Completion Report

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Biologic Cleanup of Effluent from
an Ash Basin

Submitted by:

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PREFACE

Contract #AT(38-1-824) officially began December 18, 1973 and extended through December 17, 1974. Preliminary work in preparation for performing the contract work began in September, 1973. Final analysis of data collected continues to the present time. Preliminary reports have been submitted periodically since January, 1974, and copies of papers contributed to symposia and journals for publication have been submitted as completed. At the present time six abstracts and three journal articles have been published from this work. As analysis is completed ten additional journal articles are in preparation or are planned from data collected during this period. Copies of these articles will be provided as they are completed prior to contribution to the journals.

BIOLOGIC CLEANUP OF EFFLUENT FROM AN ASH BASIN

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INTRODUCTION

Surface disposal of wastes resulting from use of fossil fuel in industrial plants presents dual problems which are totally different in requirements for handling and in resulting impact on the environment. In tonnage and cubic footage, particulate ash is the major residue. Solid, particulate ash is frequently sluiced from the power plant to a basin to allow for settling. This process effectively localizes and retains the major portion of particulate matter in a restricted area from which additional removal is possible. Thus disposal of this solid waste may create the need for consideration of the environmental impact of the secondary waste in that sluice water, now containing the soluble chemicals from the ash, and carrying the lighter particles, now must be emptied into a drainage system. It is in this drainage system that the impact of wastes on the environment is observed over a larger area.

The addition of precipitators to smoke stacks to prevent release of lighter weight (fly ash) particles into the air, adds an additional parameter to the disposal of fossil fuel waste in that this material may well contain higher concentrations of volatile chemical elements or compounds. Due to the light weight of fly ash, basin settling is not likely to be as effective and therefore more of the finer particles and higher concentrations of dissolved chemicals may be expected to be carried into the drainage system, creating a new and perhaps different environmental impact. Before this impact can be assessed, the drainage system must be studied to determine physical, geographic, abiotic and biotic characteristics of the system, and where possible to detect the mechanisms, both abiotic and biotic, which operate to clean up, or recycle the wastes present.

SITE DESCRIPTION

The drainage system (Fig. 1) which removed effluent from the fly ash basin of the 400D area power house of the Savannah River Project consisted of a small, essentially straight channel, approximately 300 m long, between the basin and its influx into the swamp. This channel varied in width from approximately 0.7 to 7 m. Depth of the channel was 20 to 50 cm along most of its course, with several washed areas below rocky outcroppings which varied in depth from 0.7 to as much as 3 m.

Land on either side of the channel was heavily wooded (mixed pine and hardwood) with underbrush more dense near the basin outflow. Soil surface was covered by ash, apparently as a result of flooding in periods of heavy rainfall and basin overflow. Although some higher plants were growing in the basin, no plant growth occurred in the channel between the basin and the swamp.

Water from the channel divided into several small streams at the junction of the channel with the swamp. The swamp extended approximately one km west of the channel entrance to the Savannah River. At the point of channel entrance, the swamp was approximately 3 km wide. Along the swamp edge, the distance from channel entrance to the entrance of Beaver Dam Creek water was approximately 3 km. Beaver Dam Creek water was the first major water supply to enter the swamp which diluted the effects of the ash basin effluent below the channel entrance. A major flow (20% of the total) from the ash basin followed the swamp edge from channel entrance to Beaver Dam Creek. Below the entrance of Beaver Dam Creek, water from the ash basin flow and the creek are mixed, dividing again into several smaller channels which enter the swamp area. A major channel again followed the edge of the swamp to the entrance of Four Mile Creek where ash influence was no longer evident.

MATERIALS AND METHODS

Sampling Stations: Sampling stations have been established (Fig. 1), after preliminary sampling in additional areas, (A) within the ash basin

SCALE IN KILOMETERS

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FIG.1. ASH BASIN DRAINAGE SYSTEM

near the outflow: (B) in the deepest, widest pool in the channel (approximately 160 m below the basin); (C) at the swamp entrance; (D) approximately 500 m from the channel entrance; (E) approximately 1200 m from the channel entrance; and (F) approximately 1 km below Beaver Dam Creek into the swamp.

SAMPLE COLLECTION AND EXAMINATION:

Abiotic Parameters: Temperature and dissolved oxygen measurements were taken in the field by use of a YSI oxygen meter previously calibrated by the Winkler method. A portable Corning pH meter was used to measure pH. Water samples were collected in sterile, one l polyethylene bottles and returned to the laboratory for testing conductivity, alkalinity, and turbidity. Conductivity and alkalinity were measured by the procedures described in Standard Methods for the Examination of Water and Wastewater (1965). Turbidity was measured in Jackson Turbidity Units (JTU) by use of the Hach Turbidimeter.

Bacteria: Water for bacterial cultures was collected in sterile, 50 ml glass bottles. Samples were immediately iced for return to the laboratory for plating. Spread plates of 1/4 strength Standard Plate Count Agar (Difco) were inoculated with the appropriate dilution of the samples. Dilutions in most cases ranged from 1×10^2 to 1×10^5 . All samples were plated in duplicate at each of two dilutions. Plates were incubated for four days at room temperature before enumeration of colonies. Total plate counts, total counts of chromogenic bacteria, and the number of different colony types were determined for each sample.

Benthos: Benthic samples were collected by use of a dip net set across a transect which removed benthic materials from 10 representative locations within the sampling station. Benthos collected was placed in a wide mouth, two l polyethylene bottle. A minimum of one l of sample was collected and returned to the laboratory. At the laboratory, samples were placed in a shallow white pan, allowed to settle (following addition

of water) and separated from the benthic organisms. Organisms removed from the benthos were placed in screw capped glass bottles and preserved with isopropyl alcohol for later identification. Identifications were made on the basis of morphological characteristics observed microscopically.

Plant: Macroscopic plant growth was collected by hand into glass bottles, to which benthic materials and 20 ml of water was added. These samples were immediately iced and returned to the laboratory for identification. Aquatic plants were identified on the basis of morphological characteristics observed microscopically.

Invertebrates: Aquatic invertebrate samples were taken along a transect by dip net at each sampling station. Ten sample attempts were made per station at representative areas of the site, and the organisms were pooled into a screw capped glass bottle. Those invertebrates which were to be used for neutron activation analysis were removed at the laboratory, and the remainder were preserved with isopropyl alcohol for later identification. Identifications were made on the basis of morphological characteristics observed microscopically.

Vertebrates: Fish were collected at each station where present by use of a 3 m seine. All fish collected at one station were pooled in screw capped glass bottles for return to the laboratory. Those specimens to be used for neutron activation analysis were separated, and the remainder were preserved with isopropyl alcohol, for later study in the laboratory and for examination of stomach contents.

Plankton: Five gallons of water was dipped from each station and strained through a plankton net (35 μ mesh). Plankton samples were concentrated to one l volume, iced returned to the laboratory for microscopic identification and enumeration of phyto- and zooplankton.

Neutron Activation Analysis: At each station, water, benthos, plants, invertebrates and vertebrates (when present) were collected for analysis by the neutron activation procedure. All samples were collected while

wearing sterile gloves to prevent contamination. Samples were collected in sterile glass screw capped bottles and returned to the laboratory for processing. At the laboratory specimens were transferred to sterile flip-top polyethylene vials, avoiding hand contact with specimen or vial. Vials were pre-weighed, and following filling with the specimen, the total combined weight was obtained in order that specimen weight could be calculated. In the case of plant, invertebrate and vertebrate samples, depending upon the number of organisms collected, up to ten organisms or selected portions thereof, were used for the neutron activation sample. For invertebrates, the abdominal region of the specimens was dissected. These portions of the entire sample were pooled, blended and placed in sterile vials. For fish samples, the muscle tissue along the caudal peduncle was dissected, pooled and blended. Several plants were selected and blended as the plant sample for neutron activation analysis. Neutron activation samples were iced and returned to the Nuclear Research Laboratory of Virginia Polytechnic Institute and State University where analyses for 40 elements were conducted.

Toxicity Tests: A five day toxicity test was done at sampling sites within the drainage system to test the survival ability of organisms from nearby aquatic systems, and to test the survival in the ash basin of organisms obtained at sites within the basin drainage system. Organisms from outside the basin drainage system which were tested included fresh water shrimp, salamanders, channel catfish, largemouth bass and darters. Dragonflies, crayfish and mosquito fish were collected from within the drainage system and tested in the ash basin. Test organisms were placed in stainless steel cages 4" x 12" x 12", covered with 2 mm mesh stainless steel wire. Cages were set in locations in water so that there was at least 2", but no more than 6" of water above the cage lid. Observations for survival were made within 10 min and at 4, 24, 48, 72, 96, and 120 hours.

Flow Rates: Flow rates were measured by use of a pigmy water current meter (Weathermeasure Corp.) to determine variations in the flow of effluent at different stations within the drainage system.

RESULTS

Abiotic Water Quality Measurements

The mean range of pH at stations within the drainage system was 7.1 - 7.3, whereas the overall range of individual measurements was from 6.1 - 8.7 (Table 1). These values were essentially identical to reference streams within the area.

Other parameters measured were observed to have changing values at stations progressing down the drainage system. Temperatures decreased, and dissolved oxygen values increased from Station A to Station E. Reference Station F had the highest temperature at each sampling date, and the lowest DO, regardless of seasonal influence. Turbidity was highest within the channel below the basin, and was progressively reduced as the flow rates decreased in the swamp portion of the basin (Table 1). The highest turbidity measurements were made between July and November when the basin had filled and no settling of heavier ash was accomplished before the effluent reached the swamp. This is in contrast to increasing conductivity in the swamp stations, where there was apparently less interference with conductance in the absence of the very small suspended ash particles. The lowest conductance measurements were made during the period of highest turbidity when the basin was full.

Nitrates, ortho-phosphates, sulfates and alkalinity (CaCO_3) were all reduced from the basin to the final (clean) station within the drainage system (Table 1), indicating that there was some utilization of these materials by the increasing biotic diversity in the more distant swamp sampling stations. The relatively high values for these parameters were reduced to acceptable levels at the final station.

Neutron Activation Analyses

Forty elements were analyzed in benthic, water, plant, bacteria, invertebrate and vertebrate samples to determine concentrations in these components of the drainage system (Table 2). The overall mean concentrations

Table 1. Mean Abiotic Water Quality Measurements in Ash Basin
Drainage System. Ranges in Parentheses.

A	B	C	D	E	F
pH					
7.1 (6.3-7.9)	7.2 (6.1-8.7)	7.2 (6.2-8.5)	7.2 (6.2-8.1)	7.3 (6.2-8.1)	7.3 (6.3-8.9)
Temperature (°C)					
23.3 (12.2-33.0)	22.2 (12.0-33.0)	21.9 (12.0-33.0)	20.6 (11.7-33.0)	11.0 (10.0-30.0)	29.6 (19.8-44.5)
Dissolved Oxygen (D.O.)					
7.3 (6.1-9.5)	7.8 (6.1-10.3)	7.8 (5.9-10.4)	7.9 (5.8-10.5)	8.3 (6.8-10.5)	6.1 (5.4-8.7)
Turbidity (JTU)					
102 (22-275)	110 (16-270)	96 (13-250)	79 (10-240)	13 (3-35)	18 (12-45)
Conductivity (u mhos/cm)					
88 (24-180)	90 (30-180)	75 (30-200)	89 (29-200)	91 (25-185)	63 (20-150)
Nitrates (ppm)					
5.30 (4.3-7.1)	5.08 (2.3-9.0)	5.69 (3.9-8.1)	5.32 (0.8-9.0)	2.74 (1.0-6.0)	4.86 (2.4-9.1)
Ortho-Phosphates (ppm)					
1.21 (0.07-6.4)	1.29 (0.07-7.0)	0.32 (0.08-0.8)	0.28 (0.05-0.7)	0.11 (0.01-0.3)	0.24 (0.02-0.7)
Sulfates (ppm)					
16.4 (9.3-27.5)	16.7 (10.3-28.0)	17.3 (10.0-32.5)	16.4 (11.8-33.0)	14.3 (12.0-21.3)	11.3 (5.5-23.0)
Alkalinity (ppm CaCO ₃)					
20.8 (12.0-36.1)	19.8 (11.0-37.1)	19.0 (12.0-31.2)	19.5 (11.0-37.1)	18.6 (11.2-25.0)	14.4 (8.0-27.3)

Table 2. Annual mean concentration in mg/l of 40 elements measured
(in decreasing concentration) in the drainage system.

No.	Element	Overall $\bar{X}$ Conc.	No.	Element	Overall $\bar{X}$ Conc.
1.	Aluminum (Al)	9,213.98	21.	Thorium (Th)	3.72
2.	Iron (Fe)	4,679.96	22.	Bromine (Br)	3.46
3.	Potassium (K)	2,914.26	23.	Selenium (Se)	3.40
4.	Calcium (Ca)	2,222.68	24.	Cobalt (Co)	2.92
5.	Magnesium (Mg)	1,359.54	25.	Scandium (Sc)	2.14
6.	Titanium (Ti)	518.11	26.	Iodine (I)	1.96
7.	Sodium (Na)	395.44	27.	Uranium (U)	1.82
8.	Chlorine (Cl)	156.48	28.	Cadmium (Cd)	1.72
9.	Barium (Ba)	80.28	29.	Molybdenum (Mo)	1.18
10.	Strontium (Sr)	76.23	30.	Ytterbium (Yb)	1.14
11.	Manganese (Mn)	39.59	31.	Cesium (Cs)	1.14
12.	Cerium (Ce)	29.10	32.	Samarium (Sm)	1.13
13.	Tin (Sn)	25.43	33.	Antimony (Sb)	0.94
14.	Rubidium (Rb)	23.34	34.	Wolfram (W)	0.91
15.	Copper (Cu)	19.54	35.	Hafnium (Hf)	0.72
16.	Vanadium (V)	14.72	36.	Tantalum (Ta)	0.45
17.	Chromium (Cr)	11.36	37.	Mercury (Hg)	0.41
18.	Zinc (Zn)	7.70	38.	Indium (In)	0.14
19.	Arsenic (As)	5.32	39.	Lutetium (Lu)	0.10
20.	Lanthanum (La)	4.64	40.	Gold (Au)	0.01

of these elements presents the total amount of each in the drainage system. The neutron activation procedure could not distinguish between aluminium and silicon, the largest concentration measured in the system.

The location of elemental concentrations within the components of the drainage system indicates the requirement for biotic diversity to accomplish elemental cycling (Table 3). Benthic concentrations were greater than other components for all elements except calcium (Ca), sodium (Na), chlorine (Cl), zinc (Zn), bromine (Br), selenium (Se), cadmium (Cd), and antimony (Sb). Of these eight elements, fish had the highest concentrations of Ca and Se and invertebrates had the highest concentrations of the remainder. Changes in elemental concentrations in water and benthos at successive sampling sites was associated with the concentration of those elements in biotic components and is presented in a later section.

The concentrations of some chemical elements in the basin drainage system exceeded the EPA recommended limits at some stations (Table 4), and concentrations of others approached these limits. Concentrations exceeding recommended limits included Hg, Se, Cd, Cr and Fe.

Bacterial Populations

The bacterial populations at one drainage system sampling station (E) were found to be essentially the same as at two nearby reference streams (Upper Three Runs and Tims Branch), although the populations at station A were considerably higher (Fig. 2). When correlated with other parameters, it was apparent that the bacterial differences were affected by nitrate and phosphate concentrations as well as temperature levels at the four locations (Fig. 3).

The effects of temperatures and of improved water quality within the drainage system are apparent in values for total culturable bacteria (TCB) and the number of bacterial colony types, or diversity (Fig. 4). Mean annual temperature at station A was 3.3°C, and at station F was 10.6°C greater than at station E (Table 1). The mean TCB at station A was approximately two times, and at station F, approximately three times that at station E, whereas the number of colony types was greatest at E. The

Table 3. Cycling of selected elements through abiotic and biotic parameters of the ash basin drainage system. Values are listed as mean concentrations (mg/l) for 12 months from all sampling stations.

Element	Water	Benthos	Plant	Invert.	Fish	Overall Mean
Al	13.0	40,657.0	3,985.1	1,199.3	215.5	9,213.98
Fe	16.9	20,912.4	1,113.2	1,202.6	154.7	4,679.96
K	6.1	8,149.2	1,803.6	2,666.2	1,946.2	2,914.26
Ca	9.2	1,844.8	850.1	2,656.4	5,752.9	2,222.68
Mg	4.1	5,460.8	656.2	369.4	307.2	1,359.54
Ti	0.9	2,388.5	109.4	71.5	15.1	518.11
Na	7.7	688.0	267.9	703.8	309.8	395.44
Cl	3.8	84.1	198.2	364.9	131.4	156.48
Ba	0.7	294.2	36.3	50.2	20.0	80.28
Sr	0.3	236.0	60.3	48.4	36.3	76.23
Mn	0.07	96.2	70.2	21.5	10.0	39.59
Ce	0.2	129.7	9.7	4.3	1.6	29.10
Sn	0.1	85.0	18.0	20.7	3.4	25.43
Rb	0.4	83.5	11.2	11.1	10.5	23.34
Cu	0.4	51.6	8.2	29.0	8.5	19.54
V	0.04	63.9	4.7	4.4	0.6	14.72
Cr	0.2	38.4	5.7	9.7	2.8	11.36
Zn	0.4	6.4	5.0	14.9	11.8	7.70
As	0.06	19.7	4.2	2.1	0.5	5.32
La	<0.01	20.3	1.4	1.4	0.1	4.64
Th	0.03	15.3	1.3	1.7	0.3	3.72
Br	0.1	1.2	3.0	10.1	2.9	3.46
Se	0.1	6.1	1.8	2.6	9.4	3.40
Co	0.1	10.6	1.7	1.7	0.5	2.92
I	0.1	4.6	1.3	3.4	0.4	1.96
U	0.01	8.0	0.7	0.3	0.1	1.82
Cd	0.1	1.7	1.5	4.0	1.3	1.72
Cs	<0.01	3.9	0.6	0.7	0.5	1.14
Sb	0.07	1.0	0.8	2.1	0.7	0.94
Hg	0.03	0.8	0.5	0.5	0.2	0.41
Σ	65.23	81,362.9	9,231.8	9,486.9	8,955.2	21,819.19 (Σ)
% Total	<0.1	74.6	8.5	8.7	8.2	[109,102.0 (Σ)]

Table 4. Comparison of the annual aquatic concentration of elements in the ash drainage system to the EPA recommended limits for drinking water. Letters represent the sampling station containing the highest concentration in mg/l.

Element	EPA Concentration Limit (mg/l)	Concentration in Ash Drainage System	
		Highest	Mean
Mercury	0.002	0.04 ^A	0.03
Arsenic	0.10	0.07 ^C	0.06
Manganese	0.05	0.10 ^F	0.07
Selenium	0.01	0.12 ^A	0.11
Cadmium	0.01	0.17 ^D	0.12
Chromium	0.05	0.18 ^A	0.16
Zinc	5.00	0.46 ^D	0.37
Copper	1.00	0.56 ^A	0.40
Barium	1.00	0.98 ^A	0.71
Chlorine	250.00	4.35 ^F	3.75
Sodium	no limit	8.85 ^F	7.67
Iron	0.30	21.62 ^E	16.89

FIGURE 2. BACTERIAL POPULATIONS OF AQUATIC SYSTEMS WITH NUMBERS REPRESENTING THE TOTAL MEAN COLONY TYPES (O) WITHIN TOTAL RANGES (I).

FIGURE 3. ABIOTIC PARAMETERS OF AQUATIC SYSTEMS WITH NUMBERS REPRESENTING THE RANGES () AROUND THE MEAN TEMPERATURE (Δ) IN $^{\circ}\text{C}$.

FIG.4. BACTERIAL POPULATIONS IN ASH DRAINAGE SYSTEM.

lowest TCB and the greatest colony type diversity were found at station E throughout the year (Fig. 4). These results indicate that bacteriological quality and population stability improved throughout the immediate drainage system, and were adversely affected by the higher temperatures at station F.

Bacterial populations of the ash basin system were shown to concentrate Ca, Cl, Fe, Ti and Hg relative to the concentration of these elements in water, although in no case was any of these elements concentrated to the same extent as was measured by neutron activation in all other biota.

Plant Populations

More different aquatic plant species or genera were observed in the ash basin than in either of the next two sampling sites (Fig. 5). This number included vascular plants, attached algae and phytoplankton. The greatest number of different plants, however, was observed in station E (37), most distant from the ash basin. The observed plant diversity at the station with the highest temperature (F) was less than that at stations D and E, but greater than that in the ash basin and in the two nearest sampling stations (26, 30, 37, 22, 15 and 19 respectively). The number of individual plants of each genus or species observed at each station was highest in the ash basin and decreased at each successive sampling site through E (25 to 11 overall decrease). The second highest number of individuals of each type observed was found at station F, 23 (Fig. 5).

The higher plants in and adjacent to the ash basin drainage system channel were found to be more diverse progressing down the system, as were the aquatic algae (Tables 5, 6, 7).

Animal Populations

The greatest diversity of animals observed (number of different taxa) was observed in station E, furthest removed from the ash basin, and not influenced by elevated temperatures (Fig. 6). The 30 different

FIG.5. PLANT POPULATIONS IN ASH DRAINAGE SYSTEM.

Table 5. List of Plants Identified from SRP Sampling Sites

A

Lemna perpusilla - Duckweed
Andropogon virginicus - Broom sedge
Typha latifolia - Cat-tail
Solidago sp. - Goldenrod
Cyperus retrofractus - Cyperus, Nut grass
Liquidambar styraciflua - Sweet gum
Daucus carota - Queen Anne's Lace, Wild Carrot
Anisostichus capreolata - Cross vine

B

Lemna perpusilla - Duckweed
Pinus taeda - Loblolly pine
Quercus nigra - Water oak
Rhus radicans - Poison ivy
Cornus florida - Flowering dogwood
Pinus echinata - Shortleaf pine
Passiflora incarnata - Maypop
Malus angustifolia - Crab-apple

C

Lemna perpusilla - Duckweed
Pinus taeda - Loblolly pine
Andropogon virginicus - Broom sedge
Cyperus retrofractus - Cyperus, Nut grass
Typha latifolia - Cat-tail
Pinus echinata - Shortleaf pine
Vitis rotundifolia - Muscadine
Rhus radicans - Poison ivy
Ipomoea pandurata - Bigroot Morning Glory, Wild Potatoe Vine
Sagittaria latifolia - Common Arrowhead
Malus angustifolia - Crab-apple

D

Lemna perpusilla - Duckweed
Pinus taeda - Loblolly pine
Quercus nigra - Water oak
Smilax rotundifolia - Common Greenbrier
Tillandsia usneoides - Spanish moss
Rubus sp. - Blackberry
Typha latifolia - Cat-tail
Arundinaria gigantea - Cane
Vitis rotundifolia - Muscadine
Rhus radicans - Poison Ivy
Illex opaca - America Holly
Quercus phellos - Willow oak
Ipomoea pandurata - Bigroot Morning Glory, Wild Potatoe Vine

(Cont.)

D (cont.)

Aesculus pavia - Red buckeye
Ulmus alata - Winged elm
Pinus echinata - Shortleaf pine

E

Lemna perpusilla - Duckweed
Taxodium distichum - Bald Cypress
Tillandsia usneoides - Spanish Moss
Cyperus strigosus - Cyperus
Yucca filamentosa - Yucca, Bear Grass
Smilax rotundifolia - Common Greenbrier
Andropogon virginicus - Broom Sedge
Quercus nigra - Water oak
Quercus alba - White oak
Typha latifolia - Cat-tail
Arundinaria gigantea - Cane
Ludwigia palustris
Peltandra virginica - Peltandra
Ulmus alata - Winged elm
Zephyranthes atamasco - Atamasco Lily
Ipomoea pandurata - Bigroot Morning Glory, Wild Potatoe Vine
Rhus radicans - Poison ivy
Orontium aquaticum - Gold club
Rhododendron nudiflorum - Wild azalea
Aesculus pavia - Red buckeye
Carya aquatica - Water hickory

F

Lemna perpusilla - Duckweed
Taxodium distichum - Bald cypress
Tillandsia usneoides - Spanish moss
Smilax rotundifolia - Common Greenbrier
Arundinaria gigantea - Cane
Pinus taeda - Loblolly pine
Quercus nigra - Water Oak
Quercus phellos - Willow oak
Quercus laurifolia - Laurel oak
Cyperus strigosus - Cyperus
Yucca filamentosa - Yucca, Bear grass
Typha latifolia - Cat-tail
Baptisia alba - White wild indigo
Aesculus pavia - Red buckeye

Table 6 Occurrence of Aquatic Plants in the Ash Basin
Drainage System

Taxa	Sampling Stations					
	A	B	C	D	E	F
<u>Lemna perpusilla</u>	*	*	*	*	*	*
<u>Navicula</u> sp.	*	*	*	*	*	*
<u>Tabellaria</u> sp.	*	*	*	*	*	*
<u>Fragilaria</u> sp.	*	*	*	*	*	*
<u>Tribonema</u> sp.	*	*	*	*	*	*
<u>Anabaena</u> sp.	*	*	*	*	*	*
<u>Oscillatoria</u> sp.			*	*	*	*
<u>Oedogonium</u> sp.	*		*	*	*	
<u>Synedra</u> sp.	*		*		*	*
<u>Cosmarium</u> sp.			*	*	*	*
<u>Pinnularia</u> sp.			*	*	*	*
<u>Spirogyra</u> sp.				*	*	*
<u>Phormidium</u> sp.				*	*	*
<u>Pleurotaenium</u> sp.				*	*	*
<u>Gyrosigma</u> sp.				*	*	*
<u>Staurastrum</u> sp.				*	*	*
<u>Hydrodictyon</u> sp.				*	*	
<u>Syrosigma</u> sp.				*		*
<u>Cymbella</u> sp.				*		
<u>Cladophora</u> sp.					*	
<u>Spirulina</u> sp.					*	*
<u>Melosira</u> sp.					*	
<u>Micrasterias</u> sp.					*	
<u>Meridon</u> sp.					*	
<u>Closterium</u> sp.					*	*
<u>Gomphonema</u> sp.					*	
<u>Surirella</u> sp.					*	*
<u>Ludwigia</u> sp.					*	
<u>Peltandra</u> sp.					*	
<u>Azolla</u> sp.					*	
<u>Hydrocotyle</u> sp.					*	
<u>Eunotia</u> sp.						*
<u>Rhizoclonium</u> sp.						*
<u>Achanathes</u> sp.						*
<u>Vaucheria</u> sp.						*
<u>Scenedesmus</u> sp.						*
<u>Chlamydomonas</u> sp.	*					
<u>Pandorina</u> sp.	*					
<u>Nostoc</u> sp.	*				*	
<u>Euglena</u> sp.	*				*	
Total *	12	6	11	18	31	24

* For some genera, more than one species was observed.

Table 7. Phytoplankton observed in ash drainage system. Numbers represent relative concentrations.

	A	B	C	D	E	F
<u>Fragilaria</u> sp.	10	10	10	10	15	10
<u>Navicula</u> sp.	15	15	15	20	20	10
<u>Tribonema</u> sp.	25	20	25	25	20	30
<u>Oscillatoria</u> sp.	15	15	25	25	15	25
<u>Anabaena</u> sp.	10	1	15	15	15	20
<u>Melosira</u> sp.	1	1	15	15	15	
<u>Cymbella</u> sp.	10		10	10	15	
<u>Cosmarium</u> sp.	5			15	15	
<u>Nostoc</u> sp.	35		15	15		
<u>Pleurotaenium</u> sp.		5	5	5	10	
<u>Tabellaria</u> sp.	20	5	20	15		
<u>Euglena</u> sp.		5	20	1	20	
<u>Gyrosigma</u> sp.			10	5	10	
<u>Spirogyra</u> sp.				15	15	
<u>Staurastrum</u> sp.				5	5	
<u>Scenedesmus</u> sp.			5			
<u>Gomphonema</u> sp.				15		
<u>Meridon</u> sp.				15	15	
<u>Pinnularia</u> sp.				15	20	
<u>Synedra</u> sp.				20	20	
<u>Hydrodictyon</u> sp.					25	
<u>Chlamydomonas</u> sp.	5		5		25	15
<u>Phormidium</u> sp.	5		20		15	
<u>Eunotia</u> sp.	5		5		10	
<u>Pandorina</u> sp.	5	5				25
<u>Surirella</u> sp.			5	10	15	1
<u>Closterium</u> sp.				15	15	1
<u>Micrasterias</u> sp.					5	1
<u>Achananthes</u> sp.					5	5
<u>Rhizoclonium</u> sp.						5
Total sp.	14	10	17	21	24	12

FIG. 6. ANIMAL POPULATIONS IN ASH DRAINAGE SYSTEM.

animals observed at E was 100% greater than were observed at the station of lowest diversity (B); 27% greater than in the ash basin and 47% more than in the temperature influenced station (F). Contrary to results observed in plants and bacteria, the number of individuals of each taxon present was greatest (32/taxon) at the station having greatest diversity (E) and lowest (13/taxon) at the station having least diversity (B) (Fig. 6).

The classification of animals and their relative group distributions were observed to follow the general pattern of the number of different types and the number of each type observed (Tables 8,9).

Elemental Cycling

Three modes of dissipation of 40 elements through the ash basin system to stations beyond ash influence were apparent. These were; 1) a relatively linear dissipation at successive stations throughout the system, 2) primary dissipation in the early swamp stations where flow rates decreased, and 3) random dissipation at all stations through the system (Table 10, Fig. 7).

The dissipation, or removal of 40 elements in the ash effluent varied, depending upon the specific elements involved, and upon the components of the drainage system (Fig. 8, 9). The overall trend for 40 elements was toward a linear decrease in water concentration from the basin through each successive sampling station, whereas the highest benthic concentration was found in the first swamp station (C) where flow rate most rapidly decreased and the majority of settling occurred (Fig. 8). In successive stations after C, the benthic concentrations declined. In biotic components of the system, the variable concentrations of elements in plants and invertebrate were apparently due to the relative immobility of these population segments, whereas the fish populations within the system were able to move throughout the area from station B to F and vice versa, and maintained a relatively stable concentration of all elements throughout the system.

Table 8. Occurrence of Aquatic Animals in the Ash Basin
Drainage System

Taxa	Sampling Stations					
	A	B	C	D	E	F
Vertebrates						
Rana sp.	*	*	*	*	*	*
Gambusia affinis		*	*	*	*	*
Invertebrates						
Cladocera	*	*	*	*	*	*
Copepoda	*	*	*	*	*	*
Chironominae	*	*	*	*	*	*
Culicidae	*	*	*	*	*	*
Chaoborinae	*	*	*	*	*	*
Physidae	*	*	*	*	*	*
Cambarinae		*		*	*	*
Hydropsychidae	*	*	*	*	*	
Gerridae	*	*	*	*	*	
Gammaridae				*	*	
Leptoceridae			*	*	*	
Dytiscidae			*	*	*	
Tipulidae			*	*	*	
Gyrinidae			*	*	*	
Ephemerellidae			*	*	*	
Tubificidae			*	*	*	
Corydalidae				*	*	
Tabanidae				*	*	
Hydrophilidae	*			*	*	
Notonectidae					*	
Haliplidae	*				*	
Stratiomyidae					*	
Leptoceridae	*				*	
Belastomatidae	*			*	*	
Hydroptilidae	*				*	
Coenagrionidae	*				*	*
Aeschnidae	*				*	*
Libellulidae	*				*	*
Dytiscidae	*					*
Baetidae	*					
Corixidae	*					
Total *	20	11	16	22	30	13

* More than one species was observed in some families.

Table 9. Zooplankton observed in ash drainage system. Numbers represent relative concentrations.

	A	B	C	D	E	F
Spathidium	25	15	25	25	50	5
Cryptomonadina	150	10	150	200	200	25
Rotifers	5	5	5	5	5	1
Chironomids	1	5	5	5	5	
Cladocerans	5	1	5	5	10	
Larva phantom midge	5	1	5	5	10	
Amoeba		1	1	10	10	
Amoeba radiosa		1	1	1	1	5
Euglena			10	10	10	
Ostracods			5	5	5	
Nematodes			10	5	2	
Ciliates			5	5	5	1
Annelids			1	1	1	
Holotricha			1	1	1	
Larva biting midge				1	1	
Larva black fly				1	1	
Pleuronema					1	
Mosquito larva	5	1				1
Vorticella	1					1
Aspidisca	5					
Euplotes	5					
Total taxa	10	9	14	16	17	7

Table 10. Mode of dissipation (relatively linear, swamp, or random) of 40 elements from the ash basin through stations beyond ash influence in the drainage system.

Mode of Dissipation	Elemental Dissipation in				
	Water	Benthos	Plant	Invert.	Fish
A. Relatively Linear	Al, Ba, Cl, Co, Cr, Cs Cu, I, In, K, La, Lu Mg, Mn, Mn, Na, Sb, Sc, Sm, Sn, Sr, Ti	As, Br, Hf, Se, Zn	Cd, Mo, Na, Sb, Se, Zn	Co, Cr, Cs, Cu, Mo, W, Zn	Ba, Br, Hg, In, K, Rb, Se, Zn
Total:	22	5	6	7	8
B. Swamp	As, Au, Ca, Cd, Ce, Fe, Hf, Hg, Mo, Se, Ta, V, W	Al, Ay, Ba, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Fe, Hg, I, In, K, La, Lu, Mg, Mn, Mo, Na, Rb, Sb, Sc, Sm, Sn, Sr, Ta, Th, Ti, U, V, W, Yb	Al, As, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Cs, Cu, Fe, Hf, Hg, I, In, K, La, Lu, Mg, Mn, Rb, Sc, Sm, Sn, Sr, Ta, Th, Ti, U, V, W, Yb	Al, As, Au, Ba, Br, Ca, Cd, Ce, Fe, Hf, Hg, I, In, K, La Lu, Mg, Mn, Rb, Sb, Sc, Se, Sm, Sn, Sr, Th, Ti, U, V, Yb	Al, As, Au, Ca, Cd, Ce, Cl, Co, Cs, Cu, Fe, Hf, La, Lu, Mn, Na, Sb, Sc, Sm, Sn, Sr, Ta, Ti, V, V, W, Yb
Total:	13	35	34	30	27
C. Random	Br, Rb, Th, U, Zn	---	---	Cl, Na, Ta	Cr, I, Mo, Mg, Th
Total:	5	---	---	3	5

FIG. 7-MODE OF DISSIPATION OF 40 ELEMENTS IN THE ASH DRAINAGE SYSTEM.

FIG. 8 - DISSIPATION OF 40 ELEMENTS IN THE ASH DRAINAGE SYSTEM.

FIG. 9 -MECHANISM FOR REMOVAL OF 40 ELEMENTS IN THE ASH DRAINAGE SYSTEM. ELEMENTS WITHIN BRACKETS FOLLOWED THE SAME TREND NEAREST TO THE ELEMENT PLOTTED.

The drainage system components followed the same pattern for 30 elements as to concentration in individual components. Different concentration patterns were observed for ten elements in which at least one biotic component was found to have higher concentrations of the elements than did the benthos (Fig. 9).

The importance of the biotic component of the system for cycling of elements present in excess of EPA recommended limits was emphasized by the fact that mean biotic concentrations of these elements show a small, yet continuous increase throughout the drainage system (Fig. 10).

The major role of each biotic form in cycling the 18 most prevalent elements was obvious from the total biotic concentrations of each element (Fig. 11). No single species of organism was capable of concentrating every element, and no single species was capable of concentrating any one element to a greater extent than all other organisms combined, with one exception. The largest segments of biotic concentration of one single element by one type of organism were the 52% concentration of Mn by cattails, 38% concentration of Ti by duckweed, 38% concentration of Co by midges and 38% concentration of Cl by tadpoles. Of the 18 elements listed (Fig. 11) plants were more efficient than animals, only in concentrating Mn and Ti. Cattails were the greatest concentrators of K and Mn, and duckweed of Co. Animal forms were the greatest concentrators of all other elements.

Toxicity Tests

Animal species which were the most resistant biotic forms in toxicity tests in the ash basin (Station A) were those from sites further removed from the basin, and two fish species which were not found to exist in the drainage system (Table 10); i.e. odonates, crayfish, mosquito fish, channel catfish and largemouth bass.

Flow Rates

Flow rates in the system varied, due to rainfall and pumping rate, from the calculated flow of 16,000 l/m out of the basin. Low flow rate measured at A was 9,000 l/m, and high rate measured was 12,000 l/m. The segment of this flow which was sampled down the swamp (Station C) varied between 1,900 l/m and 2,300 l/m, while at Station E the flow rate varied between 400 l/m and 1,700 l/m.

FIG. 10-DISSIPATION OF ELEMENTS (Cd, Hg, Cr, Se) THAT EXCEEDED THE EPA RECOMMENDED CONCENTRATION IN DRINKING WATER.

ELEMENTAL CONCENTRATORS

Fig. 11. Relative accumulation (ppm) of most plentiful elements in the most abundant representatives of food chain in all sampling sites. 1. Includes bacteria and cypress. 2. Includes clam and shrimp.

TABLE 11. Survival of Biota in Ash Basin System

ORGANISM	SAMPLING STATIONS			
	A	C	E	Control U3R
	0- 4-24-48-72-96-120	0- 4-24-48-72-96-120	0- 4-24-48-72-96-120	0-120
SHRIMP	22- 3- 0-	24- 6- 0-	31-31-25-25-22-20- 17	12- 12
ODONATES*	6- 6- 6- 6- 4- 3- 3	6- 6- 6- 6- 6- 6- 6	6- 6- 6- 6- 6- 6- 6	6- 6
SALAMANDERS	8- 8- 3- 0-	8- 8- 6- 4- 2- 0-	5- 5- 5- 2- 2- 2- 1	6- 6
CATFISH	6- 6- 6- 6- 6- 6- 6	7- 7- 7- 7- 7- 7- 7	16-16-16-16-16-16- 16	6- 6
LARGEMOUTH BASS	5- 5- 5- 5- 5- 4- 4	6- 6- 6- 6- 6- 6- 6	6- 6- 6- 6- 6- 6- 6	6- 6
CRAYFISH*	6- 6- 6- 6- 6- 6- 6	6- 6- 6- 6- 6- 6- 6	6- 6- 6- 6- 6- 6- 6	6- 6
MOSQUITO FISH*	20-20-20-20-18-16- 12	20-20-20-20-20-20- 20	20-20-20-20-20-20- 20	6- 6
DARTERS	6- 3- 0-	6- 6- 3- 0-	6- 6- 6- 6- 6- 6- 4	6- 6

* Organisms found in the Ash Basin Drainage System. All other organisms not found in drainage systems.

DISCUSSION

The abiotic water quality measurements during a period of 15 months in the drainage system of the 400D area ash basin, indicated that when the basin operates properly, allowing for sedimentation of much of the heavy ash, the components of the system clean up the effluent to within acceptable limits for all parameters by the time the effluent had moved 1200 m into the swamp (Table 1). Calculating from the swamp dimensions on this basis, 77 sq m of swamp area in this system were required each year for the clean up of effluent from one ton of ash sluiced to the basin. This clean up was dependent on the physical terrain of the system, flow rates of effluent and the stability of the biotic communities present within the system.

Beginning in July, the basin had filled with ash and no sedimentation was accomplished before the effluent flowed into the drainage system. The situation was not corrected completely throughout the remainder of the contract period. Due to the increased particulate load carried into the channel and swamp, elevated values were obtained in measuring turbidity, nitrates, phosphates and alkalinity during the last six months of sampling. Obvious ash deposits on the benthos progressed down the swamp drainage from between stations C and D to just above station E. In addition to the effects on abiotic parameters, the ash sedimentation on the benthic layer obviously reduced the diversity and numbers of all benthic organisms.

Water temperatures were considerably affected, within the basin and well into the swamp, by heat absorption by the turbid water moving slowly through the exposed basin. With movement down the drainage system, largely shaded by adjacent plants, this heat was dissipated by the time the water had moved to station E (1200 m from the swamp entrance). Similarly, DO increased to its highest mean (8.3 ppm) by the time water reached E (Table 1). The relatively constant pH and conductivity throughout the system reflected the fact that the majority of chemicals were suspended in association with the particulate ash, which rapidly settled to the benthic layer. This fact is confirmed by the change in turbidity from a high of 110 JTU at B to a low mean of 13 JTU at E, and by the mean relative total

chemical concentrations in water (65.23 ppm) and in benthos (81,362.9 ppm) (Tables 1, 3).

The values for nitrates, ortho-phosphates, sulfates and alkalinity were all high within the basin, and the early sampling sites, but were reduced to near, or below the reference site by the time effluent reached station E. When this change in water quality is compared to the increasing diversity of biota down the drainage system, it would appear that this improvement must be attributed to recycling and utilization of these chemical components by the biota.

Published figures on elemental concentrations in coal in the United States, indicate that aluminum and silicon are the most abundant elements. In analyses by the neutron activation procedure, which was unable to distinguish between these elements, combined Al-Si (reported as Al in Tables 2, 3, 8, Fig. 7, 8, 9 and 11) made up 42% of the total mean elemental concentration of 40 elements in the components of this drainage system (Table 3). Similarly, other reported major elemental concentrations in U. S. coals were found to be in high concentration in the components of this system (Fe, K, Ca, Mg, Ti, and Na).

The distribution of chemical elements among components of this drainage system indicated that the single major clean up mechanism involved was sedimentation of particulate ash as flow rates decreased into the swamp system. Seventy-four and six tenths percent of the total concentration of 40 elements was found to be in the benthos, and less than 0.1% was in water (Table 3). The remaining 25.3% was relatively evenly distributed between plant, invertebrate and fish groups. Fish contained higher concentrations of Ca and Se than did benthos, and invertebrates contained higher concentrations of Na, Cl, Zn, Br, Cd and Sb. It follows then, that these organisms were most active in recycling these elements.

Analysis of biota within the ash basin drainage system clearly showed that there was a simplification, or streamlining of biotic communities in the first sampling sites below the basin. Comparative sedentary

conditions within the basin apparently permitted a somewhat greater diversity in that site, and combined with the elevated temperature, permitted a seasonal increase in diversity of the primary producers (bacteria and algae) (Fig. 2, 3, 4). Although some community stability among these groups could be detected in the basin, the populations of bacteria and algae within the system were demonstrated to have greater stability (diversity of types compared to numbers per type) at stations more distant from the basin within the swamp (Fig. 4, Table 6).

Changes in diversity and numbers of organisms in each taxon observed were most apparent in the animal populations as sampling progressed from station B to E in the drainage system (Fig. 6, Table 7). The kinds of animal populations found in station E, and the results of toxicity tests, attest to the conclusion that most of the major effects of ash basin effluent have been cleaned up prior to the effluent reaching this site. Further evidence supporting this fact is found in the observation of Hydrodictyon sp. and Pontedera sp. growing in this location since these plants are generally found only in water of very good quality.

The three modes of elemental dissipation of the 40 elements measured, were compatible with the fact that different mechanisms are involved in cycling different chemicals (Table 8, Fig. 7, 8, 9). Regardless of mode of dissipation, however, the linear decrease of water concentrations of all 40 elements at successive sampling sites within the system, reflects the increasing biotic diversity from B through E, and the lack of ash influence at F. The relative immobility of plant and invertebrate populations may account for the variable elemental concentration of these groups as compared to the relative constant elemental concentrations measured in the more mobile fish. The decreasing concentration of all elements in benthos after station C, confirms the conclusion that a major clean up mechanism is particulate settling, and most of this settling is accomplished as flow rates decrease upon entry into the swamp.

By comparison of the concentrations of two elements which exceeded the EPA recommended limits (Fig. 10) with the elemental concentra-

tions in the most abundant biota (Fig. 11), the importance of increasing diversity of biota was emphasized. Cr was most efficiently concentrated by midges, whereas Hg was most concentrated by Oscillatoria sp. Fe also exceeded recommended limits and was heavily concentrated by Hydrodictyon sp., tadpoles and midges. Se was most highly concentrated in tadpoles and Cd in Oscillatoria sp.

For the most plentiful elements, animals were found to contain the greatest concentrations, with the exception of K, Mn and Ti, which were most highly concentrated in plants. The variety of cycling pathways are illustrated by the elemental concentrations measured in different groups of organisms (Fig. 11).

Toxicity tests, and organism diversity observed at station E, demonstrated the extent of cleanup of effluent at that location.

SUMMARY AND RECOMMENDATIONS

Major environmental effects which were attributable to ash basin effluent were: 1) increased turbidity, conductivity and chemical concentration in the channel and swamp area; 2) streamlined and simplified biotic communities with greatest loss of community stability nearest the basin; and 3) chemical elements from coal ash were most concentrated in the benthos (74.6% accumulation), second highest in the food webs (8.5% in plants and bacteria, 8.7% in invertebrates and 8.2% in vertebrates), and least in the water (0.1%). 4) The elements not highest in benthos were Ca and Se (highest concentration in fish) and Na, Cl, Zn, Br, Cd and Sb (highest concentration in invertebrates). 5) The two most abundant chemicals measured were Al-Si and Fe. 6) Two major clean up mechanisms were observed a) sedimentation of particulate ash, and b) recycling of chemical elements by food webs present. 7) The overall concentrations of four toxic (Cr, Cu, Hg and Se) and one non-toxic (Fe) elements were greater than the EPA recommended limits for surface waters. The toxic elements did, however, appear to be concentrated, and therefore recycled by major components of the food webs.

Direct toxicity testing, using organisms from outside the drainage system, and others from within the system, indicated that the effluent at a distance of 1500 m from the basin, within the swamp, was restored to a quality level which was non-toxic except to the most sensitive test organisms from nearby non-polluted streams. In this system, and under these conditions, 77 sq m of swamp system are required for each ton of ash produced in one year, to provide this amount of cleanup.

With this baseline data available, and with a properly operating ash basin which permits sedimentation of heavier particulates, this system should be studied for a minimum continuous period of two years 1) to assess the effects of basin overflow for the last six months of 1974, 2) to assess the additional environmental impact of fly ash precipitation to the basin, and 3) to determine more precisely the food web recycling mechanisms which

operate to remove ash effluent effects, and those which must operate to remove the effects of fly ash addition.

If those determinations are made, data from this drainage system may be used for modeling and predicting the impact of other ash basin effluents in other geographical locations, thereby reducing the needs for more extended studies of those drainage systems.