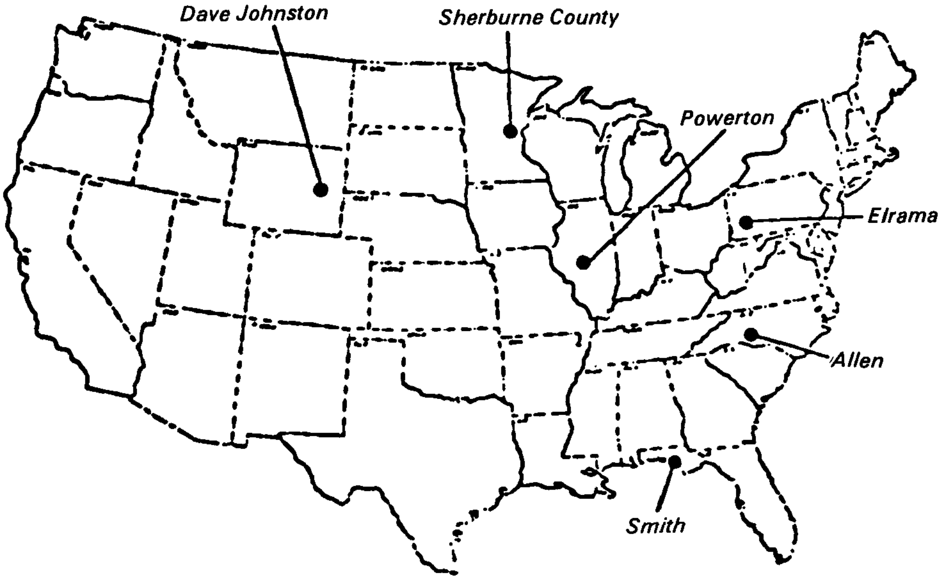

Figure 1. Location of waste disposal sites selected for evaluation.

posed program of site development, physical and chemical sampling, and analysis and engineering/cost assessments, were developed. 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.

Site Development and Physical Testing

After approvals from the utility and, in some cases, from state regulatory agencies, site development was begun. Site development and physical testing were governed by procedure manuals developed for this project. 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 ground water 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 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; i.e., laboratory soil classification and permeability tests on waste samples from the sites. Preliminary water balances were also developed for each site.

Chemical Sampling and Analysis

At each site, a program of chemical sampling and analysis was undertaken. This program included characterization of waste, water, and soil samples obtained from site development, and ground water well and (in some cases) surface water samples subsequently obtained from a series of visits scheduled to correspond to relatively wet, relatively dry, and intermediate periods for each site. Table 5 summarizes the sampling and analysis program.

Chemical samples are 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 5, these types of analyses were performed on a mix of solid and liquid samples for each site. In addition, a limited number of experiments were performed to assess the attenuative capacity of various soils obtained at the sites. Furthermore, during the initial phase of this project, 23 grab samples of wastes from 18 plants were obtained and analyzed using the EPA Extraction Procedure (EP); results from these tests are summarized in Table 6. Further details on these tests, as well as results of radioactivity measurements, are included in the final report of the project.

Site-Specific Environmental Evaluations

The data and information from site development and sampling/analysis were subjected to environmental effects evaluation throughout the project. The individual site evaluations were developed in five steps: (1) a review and evaluation was made of available background information on the disposal operation and its environmental setting; (2) present disposal-related water quality effects were identified and described based on evaluation and measured information developed in this project; (3) apparent cause/effect relationships were hypothesized to explain the findings at the sites; (4) potential future ranges of water quality effects were considered to the extent that suitable data were available; and (5) industry-wide implications of the findings at the individual sites were considered in the generic assessment, discussed later in this summary.

Environmental evaluation of *all* six sites has generated a significant amount of data and information. The following general items can be reported:

1. 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 suggest that the contribution of waste leachate to the ground water has resulted in concentrations of chemicals less than the primary drinking water standards established by EPA.
2. The results from the sites are internally consistent. In other words, the analyses of samples taken on different dates at the same locations are very similar.
3. The total integrated evaluation of data from site development, site water balances, physical testing of wastes samples, and chemical sampling and analysis is providing a large significant data base to explain many of the environmental effects that can result from coal ash and FGD waste disposal.

Table 4. Summary of Site Development/Physical Testing

Plant	Date Development Completed (mo/yr)	Number of				Number of Laboratory Physical Tests	
		Borings	Wells	Test Pits	Soil Samples	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
Sherco	08/81	13	11	-	178	20	6
Powerton	11/81	11	9	1	112	30	8
Smith	12/81	25	24	-	146	15	8

Table 5. Summary of Chemical Sampling and Analysis Program

	Samples[a]		Analyses[b]				
			Trip 1	Trips 2, 3, and 4			
Site	Trip 1	Trips 2, 3, and 4	ICAP	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	
	waste solids		X		X		X[d]
	soil		X		X		
	waste extracts			X			
Sherco	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	liquids	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^-, $SO_4^=$, Br^-, PO_4^{3-}.

As/Se—either or both on selected samples.

Field Data—ground water 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.

A brief account of the results at each of the sites is presented below.

Allen—The results indicate:

1. Leachate generated within the ash ponds contain elevated (over background) concentrations of several waste-related chemical constituents (e.g., boron, sulfate, calcium, arsenic). However, the surrounding soils have attenuated significant fractions of leachate constituent contaminants within the immediate vicinity of the ponds.
2. Leachate water from the upgradient portions of the ash ponds has not moved sufficiently to create steady-state concentrations of unattenuated constituents (e.g., sulfate) in downgradient wells. However, concentrations of these constituents are expected to only reach or barely exceed secondary drinking water standards (e.g., for sulfate, 250 ppm).

Elrama—The results indicate:

1. Prior to disposal of FGC wastes, much of the site was contaminated by acid mine drainage, resulting in low pH (4.5 to 5) and high concentrations of chemical constituents (e.g., about 2000 ppm sulfate) in the ground water.
2. The landfill and runoff collection ponds may serve as potential sources of some constituents via leachate and overflow, including chloride and calcium (both at about 500 ppm). However, neither chloride nor calcium is at a level to cause major concern. In addition, an elevated level (about 0.2 ppm) of arsenic was measured at one waste/soil interface lysimeter; however, it does not appear to be a general problem. In any event, substantial attenuation of arsenic by soils at the site is expected.
3. The relative absence of elevated levels of these waste-related constituents in downgradient ground water may be explained by the relatively short time the fill has been in operation (4 years), chemical/physical attenuation phenomena (including the effects of the treatment/disposal process), or a combination of these factors.
4. The landfill does not appear to alter significantly the local concentrations of some constituents (such as sulfate) potentially available from both mine drainage and FGC wastes.

Dave Johnston—The results indicate:

1. The water balance and estimates of plume arrival time indicate that the widespread measurement at the site of what might elsewhere be considered elevated chemical constituent levels (e.g., sulfate, about 1000 ppm) is not due to the 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 considering only travel time in the saturated zone. Travel time from the 20-year old inactive landfill to a much closer (to the landfill) downgradient well is estimated to be in excess of 20 years, accounting for both unsaturated and saturated zone travel.
2. Most of the "elevated" measurements reflect pervasively high background levels characteristic of highly mineralized ground water in many western settings. However lower measured values (e.g. sulfate about 100 ppm) at one background and one periphera well indicate that even in highly mineralized arid areas there may be areas of good water quality that require protection in waste disposal site planning and management.

Sherco—The results indicate:

1. Leachate movement from the ponds has thus far been sufficiently retarded by the clay liner to preclude development of significant elevations of chemical constituents in the leachate at downgradient wells.
2. 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, but it is not clear whether this is due to past leakage from the sheet piling/conduit area, to leachate that has moved through the liner, or to a combination of these two sources.
3. Because of the pervious soils in the area of the site, significant in-

Table 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*	*<1*	*<1*	*<1*
Selenium	*<2 – 340*	*8 – 49*	*10*	*<0.2 – 34*	*0.8 – 4.9*
Silver	*<1*	*<1*	*50*	*<0.02*	*<0.02*

[a] *These standards are "...for use in determining whether solid waste disposal activities comply with ground water criteria." Standards included, 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] *An amendent to the chromium criteria for the EP revises 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.*

creases in concentrations of major soluble species are expected to occur in downgradient wells in the next few years. Secondary drinking water standards are expected to be exceeded in these wells. However, any effects of movement of these species off-site will be mitigated (diluted) by the Mississippi River, which flows by the plant.

4. The higher concentrations of waste parameters in FGC pond supernatant versus underlying waste interstitial waters may be due to two factors: (1) 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 (2) the evaporation of water in the pond would also increase remaining chemical concentrations.

Powerton—The results indicate:

1. Although the completed landfill was supposed to have a 0.25 m (8 in.) Poz-O-Tec liner, during the coring operation a general absence of liner material was observed. This observation is consistent with the practical difficulty of achieving uniform placement of such a relatively thin layer of soil-like material over a large area. Current engineering practice suggests that a minimum thickness of 0.45 to 0.60 m (18 to 24 in.) of liner placement would be desired to ensure full effectiveness.
2. The surface water analytical results for Lost Creek are consistent with the water balance calculations. Both sets of results indicate that the stream has adequate assimilative/dilution capacity to lower current concentrations of chemical constituents in leachate reaching Lost Creek to insignificant levels.
3. The results also suggest that the stream, if an effective ground water flow divide, may limit the extent of further downgradient ground water contamination by the waste plume.
4. The general lack of elevated trace metal concentrations in ground water suggests that a combination of chemical attenuation (especially for chromium and lead) and dilution is preventing the release of significant quantities of these elements and/or elevation to significant concentrations at downgradient locations.
5. 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.

Smith—The results indicate:

1. There appears to have been a steady state achieved between the concentrations of soluble species in the pond and in the immediately adjacent downgradient areas.
2. There appears to be little or no chemical attenuation of the major tracer species such as calcium and strontium, but rather a progressive reduction in concentrations in the downgradient direction. This is consistent with what would be expected due to admixing of leachate with the greater amounts of dilution water.
3. 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.

Generic Environmental Evaluation of Coal Ash and FGD Waste Disposal

The environmental effects of solid waste disposal practice are determined by three factors: waste type, disposal method, and the environmental setting. The data base from this project and other related projects suggests that present and future practices of coal ash and FGD waste disposal may be effectively evaluated using 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 those containing fly ash. Thus this category of wastes 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. This category includes bottom ash (or boiler slag) and FGD wastes that are disposed of separately from fly ash (including forced oxidation wastes). This category usually contains lesser concentrations of trace metals, but can result in higher concentrations of major species (e.g., chlorides from FGD waste).
3. Stabilized FGD wastes. FGD wastes may be processed or stabilized for full-scale disposal by a variety of processes; the processes presently in commercial practice involve the addition of lime and fly ash, or processed slag. Lime/fly ash stabilization for landfill disposal is presently practiced at some power plants and is expected to grow in importance. Processed FGD wastes are a separate category because of the differences in their physical and chemical properties created by the stabilization process.
4. Dry FGD wastes. Several dry FGD systems are expected to come into commercial use over the next 3 years. It appears that calcium-based dry FGD systems are anticipated to grow more than sodium-based systems. By either process, dry FGD systems provide a combined waste (containing fly ash and the sulfur compound) 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 be different from the other categories discussed above; additionally, there is a relative lack of even limited field scale information on their leaching characteristics to date.

Three disposal methods for coal ash and FGD wastes are in practice and expected to continue in the future: (1) pond disposal; (2) interim ponding followed by landfill disposal; and (3) 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: (1) coastal areas, specifically where surface water and ground water 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, characteristic of the non-coastal portions of the eastern U.S. where there tends to be more of a balance between precipitation and evaporation and where permanent surface water bodies are in such abundance as to be near many disposal sites.

Further evaluations during this project suggested that a further breakdown of two special categories would be useful because of their significant characteristics: (1) arid areas in the west where ground and surface waters are very highly mineralized, and (2) interior areas subject to acid mine drainage. Both these settings and 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 7 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), the Electric Power Research Institute (EPRI), and the Department of Energy (DOE). DOE is currently sponsoring a study of disposal of FGD wastes in a surface mine; the study was originally sponsored by EPA. As is clear, some information is available for most of the combinations that are being practiced today or are likely to be practiced in the future.

It appears that, on balance, technology exists for environmentally sound disposal of coal ash and FGD wastes using 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 ground water and/or surface water contamination. However, site specific application of good engineering design and practice can mitigate most potentially adverse environmental effects of waste disposal.

Engineering/Cost Evaluations

The first major efforts in the engineering/cost evaluations involved development of site-specific conceptual engineering designs and costs (capital and first year operating and maintenance costs) for the current solid waste handling and disposal operations at the six study sites. To facilitate the ultimate use

Table 7. *Summary of Information Available for Combinations of Waste Types, Disposal Methods, and Environmental Settings*

	Ponding				*Interim Ponding/Landfilling*				*Landfilling*			
Setting	*Fly Ash[a]*	*Non-Fly Ash[b]*	*Processed FGD*	*Dry FGD*	*Fly Ash[a]*	*Non-Fly Ash[b]*	*Processed FGD*	*Dry FGD*	*Fly Ash[b]*	*Non-Fly Ash[b]*	*Processed FGD*	*Dry FGD*
Coastal	*X* *Smith[c]*	*P*	*NA*	*NA*	*X/P[d]* *Chisman Cr.* *(USWAG)*	*P*	*P*	*NA*	*P*	*P*	*P*	*P[e]*
Arid Western— Not Highly Mineralized	*P*	*P*	*NA*	*NA*	*P*	*P*	*P*	*NA*	*P*	*P*	*P*	*P[e]*
Arid Western— Highly Mineralized	*P*	*P*	*NA*	*NA*	*P*	*P*	*P*	*NA*	*X* *Dave Johnston;* *Milton Young* *(DOE/EPA)*	*P*	*P*	*P[e]*
Interior— Not Highly Acidic	*X* *Allen,* *Sherco,* *Michigan City* *(USWAG),* *Wallingford* *(USWAG)*	*P*	*X* *Bruce Mansfield*	*NA*	*X/P[d]* *Bailly* *(USWAG)*	*P*	*P*	*NA*	*X* *Powerton,* *Zuellinger* *(USWAG)* *Hunts Brook* *(USWAG)* *Dunkirk* *(DOE)*	*P*	*X* *Conesville* *(EPRI/USWAG)*	*P[e]*
Interior— 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 or landfill aspect of operation studied 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 practice.

of the cost data, the estimates were developed by breaking down the waste handling and disposal operations into five modules: (1) raw material handling and storage; (2) waste processing and handling; (3) waste storage; (4) waste transport; and (5) waste placement and disposal (including site monitoring and reclamation).

Based on the site-specific cost estimates and other studies by TVA, EPRI, and other organizations, generic capital and O&M cost estimates were then prepared for individual modules comprising waste handling and disposal for coal ash and FGD wastes. Tables 8 and 9 summarize results of this effort.

The range of costs given represents variations in specific plant operations as well as variations in the several cost estimates used in preparing these estimates. For example, the higher end of the range for FGD waste handling/processing might include thickening, vacuum filtration, and mixing with lime and fly ash, while the lower end could represent a simpler operation with little or no processing. Figures 2 and 3 show the estimates for the FGD waste handling/processing "module." Similar figures for all the modules listed in Tables 8 and 9 are included in the final report for the project.

Conclusions

Results from this 3-year study of disposal of coal ash and FGD wastes from coal-fired electric generating plants provide major technical guidance for regulatory bodies and the utility industry. However, results from field studies of this type are limited, and predictive

Table 8. *Generic Capital Cost Estimates for FGC Waste Disposal (Late 1982 Dollars)*[a]

		Capital Cost Range ($/kW)			
		Plant Size (MW)			
Module	*Submodule*	*250*[b]	*500*[b]	*1000*[b]	*2000*[b]
Fly ash handling/processing	*Wet handling w/o recycle*	*2.3–4.3*	*1.9–3.5*	*1.5–2.9*	*1.3–2.3*
	Wet handling w/recycle	*3.7–6.8*	*3.0–5.5*	*2.4–6.4*	*1.9–3.6*
	Dry handling	*2.2–4.1*	*1.8–3.3*	*1.4–2.7*	*1.2–2.2*
Fly ash storage	*Dry*	*4.7–8.8*	*4.2–7.7*	*3.7–6.8*	*3.2–5.9*
Fly ash transport	*Wet sluicing*	*3.5–6.4*	*2.7–5.1*	*2.2–4.0*	*1.7–3.2*
	Dry trucking	*0.3–0.5*	*0.3–0.6*	*0.3–0.5*	*0.2–0.5*
Fly ash placement/disposal	*Unlined pond*	*15.1–27.8*	*12.9–23.9*	*11.0–20.5*	*9.4–17.5*
	Landfill	*4.3–8.1*	*3.3–6.1*	*2.5–4.7*	*1.9–3.6*
Bottom ash handling/processing	*Wet handling w/o recycle*	*2.2–4.1*	*1.7–3.2*	*1.3–2.5*	*1.0–1.9*
	Wet handling w/recycle	*2.5–4.6*	*2.0–3.7*	*1.6–3.0*	*1.3–2.4*
Bottom ash transport	*Wet sluicing*	*3.0–5.6*	*2.4–4.5*	*1.9–3.6*	*1.5–2.8*
	Dry trucking	*0.2–0.4*	*0.2–0.3*	*0.1–0.2*	*0.1–0.2*
Bottom ash placement/disposal	*Unlined pond*	*6.4–11.8*	*5.1–9.6*	*4.2–7.7*	*3.4–6.2*
	Landfill	*1.3–2.4*	*1.1–2.0*	*0.9–1.6*	*0.7–1.3*
Raw material handling/storage	*Dry (lime and fly ash)*	*2.4–4.5*	*2.1–3.9*	*1.9–3.4*	*1.6–3.0*
FGD waste handling/processing[c]	*Wet handling*	*18.1–33.6*	*15.2–28.3*	*12.8–23.8*	*10.8–20.0*
FGD waste transport	*Wet sluicing*	*0.7–1.3*	*0.5–1.0*	*0.4–0.8*	*0.4–0.7*
	Dry trucking	*0.4–0.7*	*0.3–0.6*	*0.3–0.5*	*0.3–0.5*
FGD waste placement/disposal	*Unlined pond*	*10.0–18.6*	*8.9–16.6*	*7.9–14.7*	*7.0–13.1*
	Landfill	*4.1–7.6*	*3.3–6.2*	*2.7–5.0*	*2.2–4.0*

[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:	*2% S, 13% Ash, 10,500 Btu/lb* (24.4×10^6 *MJ/kg)*
Load Factor:	*70%*
Heat Rate:	*10,250 Btu/kWh* (10.8×10^6 *MJ/kWh)*
SO_2 *Removal:*	*90%*
Lime Stoichiometry:	*1.1*
Fly Ash/Bottom Ash Ratio:	*80/20*

[c] *Assumed FGD System: Wet Lime Scrubbing*

tools (e.g., computer models) for evaluating interactions between these wastes and site-specific hydrogeologic systems are, in many cases, inadequate. For this reason, additional efforts sponsored by industry are currently underway to develop more sophisticated tools for predicting and analyzing the potential environmental effects of coal ash and FGD waste disposal.

Table 9. *Generic Annual Cost Estimates for FGC Waste Disposal (Late 1982 Dollars)*[a]

		Annual Cost Range ($/dry metric ton)			
		Plant Size (MW)			
Module	Submodule	250[b]	500[b]	1000[b]	2000[b]
Fly ash handling/processing	*Wet handling w/o recycle*	2.5–4.6	1.0–3.7	1.6–3.0	1.3–2.3
	Wet handling w/recycle	3.7–6.8	2.9–5.4	2.3–4.3	1.8–3.6
	Dry handling	2.5–4.7	2.1–3.9	1.7–3.2	1.5–2.7
Fly ash storage	*Dry*	3.3–6.1	3.0–5.6	2.8–5.2	2.5–4.7
Fly ash transport	*Wet sluicing*	4.2–7.6	3.2–5.9	2.5–4.7	2.0–3.7
	Dry trucking	1.7–3.1	1.5–2.8	1.3–2.5	1.2–2.2
Fly ash placement/disposal	*Unlined pond*	11.5–21.3	9.1–16.8	7.2–13.5	5.7–10.5
	Landfill	7.0–13.0	5.6–10.5	4.6–8.5	3.7–6.9
Bottom ash handling/processing	*Wet handling w/o recycle*	11.3–21.0	9.0–16.7	6.9–12.8	5.3–9.9
	Wet handling w/recycle	12.3–22.8	10.3–19.1	8.4–15.7	6.9–12.8
Bottom ash transport	*Wet sluicing*	9.2–17.1	7.3–13.5	5.6–10.3	4.3–7.9
	Dry trucking	3.4–6.3	2.8–5.2	2.2–4.1	1.8–3.3
Bottom ash placement/disposal	*Unlined pond*	9.2–17.1	7.9–14.6	6.5–12.1	5.4–10.0
	Landfill	5.4–10.0	4.7–8.8	4.1–7.6	3.5–6.5
Raw material handling/storage	*Dry (lime and fly ash)*	4.1–7.6	3.7–6.7	3.4–6.2	3.0–5.6
FGD waste handling/processing[c]	*Wet handling*	17.2–31.9	13.8–25.5	11.0–20.5	8.8–16.4
FGD waste transport	*Wet sluicing*	1.1–2.1	0.9–1.7	0.7–1.3	0.6–1.1
	Dry trucking	2.9–5.4	2.3–4.3	1.8–3.3	1.4–2.6
FGD waste placement/disposal	*Unlined pond*	8.5–15.8	6.7–12.4	5.2–9.7	4.1–7.6
	Landfill	4.0–7.5	3.4–6.3	2.8–5.3	2.4–4.4

[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
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FGD Waste	240

"Typical Case" Assumptions

Coal Properties: 2% S, 13% Ash, 10,500 Btu/lb (24.4 × 10^6 MJ/kg)
Load Factor: 70%
Heat Rate: 10,250 Btu/kWh (10.8 × 10^6 MJ/kWh)
SO_2 Removal: 90%
Lime Stoichiometry: 1.1
Fly Ash/Bottom Ash Ratio: 80/20

[c] *Assumed FGD System: Wet Lime Scrubbing*

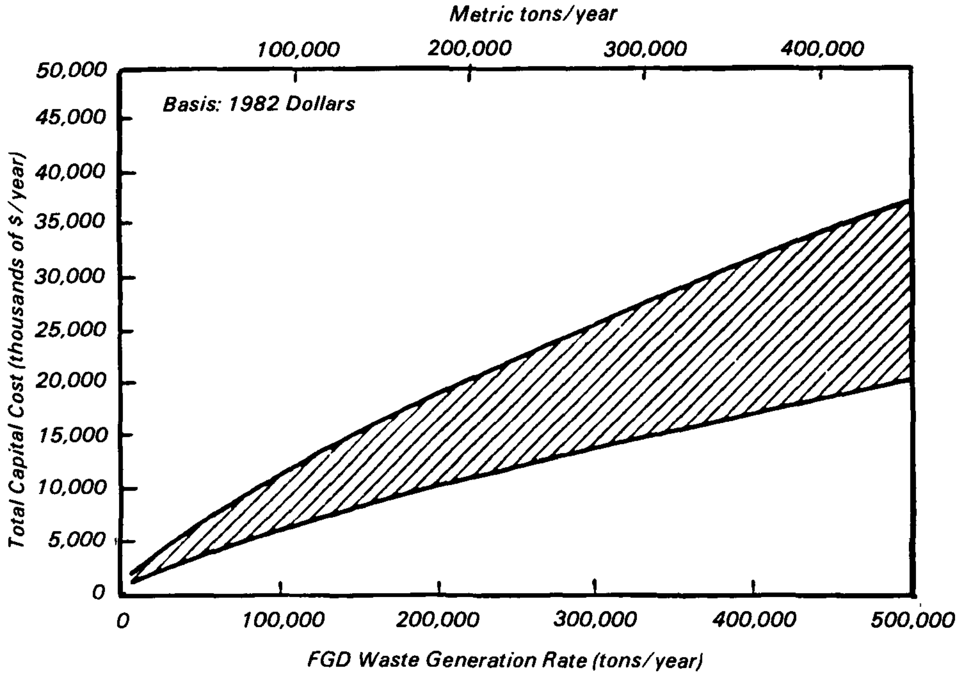

Figure 2. FGD waste handling and processing: capital costs versus FGD waste generation rate.

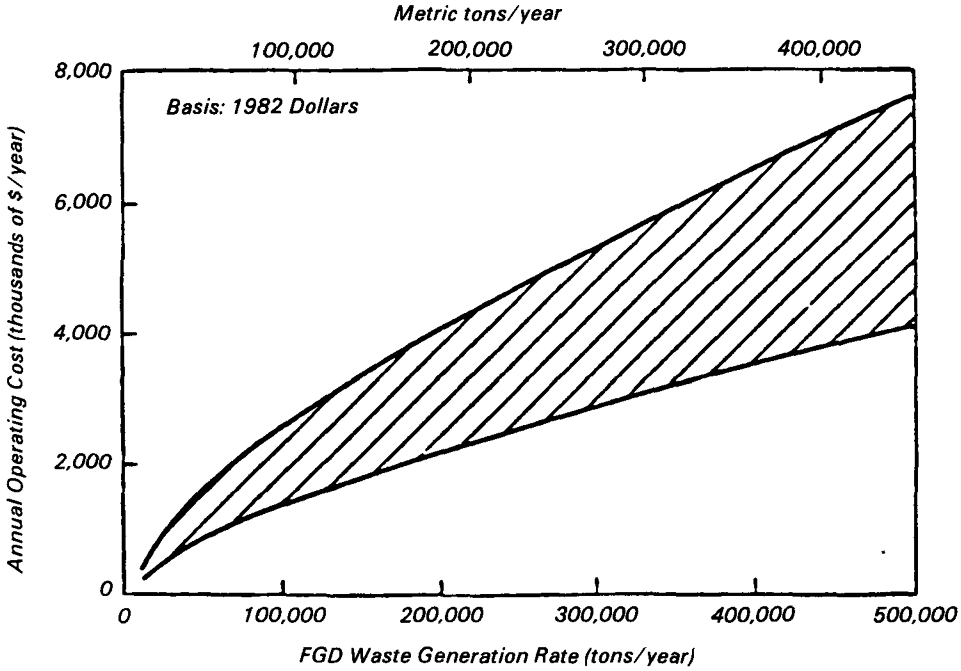

Figure 3. FGD waste handling and processing: annualized costs versus FGD waste generation rate.

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