Environmental Health Perspectives
Vol. 27, pp. 275–281, 1978

Impact of Solid Discharges from Coal Usage in the Southwest

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The Southwestern region of the United States is extremely wealthy in low sulfur coal resources which must be eventually utilized in response to national energy balance priorities. Fly ash and scrubber sludge can be safely disposed of using properly managed techniques to ensure that any potential impact from elements such as boron, molybdenum, or selenium is rendered insignificant. Alternative methods of solids utilization are presently being developed. Fly ash is presently being marketed commercially as an additive for concrete manufacture. Successful experiments have been completed to demonstrate the manufacture of commercial-grade wallboard from scrubber sludge. Also, greenhouse studies and field experiments have been conducted to demonstrate increased yields of selected crops grown on typical soils amended with fly ash in amounts ranging from 2% to 8%, by weight. These studies also indicate that barium and strontium may be good monitoring indices for determining atmospheric deposition of fly ash, due to their concentration ratios in soil and vegetation samples. Further studies are being conducted to confirm encouraging irrigation and crop-yield data obtained with fly ash amended soils. Finally, the composition of many fly ashes and soils are similar in the Southwest, and there are no anticipated solid discharges from coal usage which cannot be rendered insignificant with proper management of existing and emerging methods of treatment. Compared with the water availability impact of coal usage in the Southwest, the impact of solid waste discharges are insignificant.

Introduction

The current national energy policy demands that the use of Southwestern coal be increased. In considering potential environmental impact of this energy related development, it is important to analyze impacts in the context of biotic provinces, the principal biotic divisions of a nation or of the world (*1*). Biosphere reserves, selected natural areas within and representative of the biotic provinces, have been defined as major elements of UNESCO's Man and the Biosphere (MAB) program, and they form the basis of current international Environmental Agreements. The purpose of defining biotic provinces is to classify data obtained within selected natural ecosystems for establishing conservation guidelines and research programs, and for providing a common basis for comparison within a given province, with respect to environmental sensitivity. The biotic provinces within the continental United States and 27 designated biosphere reserves which encompass representative ecosystems of these provinces, are shown in Figure 1. The southern Rocky Mountain and Sonoran provinces comprise the area of interest for coal usage in the Southwest. The UNESCO task force recommended that biosphere reserves be segregated into core areas with strict conservation objectives, and adjacent zones where research associated with various land uses could be carried out. Areas outside such designated zones could be developed when research on the impact of that development demonstrated ecological compatibility. However, considerable development of coal has already taken place in the Southwestern states, and our intent here is to treat these developments as serendipitous experiments on ecological impacts.

The southern Rocky Mountain and Sonoran biotic provinces are extremely abundant in coal. Various estimates of the recoverable coal in these two provinces range from 30 to 90 billion tons (27.2-81.6 Pg) (*2, 3*). This represents a sufficient domestic energy resource to replace all imported oil in the USA for the next 50 to 100 years, allowing for reasonable growth rates in energy consumption. Coal thus can be considered one of the most important long-range domestic fossil resources which can bridge the gap between now and the time that more advanced forms of energy supply, such as

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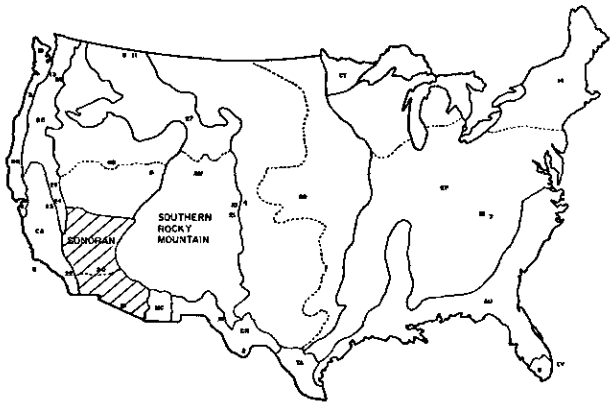

FIGURE 1. Location of established biosphere reserves and biotic provinces in the continental United States. Province subdivisions are indicated by dotted lines. Alphabetic designations refer to biotic provinces. (AU) Austroriparian; (CA) California; (CH) Chihuahuan; (CT) Canadian Taiga; (EF) Eastern Forest; (EV) Everglades; (GB) Great Basin; (GR) Grasslands; (MC) Madrean-Cordilleran; (OR) Oregonian; (RM) Rocky Mountain; (SC) Sierra-Cascade; (SO) Sonoran; (TA) Tamaulipan. Numbered areas refer to biosphere reserves.

solar power, can be perfected. The coal in the Southern Rocky Mountain and Sonoran provinces is so vast that it represents somewhere between 5% and 15% of all the recoverable coal in the world. Due to insufficient water in the arid Southwestern region it is obvious that a major portion of this energy cannot be utilized without moving the coal elsewhere or developing dry cooling systems, such as the full-scale wet/dry cooling tower demonstration program presently being carried out at one of SCE's plants in Southern California.

The purpose of this paper is to examine the potential impact of solid discharges such as fly ash, bottom ash, and scrubber sludge in the Southwestern biospheres. The subjects to be considered include differences in coal composition with native soils, physical impact due to fly ash deposition rates and biochemical impact of trace elements on vegetation. Quantities of ash and sludge collected for disposal at conventional coal fired generating stations and current disposal techniques will also be reviewed.

Coal Composition and Geology

Coal was formed in the Southwest from millions of years of vegetative accumulation in swamplands, and covered over with thick layers of sediment eroded from the Rocky Mountains. The coal which can be surface mined lies in seams from 5 to 50 ft (2–15 m) thick, covered with overburden sediment from 30 to 180 ft (9–55 m) thick. Normal surface mining practice includes removing topsoil followed by drilling, blasting and removal of the overburden with draglines. The coal is then drilled, blasted and removed. Then the overburden is replaced in the trench and the topsoil is replaced. Geology and climate have a significant influence on reclamation costs, which range from $500 to $5000 per acre ($0.10-1.00/m^2), depending on soil structure, hydrology, natural vegetation, terrain features, and precipitation (*4*).

Ash and other noncombustible material in coal arises from two sources. First, the deposition of volcanic ash, silt, and other solids into the swampland regions occurs during the vegetation growth period and these solids become entrapped in the peat precursor of coal. For Western coals, this ash content in a seam of pure coal can vary from 4% to perhaps 20%. Second, groundwater activity during and after geologic burial has resulted in the intrusion of suspended and dissolved material into coal seams. Normal coal seams in the Southwest therefore are frequently segregated by numerous layers of parting material consisting of clay, shale, or limestone deposits left primarily as a result of groundwater activity.

Examination of the microcrystalline structure of fly ash collected from Western coal-fired power plants indicates that the composition is similar to that of clay minerals (such as kaolinite) with intrusions of limestone (*5*).

It is extremely important to recognize that the ash material in Western coal was deposited primarily by natural groundwater activity, both during and after formation of the coal seams. Coal combustion essentially accelerates the natural breakdown of claytype ash material and elements which would otherwise be released much more slowly in the course of normal geologic processes. This point is important in examining the effects of groundwater activity, irrigation methods and weathering on the trace element composition of natural solids amended with fly ash.

Typical Power Plant Solid Discharges

A typical Western subbituminous coal would be expected to have the following characteristics: heating value, 10,000 BTU/lb (23 MJ/kg) (as received); ash content, 14%; sulfur content, 0.6%; moisture content, 12%.

If such a fuel were burned in a 1000 MW power plant at a net heat rate of 10,000 BTU/kWh (a thermal-electrical efficiency of 34%) and at an annual capacity factor of 70%, then the quantity of ash produced would be estimated as shown in Table 1.

Table 1. Calculation of ash from coal.

	Tons/year (Gg)	
Coal required	3,000,000	(2700)
25% bottom ash (or slag)[a]	105,000	(95)
Fly ash collected in an electrostatic precipitator (97%)	305,600	(277)
Fly ash discharged from the stack (3%)	9,400	(8.5)
Total Ash	420,000	(381)

[a] Bottom ash consists primarily as fused slag which has a coated, glass-like surface, and is not considered further in this report.

If stack gas scrubbers were used to remove SO_2, and assuming that 80% SO_2 removal were achieved with lime reagent at a utilization factor of 90%, then an additional 200,000 tons (181 Gg)/year of wet scrubber sludge (50% solids) would be produced along with the fly ash and bottom ash. The ash could be compacted into a disposal area of about 40 acres (0.16 km^2) at a depth of 5 ft. (1.5 m), while the sludge would require an area of about half as much at the same depth. Ash disposal costs range from \$0.75 to \$1.50/ton (\$0.85–1.70/Mg) while ponding and/or disposal of 50% solids scrubber sludge can easily range to over twice as much per wet ton.

Conventional Waste Disposal Techniques

Fly ash can be used as a cement additive, and as will be discussed, as a soil amendment additive to improve crop yields for certain types of soil. Not all crops, however, are amenable to fly ash treatment of soils. Scrubber sludge research has been conducted by SCE to successfully manufacture wallboard from wet scrubber sludge. In one experiment, approximately 60 tons (54 Mg) of scrubber sludge were processed into commercial wallboard panels, which were subsequently sold for use in the construction industry. Scrubber sludge can also be used for cement additive or soil amendment in some cases. However, very little fly ash or scrubber sludge has been marketed, although the use of Western fly ash, especially in cement additive applications, has become more economically attractive in recent years (6).

At the Mohave Generating Station in Southern Nevada, for example, nearly 25% of the total amount of fly ash is sold for commercial use at a cost to the user of about \$2.00 per ton (\$2.20/Mg). As the market for this material grows, the additional cost of trucking can probably be reduced to make the commercial use of fly ash in the Southwest more economically feasible than it is today.

Fly ash disposal at or near the generating station site is usually done by one of two methods: dry compaction or ponding. The dry compaction method can be successfully used when the fly ash tends to contain calcium sulfate aluminate or other pozzolanic ingredients which hydrolyze to form hard cement structures. Dry fly ash is dumped into hauling trucks with sufficient water to provide wetting and dust control. The moist ash is hauled to the disposal area, dumped, and compacted in layers which harden and become much more impervious than the surrounding soil. Finally, the cured ash diposal site is covered with topsoil and revegetated. In the arid Southwest, the perennials which have been selected for revegetation studies by SCE are the four-winged saltbush (*Atriplex canescens*) and brittlebush (*Encelia farinosa*). Annuals such as rye grass or barley may also be used in arid regions if irrigation is provided.

In disposal areas which are not significantly elevated from the water table, impermeable linings such as compacted clay are generally provided. In this case, or if the fly ash will not harden like concrete, then the disposal method selected may be ponding. Groundwater quality is monitored using special test wells and periodic sampling and testing of groundwater supplies. Studies have been conducted (7) to determine the degree of trace element leaching from ash and scrubber sludge disposal pond sites. The major conclusions drawn from the 1976 studies indicate that: levels of trace elements dissolved in pond water from the disposal of ash or sludge are low and do not appear to offer potential problems regarding groundwater contamination and soil percolation tests indicate that dissolved trace elements in pond water tend to precipitate and fixate in normal soils, thus minimizing potential impact in the event of a temporary pond failure.

Note that since the evaporation rates in the Southwest are high (5–9 ft, i.e., 1.5-3 m, of water per year), the levels of the major elements dissolved in pond water can become high, on the order of 15,000–40,000 ppm. These major dissolved elements usually represent the salts of sodium chloride (NaCl) or table salt, sodium sulfate (Na_2SO_4) or Glauber salt, and magnesium sulfate ($MgSO_4$) or Epsom salt. Other salts are also present, but are generally less soluble than these three common salts.

Composition of Fly Ash and Soil

Most of the elements contained in fly ash exist in an oxide form, and western fly ash is generally quite alkaline. The soluble liquid extract taken from fly ash immersed in water may have a soluble salt content of about 8,000 ppm and a pH of 12.0.

The composition of pure fly ash from typical

Table 2. Composition of pure fly ash from typical western coal resources compared with that of typical western soils.

Element	Fly ash	Soil
Calcium	4.4%	1.4%
Barium	0.3%	0.05%
Sulfur	0.2%	0.05%
Strontium	0.09%	0.03%
Cerium	150 ppm	50 ppm
Lithium	70 ppm	30 ppm
Lanthanum	70 ppm	30 ppm
Copper	63 ppm	26 ppm
Lead	48 ppm	10 ppm
Boron	390 ppm	10 ppm
Scandium	16 ppm	7 ppm
Molybdenum	10 ppm	2 ppm
Germanium	3.3 ppm	1.0 ppm
Selenium	7.6 ppm	0.2 ppm
Silver	0.3 ppm	0.1 ppm
Cadmium	1.0 ppm	0.06 ppm

[a] Fly ash data from Swanson (*8*) and Schwitzgebel (*9*), with fly ash samples from southwestern coal-fired powerplants such as Mohave (Nevada), Hayden (Colorado), Cholla (Arizona), four corners (New Mexico) and Naughton (Wyoming). Soils data from Bowen (*10*) and Lisk (*11*).

Table 3. Elements for which the fly ash-to-soil concentration ratio is less than 2.0.

Aluminum	Chromium
Silicon	Cobalt
Magnesium	Fluorine
Sodium	Gadolinium
Potassium	Gallium
Iron	Nickel
Manganese	Niobium
Phosphorus	Rubidium
Titanium	Tellurium
Antimony	Thallium
Arsenic	Tin
Beryllium	Vanadium
Bromine	Zinc
Cesium	Zirconium

Table 4. Content of key elements in soils.

	Typical fly ash concentration	Typical soil concentration
Calcium	4.4%	1.4%
Barium	0.3%	0.05%
Sulfur	0.2%	0.05%
Strontium	0.09%	0.03%
Lead	48 ppm	10 ppm
Boron	390 ppm	10 ppm
Molybdenum	10 ppm	2 ppm
Selenium	7.6 ppm	0.2 ppm

Western coal resources is compared with that of typical Western soils in Tables 2 and 3. Based on these data and laboratory tests, it is concluded that fly ash amended soils will probably be enriched with respect to the eight elements listed in Table 4.

Of these elements, boron, molybdenum, and selenium must be considered in fly ash disposal or soil amendment programs. Boron is toxic to plants in relatively small concentrations in soil, and molybdenum and selenium are toxic to some animals when present in forage crops above critical concentrations.

Soil Salinity and Irrigation Effects

Studies have shown that boron solubility is high enough that groundwater activity can cause soluble boron enrichment in fly ash amended soils, and that boron-sensitive crops are injured at relatively low soluble boron enrichment ratios (*12, 13*). It has already been pointed out that the soluble salts in fly ash will tend to increase soil salinity when fly ash is added. Studies conducted by the USDA indicate that salt sensitive crops are injured when electrical conductivity of the fly ash/soil extract exceeds 4 mmho/cm (4 mS/cm) (*14*).

Studies have been conducted to determine the feasibility of using different irrigation schemes to simultaneously reduce soil salinity and soluble boron enrichment factors in fly ash amended soils (*15*). In one series of experiments, Colorado River irrigation was studied to determine the leaching of soluble salts introduced in Baywood Sandy soil by application of 5% Mohave fly ash to the top 3 cm of a soil column. Approximately 60 surface cm of water were required to reduce the soil salinity to background levels. This quantity of water also reduced soluble boron to background levels, and presents a feasible agricultural alternative under present irrigation practices. The same study also showed that there tends to be reduced effect on soil salinity as the fly ash dosage rate is increased. This is indicated in Figure 2, which shows the electrical conductivity of fly ash/soil extracts as a function of the application rate, using Mohave fly ash. Similar effects were noted with the pH of fly ash/soil extracts, where all soils tend to exhibit buffering characteristics which limit the increase in pH with fly ash application rate. Incubation tests for periods up to 7 months using fly ash application rates of 1% showed that significant enrichment of soils with trace metals did not occur, with the possible exception of boron, which can be leached out using normal irrigation procedures.

When soils in the Southwest are not irrigated, the trace elements deposited in the surface layer of soil

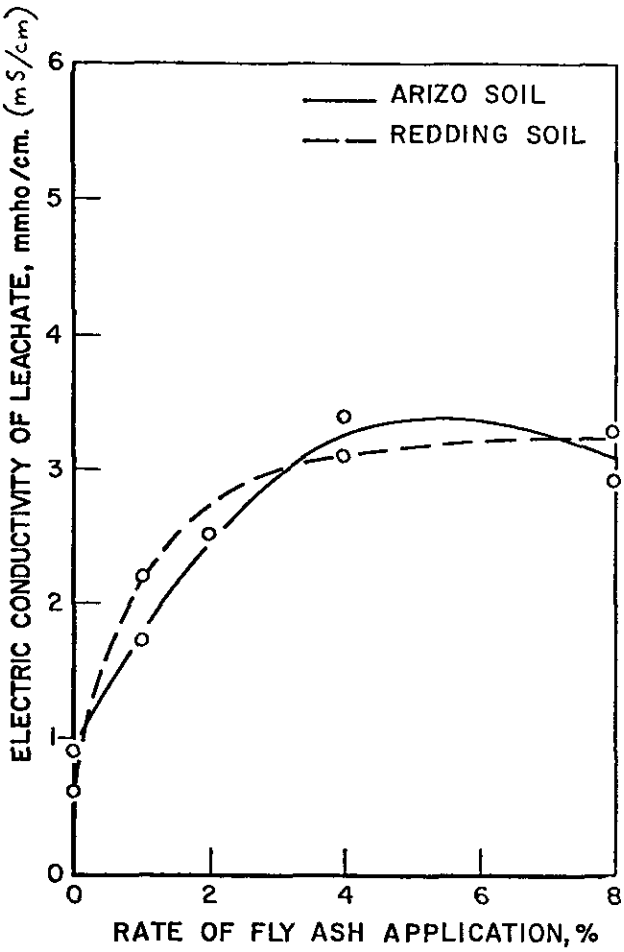

FIGURE 2. Relationship of electric conductivity (salinity) of leachate from Arizo and Redding soils treated with fly ash.

are transported almost exclusively by erosion during storm events (*16*). Soil chemistry and soil reactions are insignificant, and heavy metals do not migrate downwards but are trapped in the surface layer until erosion and silt transport phenomena occur. Lapse times of 50 to 200 years are projected to occur before trace metals deposited on nonirrigated soils in the Southwest migrate into appropriate environmental sink areas.

Potential Uses of Fly Ash for Revegetation or Agricultural Purposes

Specific studies have been conducted regarding the use of Mohave fly ash for revegetation or agricultural purposes on selected soils typically found in southern Nevada (*15*). Many of these experimental studies are still in progress, but several interesting results are indicated by the first phases of greenhouse work.

First, there are only six elements which are consistently concentrated in the plant tissues of various crops as a function of increasing fly ash additive rate. These six elements and the results for alfalfa grown on fly ash amended Arizo soil are indicated in Table 5.

Second, of the six elements, barium and strontium appear to be good candidates to use as indicators of fly ash deposition rates in the Southwest. The concentrations of these two elements in fly ash are typically higher than in the soil (Table 2), and definite concentration trends exist in vegetation (Table 5). Further work may be required to confirm this result for other specific sites.

Third, the data obtained in greenhouse experiments definitely indicate that the concentration of molybdenum in plant tissues falls off rapidly with time as successive crops are harvested. Similar results have been obtained in a three year field experiment to determine the effect of successive harvesting on the boron concentration in alfalfa (*12*). These data, in combination with the irrigation studies cited earlier, should allow the development of a predictive method for optimizing the utilization of fly ash for agricultural purposes within given crop selection, irrigation, and soil conditions. Other alternatives include the use of weathered fly ash for soil amendment purposes (*17*).

Fourth, comparisons between fly ash, gypsum, and sewage sludge show that fly ash can be used instead of other alternatives to produce crop yield improvements in cases where there is insufficient sulfur. Fly ash produced a crop yield increase of nearly 100% in dry matter yield for turnips grown in sulfur-deficient Josephine soil (*15*).

Finally, the dry matter yield ratios for five crops and a revegetation perennial were determined for various Mohave fly ash additive ratios on two types of soil (*15, 18*). The results are shown in Table 6, where improved crop yields were indicated in all cases except lettuce and white clover. The beneficial aspects of moderate fly ash amendment ratios

Table 5. Neutron activation analysis of trace elements in alfalfa plants grown on Mohave fly ash-amended Arizo soil elements showing definite concentration trends.

Fly ash, %	Sr, μg/g	Ba, μg/g	Se, μg/g	Co, μg/g	Cs, μg/g	Mo, μg/g
0	30	4.5	0.2	0.14	0.026	4.1
0.5	77	9.3	1.1	0.12	0.060	3.1
1.0	125	18.0	1.7	0.12	0.071	3.7
2.0	196	25.0	2.8	0.16	0.070	6.3
4.0	226	28.0	4.5	0.36	0.053	12.0
8.0	364	4.50	4.6	0.45	0.105	12.0

Table 6. Summary of dry matter yield data of various plant species grown under greenhouse conditions on soils amended with variable rates of Mohave fly ash.

Fly ash in soil, %	Relative yield, %					
	Alfalfa	Bermuda grass	White clover	Lettuce	Swiss chard	Brittle-bush[a]
Arizo soil						
0	100	100	100	100	100	100
1	240	182	185	69	117	125
2	315	172	276	39	114	133
4	343	183	210	20	122	142
8	306	156	150	35	87	102
Redding soil						
0	100	100	100	100	100	100
1	184	144	133	74	116	118
2	259	155	89	—	162	130
4	261	141	27	68	127	120
8	274	153	47	14	89	107

[a] A native desert plant species common to the Mojave Desert.

for improved crop yields were verified in the cases of alfalfa, Bermuda grass, Swiss chard and the brittlebush revegetation perennial.

Conclusions

This report has indicated that ash material is infused into coal seams both during the formation of the initial prehistoric deposit and as a result of subsequent geologic movement and groundwater activity. The composition of fly ash is not much different from soil in the Southwest, and with the exception of boron, molybdenum, and selenium, fly ash can be deposited on native soil without any anticipated negative impact in most areas. Use of proper disposal techniques can always insure that any potential impact from elements such as boron, molybdenum or selenium is rendered insignificant. More importantly, fly ash does have commercial value as a cement additive and is presently being sold commercially in large quantities from selected Southwestern powerplants. If appropriate disposal techniques are used, the impact of fly ash and scrubber sludge disposal is insignificant and can be monitored to whatever extent is considered necessary. Some potentially beneficial uses for fly ash and scrubber sludge from coal-fired powerplants in the Southwest are beginning to emerge.

Methodology is being developed which features greenhouse techniques for identifying crop yield improvement ratios which can be obtained using fly ash amendment on specific soils for growing specific crops. Combined with further irrigation research, this may help identify beneficial methods of utilizing highly saline waste water plus fly ash to produce beneficial agricultural crops and maximize utilization of scarce water resources in the arid Southwest.

Some research has already been conducted on manufacturing commercial grade wallboard from scrubber sludge. Additional work needs to be done to identify possible use of scrubber sludge for soil amendment, especially in sandy, sulfur-deficient soils.

Finally, it is critical that assessments of the potential environmental impact of solid wastes consider the entire biosphere reserve area. The Southwestern region of the United States is entirely unique and conclusions reached in other locations have little or no significance when extrapolated to the Southwest. The region is extremely wealthy in untapped coal but is relatively poor in water resources. New techniques for recycling water, minimizing water consumption, and research on wet/dry cooling towers are needed. If one considers the water availability problems in the Southwest, the impact of solid waste discharges from coal usage becomes almost insignificant by comparison.

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